THE BLOOD SUPPLY AND VASCULAR DISORDERS OF THE HUMAN SPINAL CORD

VOLUME I TEXT.

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J. TREVOR HUGHES



Magdalen College,
Oxford.

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CHAPTER 1.

INTRODUCTION

The human spinal cord has a blood supply of great complexity and the anatomy of this vascular system has been studied for several centuries. The earlier of these observations, based only on anatomical studies, were deficient in that one could only surmise the effects of obstruction of the spinal vessels on the nourishment of the spinal cord. This deficiency has subsequently been remedied in part by experiments designed to obstruct the spinal vessels at certain points, and, after an interval, to observe the effects on the spinal cord. When the information derived from experiments is added to that gleaned from anatomical studies in the human cadaver, there remain gaps in our knowledge of this subject. Chronic progressive ischaemia of the spinal cord has not been produced experimentally and we have no observations on the long-term effects (survival for several years) of acute ischaemia. But the main objection to the experimental work is the question of its relevance to the human situation. It is necessary to compare the results of animal experiments with analogous observations on human spinal vessels obstructed at similar points.

This thesis presents an investigation of the anatomy of the human spinal-cord vasculature combined with a study of the consequences of its obstruction. In the anatomical study normal human spinal cords were obtained at necropsy and, using special techniques, the spinal cord vessels were examined with particular attention to points arising from the simultaneous pathological studies. For the second part of this investigation it was possible to examine post mortem a large number of cases of spinal cord diseases seeking the few in which a distinctive pathological lesion has produced, by disease, an obstructive disorder of the spinal vessels.

In this work the attempt has been made to obtain for the human being observations of comparable worth to those arising from well-designed animal experiments. In previous pathological studies on these lines, only one or two types of vascular disease of the spinal cord have come before the personal scrutiny of the researcher, the remaining cases being considered from a review of the literature. In this thesis all the pathological observations have been made by the author and this wealth of rare cases is a tribute to the cooperation over several years of clinical colleagues, in particular the members of the Oxford Departments of Neurology and Neurosurgery.

CHAPTER II.

ANATOMY OF THE VASCULAR SUPPLY TO THE HUMAN SPINAL CORD

The anatomical study of the vascular supply of the human spinal cord may be said to have begun with the rebirth of earnest anatomical dissection in the Italian Renaissance. The foremost of these modern anatomists was Andreas Vesalius who was of German origin from the Rhineland town of Wesel but was born in Brussels and was a student at Louvain, Montpellier and Paris. It was at Padua, as professor of anatomy and surgery, that Vesalius made his great anatomical contributions, sweeping aside the traditional anatomical teaching of Galen and substituting new observations based on his own dissections. His greatest work is the De humani corporis fabrica illustrated by Stephen Calcar and first published in Basel (Vesalius, 1555). It is in this work that we first find a clear account of the vascular supply to the human spinal cord. Vesalius recognised that the spinal cord was supplied by segmental arteries and that these arose in the cephalic part from the vertebral arteries which gave off spinal branches which passed through the various intervertebral foramina along the spinal nerve roots. The more caudal part of the cord was supplied from the intercostal and

lumbar arteries by means of their posterior muscular branches. The descriptions of Vesalius do not include any detailed account of the spinal cord vasculature and for the first account with a particular study of the subject we must consult the work of Thomas Willis (1667).

Thomas Willis, Professor of Natural Philosophy at Oxford in the 17th century made observations on the vasculature of the spinal cord of equal importance to his more famous descriptions of the blood supply of the brain (figs 1 and 2). These observations are recorded in his book "cerebri anatome, cui accesit nervorum descriptio et usus". In this work there is an elaborate description with several diagrams giving Willis's ideas of the spinal cord blood supply. He made many dissections, some of these being on foetuses which he found easier to dissect and also to inject. He made injections into the vessels with ink of various colours. He described the origin of the spinal arteries arising in the neck from the vertebral artery and in the trunk from the aorta. He followed these spinal branches and observed that one entered the intervertebral foramen and this vessel divided into three, of which two branches supplied the spinal cord and one the spinal meninges. From the two branches to the spinal cord one, the larger, accompanied the anterior nerve root and met, in the midline, the branch from the other side.

From this union a midline channel was formed and it is clear that Willis considered this vascular channel to be a series of midline vessels united together like the links of a chain. The other branch to the spinal cord passed posteriorly, accompanied the posterior nerve root, and was finally distributed in the form of fine branching vessels to the posterior part of the spinal cord. The diagrams drawn by Willis indicate the segmental nature of the anterior spinal artery but from his work it is clear that Willis's idea of the anterior spinal artery was that of a regular vessel fed by tributaries which accompanied each anterior nerve root and that he thought these tributaries were of equal size. In this last point Willis erred, at least as regards the adult spinal cord and also the spinal cord in the infant. It is possible that some of the foetuses that he dissected might have had a more regular anterior spinal artery formation than that seen in the adult. With this exception Willis's work was accurate and of value since for the first time it described in detail and on the basis of original observation, the vascular supply of the spinal cord.

The next important contribution was that of Molinetti (1675) and this work "Dissertationes anatomico-pathologicae" is also in Latin. He describes the union of two spinal branches of the vertebral arteries into one "rete mirabile"

which he called the spinal artery, and he showed how several small branches from the vertebral artery and from the descending aorta contributed to this spinal artery.

The observations of Molinetti were elaborated by Vieussens (1684) who studied this subject in detail and produced many drawings of his findings (fig 3). His drawings showed how the anterior spinal artery began as a union of three tributaries, one from each vertebral artery and one from the basilar artery. He drew the anterior spinal artery as a very regular longitudinal structure and he drew in regular tributaries accompanying each spinal nerve root in this way perpetuating the error of Willis. He also studied the vessels of the posterior aspect of the spinal cord and showed how the cephalic origin of these was from a vessel on each side arising from a cerebellar artery and passing longitudinally down the cord. In his drawing the posterior spinal arteries seemed to unite into a single vessel throughout most of its course and also had regular tributaries accompanying each posterior nerve root. In this regular reinforcement of the spinal cord blood supply of the posterior spinal artery Vieussens again as in his description of the anterior spinal artery made similar errors to Willis.

Haller (1756) reviewed the previous anatomical work on the circulation of the spinal cord and added his own

observations which are evidence of an extensive and detailed examination. His most important contribution was in reviewing the previous publications and showing their error in describing a regular pattern to the tributaries which reinforced the anterior and posterior spinal arteries. He emphasised that only some of the nerve roots are accompanied by tributary arteries and also stated that these vessels are not uniform in size, some being very fine, whilst others are by comparison large and are comparable in size to the anterior spinal artery. He also noted that the posterior spinal arterial system was composed of much smaller vessels than the anterior spinal artery. The drawings of Haller were very remarkable for the quality of his drawings of his dissections (figs 4 and 5).

We now come to the reports beginning in the second half of the 19th century and these include the writings of Duret (1873), Ross (1880), and Moxon (1881).

The work of Duret (1873) was noteworthy because he described different types of arteries which were involved in the blood supply of the spinal cord. He recognised the arteries that penetrated into the cord through the anterior fissure and through the posterior median fissure and showed how those entering the anterior median fissure supplied the anterior horn while these entering posteriorly

supplied the posterior horn, the posterior columns, and the posterior commissure. He also described anterior and posterior radicular arteries, the former supplying the anterior horn and the latter supplying the posterior horn and adjacent white matter. The third group of these arteries were peripheral arteries which were numerous and supplied the anterior lateral columns.

Ross (1880), a physician at the Manchester Royal Infirmary, made observations on the intrinsic vessels of the human spinal cord as seen in transverse sections. He named the various groups of spinal vessels that he recognised and showed how the grey matter of the spinal cord was more richly vascularised than the white matter. His descriptions and his diagram of the intrinsic spinal cord vasculature have the defect of over-simplification and the account of the branching of the sulcal artery (called by Ross the artery of the anterior median fissure) does not agree with subsequent observers.

Another observation made at about this time was that of Moxon (1881). In the Croonian lectures on the subject "The Influence of the Circulation on the Nervous System", Walter Moxon described how, from anatomical and clinical evidence, he believed that the caudal part of the spinal cord received a more precarious blood supply than that of the cephalic part. He wrote, "Thus the tip of the cord

has its blood-supply only from above, and deficiently even there, whilst the upper parts of the cord have a better sustained supply both from above and below". Moxon also referred (Moxon 1881) to the injection experiments of Dr. Carrington, Demonstrator in Anatomy at Guy's Hospital who had shown that the blood flow in the anterior spinal artery was from above down and that in his injections the caudal part of the spinal cord filled less well than the cephalic part.

Towards the end of the 19th century appeared the publications of Adamkiewicz who was professor at the Institute of Experimental Pathology at the University of Krakow. These reports recorded his findings in a large number of observations specifically directed to the study of the spinal-cord blood supply and which were all made by anatomical dissections and histological preparations on the human cadaver. To facilitate this work, Adamkiewicz often injected the arteries and the veins of the spinal cord with distinctive injection material, and he also prepared his histological sections with particular attention to demonstrating the blood vessels. Adamkiewicz published two accounts (1881, 1882), and in the second of these publications he described in detail the origin and course of the anterior and the two posterior spinal arteries. He demonstrated clearly the origin of these vessels from the

cranial part of the vertebral arteries and also explained how they were joined by several tributary arteries accompanying the spinal nerve roots. He gave many instances of the varying number and position of these tributaries and he named the large tributary to the lower thoracic region the arteria magna spinalis. This large tributary he found, equally on either side, on one of the nerve roots from the eighth thoracic to the third lumbar, and most commonly on one of the three thoracic roots, T9, T10 and T11.

In his publication of 1881, Adamkiewicz described the results of his researches on the blood supply of individual cord segments. He noted how the grey matter of the spinal cord had a much richer capillary plexus than the white matter. Because of the manner in which the spinal arteries entered the spinal cord, Adamkiewicz divided them into two groups, the centrifugal vascular system and the centripetal vascular system. The centrifugal system was wholly derived from the anterior spinal artery via the arteries named by Adamkiewicz the arteriae sulci and which proceeded posteriorly in the anterior median sulcus. Adamkiewicz described the arteriae sulci as dividing into a pair of arteriae sulco-commissurales, but in this observation of the constant division into two equal terminal branches subsequent workers have shown Adamkiewicz to be wrong. In the lower thoracic and upper lumbar region a fairly constant

intramedullary branch passes to the region of Clark's column on each side and these branches were observed and were named by Adamkiewicz the arteriolae columnarum Clarki.

What was called by Adamkiewicz the centripetal vascular system, originates from the vascular plexuses surrounding the spinal cord and also the branches from the two posterior spinal arteries. The name centripetal was suggested by the course of these supplying vessels which was in a radial direction towards the centre of the spinal cord. Adamkiewicz gave names to many of these small arteries which, although of minor calibre, are fairly constant in their position. He subdivided these centripetal vessels into three groups and called the first group the "Randegefasse", these being the small short branches supplying the peripheral rim of the spinal cord immediately beneath the pia mater. The second of his groups were those vessels of the centripetal system supplying the remainder of the white matter. Of these he named the single artery passing anteriorly in the connective tissue of the posterior median septum the arteria fissurae. Similar paired radial arteries supplying the posterior columns pass along each posterior intermediate septum and these arteries he called the arteriae interfuniculares. The third group were those arteries of the centripetal system supplying the grey

matter mainly the posterior grey horns. Adamkiewicz gave names to three of these vessels which in all cases were paired arteries one to each side of the spinal cord. The arteria radicum posteriorum entered the spinal cord at the posterior root entry zone and supplied the most posterior part of the grey matter. The arteria cornuum posterium posticae passed through the white matter of the posterior column (lateral to the arteria interfunicularum) to the posterior horn, whilst through the lateral white column the arteria cornuum posteriorum laterales passed to a similar destination.

In the development of our knowledge of the spinal cord vasculature, Adamkiewicz's work is of considerable importance providing, as it did for the first time a very detailed account of both the large and small vessels involved. In the light of further observations on this subject only a few of the conclusions of Adamkiewicz have had to be revised.

The work of Adamkiewicz at Krakow was continued and extended by Heinrich Kadyi whose monograph (Kadyi, 1889) translated into German from his earlier Polish writings remains today the most comprehensive review of the blood supply of the human spinal cord. Kadyi examined over fifty cadaver specimens of the human spinal cord and made many injection studies to display the spinal arteries,

capillaries and veins.

In his monograph Kadyi, after an introductory account of the subject and of his injection methods, described the origin of the anterior and posterior spinal arteries from their parent intracranial branches and their course down the cord as far as the filum terminale. He was well aware of the occurrence of a duplicated anterior spinal artery which in his experience usually extended, as a double channel, to the midcervical region.

Kadyi described in great detail how the anterior and posterior spinal arteries receive tributary arteries which accompany the spinal nerve roots and in 29 of his specimens he recorded in tables the size of these tributaries and classified each artery into one of four grades of size. He found that only a quarter of the nerve roots were accompanied by tributary arteries of sufficient size to contribute to the anterior and posterior spinal arteries whilst the remainder nourished only the spinal nerve root itself. The situation of the largest and most important radicular tributary (the arteria radicalis anterior magna of Adamkiewicz), was from the ninth thoracic to the third lumbar root and more commonly on the left side.

Kadyi then described the branches of the anterior and posterior spinal arteries and in this study he went into

less detail and gave fewer names than did Adamkiewicz. He did however describe correctly the origin and course of the central arteries (the arteriae sulcae of Adamkiewicz). He maintained in a description that differed from that of Adamkiewicz that these arteries usually arose as short branches from the anterior spinal artery and passing backwards in the anterior median sulcus they were directed laterally into either the left or the right grey matter. The presence of a short common trunk which divided into two left and right branches of equal size, as described by Adamkiewicz, was, according to Kadyi, most uncommon but did occasionally occur in the lumbo-sacral region.

Kadyi gave similar attention to the venous drainage of the spinal cord and described the small veins draining into venous plexuses on the anterior and posterior aspects of the cord. Anterior and posterior radicular veins accompanied nerve roots in a similar manner to the arteries and these venous radicular vessels were graded in size by Kadyi and recorded in his tables of 29 cadaver specimens.

In the twentieth century the number of papers dealing with the spinal cord vasculature increased considerably but, as many of these writings dealt with the clinical and pathological aspects of the subject, they will be considered in the second part of this historical review. Here we

shall only consider those papers dealing primarily with anatomical findings.

Bolton (1939) carried out a series of injection experiments designed to demonstrate the direction and distribution of flow in the spinal blood vessels. She did this in one series of her experiments by injecting solutions of coloured celloidin into major arteries of the cadaver. In her second series of experiments the spinal cord was removed from the spinal canal before the injection of the spinal vessels with indian ink. The amount of information obtained from these experiments was increased by diverting the blood flow by clamping arteries at certain important points. At the end of her experiments, Bolton came to the following conclusions:-

The anterior spinal artery derives its blood from the vertebral arteries and from branches of the intercostal arteries, the direction of flow being from above downwards.

The posterior spinal arteries are formed by branches from either the vertebral or the posterior inferior cerebellar arteries but the supply from above only extends down to the lower cervical region. Caudal to this the blood flow is in an upward direction from the terminal portion of the anterior spinal artery, the flow being directed upwards as far as the upper thoracic level.

The extent of the intramedullary flow of the injection

material into the spinal cord showed that the anterior spinal artery supplied the whole cord with the exception of the posterior portion of the posterior columns and the posterior horns.

Two other american papers appeared at the same time as Bolton's report and these also dealt with the findings in injection experiments. Suh and Alexander (1939) studied 26 normal human spinal cords obtained at autopsy. In 21 of these the major vessels were injected with indian ink and observations were made macroscopically and after cutting thick frozen sections. In the remaining 5 spinal cords sections were stained with the benzidine stain which showed the intrinsic vascular pattern. Suh and Alexander classified the spinal vessels, arterial and venous, into seven categories using a system previously devised (Alexander and Putnam, 1938) for the cerebral vessels. The anterior spinal arteries and veins were in category 6 whilst the intramedullary capillary plexuses were classed as category 1. These categories were based on the measured diameters of the vessels concerned and Suh and Alexander particularly applied their measurements to the radicular tributary arteries and to the anterior spinal artery at various segmental levels. In this way they were able to demonstrate by measurement the varying sizes of the radicular tributaries and also the segmental anastomotic nature of the anterior

spinal artery. The intramedullary course of the small spinal vessels in the lumbo-sacral region they found to be in a radial direction (and so were cut longitudinally in transverse sections) whilst those in the thoracic region passed upwards or downwards towards their place of supply (and so were cut transversely). The slant of the intramedullary vessels in the cervical region was intermediate between the course in the lumbo-sacral and thoracic regions. Suh and Alexander also injected the spinal veins of some of their specimens and made similar observations on the size and position of the different venous trunks. By venous injection they could not enter, with their injection material, the venules of the second order of magnitude nor the capillaries beyond and they described a type of monocuspid valve structure at the junction of the veins.

Herren and Alexander (1939) extended the work reported by Suh and Alexander and their work dealt mainly with the intramedullary spinal circulation. They described the sulcal vessels and showed how the anterior sulcal arteries usually supplied only one side of the spinal cord at a given level but that the anterior sulcal veins usually drained both sides. A wide anastomosing branch between the paracentral vein and one of the large dorsolateral veins was described. In studying the distribution of blood

supply between the anterior and posterior spinal arteries they found that the anterior radicular arteries and the anterior spinal artery supplied the anterior horns, the central grey matter, the lateral horns and Clark's columns, and the anterior and lateral white columns. The posterior radicular arteries and the posterolateral arterial trunks supplied the posterior columns and the posterior horns.

The anterior spinal vein by means of the anterior sulcal veins drained the septomarginal white matter and the antero-central grey matter whilst the same trunk by means of its transverse meningeal branches and their tributary individual straight intra-spinal veins drained the antero-lateral and lateral white matter. The posterior radicular veins and the posterior venous trunk drained the posterior horns, Clark's columns and the posterior white columns. A narrow strip of the white matter lateral and adjacent to the posterior horn was drained sometimes by the anterior and sometimes by the posterior venous system.

Sahs (1942) and Yoss (1950) made interesting contributions to this subject through their observations and their experimental work on the blood supply of the monkey's spinal cord. Yoss performed experiments which included the occlusion by electrocautery of the anterior spinal artery and the obstruction of radicular tributaries by ligation of the certain anterior and posterior spinal nerve roots. He

was able to compare the experimentally produced vascular syndrome in the monkey with findings in reported human cases which he reviewed. In general both Sahs and Voss found that the vascular supply of the spinal cord in the monkey and in man were similar.

More recent contributions to this subject are those of Zulch (1954, 1962), Torr (1957), Corbin (1961), Romanes (1965) and Jellinger (1966).

The anatomical observations and deductions of Zulch (1954, 1962) were based on observed and reviewed cases of human vascular disorders of the spinal cord from which he drew conclusions concerning the adequacy of supply in certain regions. He considered, on the basis of these cases, that there were two regions where the spinal cord was especially vulnerable to an inadequate blood supply. One of these was at about the fourth thoracic segment where the source of the blood supply to the spinal cord changed from the subclavian artery to the intercostal arteries. Similarly a second region at the twelfth thoracic or first lumbar segment was the region of change to a lumbar artery supply from a supply derived from a major intercostal tributary.

Torr's work combined a study of the embryological development of the spinal cord blood supply with an examination of the form it attained in the foetus and the adult. Torr also considered the implications of these findings in

medical practice and with particular reference to surgical operations around the ribs and intervertebral foramina.

Corbin's monograph is a review which he divided into accounts of embryology, anatomy and pathology. Corbin also made injection experiments in cadavers but without enlarging on the results of his predecessors. The great value of Corbin's work was his review of previously published cases of vascular disorders of the human spinal cord and these will be dealt with in the next chapter.

The report of Romanes (1965) is a description of his careful observations on the arteries of 22 human spinal cords. Romanes emphasized the great variation in the pattern of the spinal arteries making it impossible, in any given individual, to predict the position of important feeding vessels. He found in his studies that in the thoracic region the majority of feeding vessels to the anterior spinal artery came in on the left side and among them was the great spinal artery usually on a left thoracic anterior root from T8 to T11. Romanes also remarked on the anastomoses which he found connecting the anterior and posterior spinal arteries. These communications were large in the cervical and lumbosacral regions and in the latter situation were often of the same order of magnitude as the vessels connected by the anastomoses. Romanes' work is important as an accurate summary of our present knowledge of the

major spinal arteries.

The most recent contribution to the study of the spinal cord vessels is that of Jellinger (1966) whose approach to the subject was similar to that of Corbin. Jellinger's account included the anatomical study of 318 human spinal cords and observations made during experiments on cats, rabbits, guinea pigs and rats. He also studied 196 cases of spinal cord diseases many of which were discovered during a systematic examination of more than 1000 human spinal cords at necropsy. Jellinger's account has the disadvantage that, in his clinical cases, clinico-pathological correlation was sometimes lacking and in most instances only the spinal cord and its intrinsic vessels were personally examined in detail. These deficiencies were partly compensated by a very full review of the literature with particular attention to important cases with necropsy observations. These observations, partly clinical and partly pathological, will be considered in the next chapter.

CHAPTER III

THE PATHOLOGY OF VASCULAR DISORDERS OF THE HUMAN SPINAL CORD

The better understanding of the anatomy of the vascular supply to the spinal cord was followed by an awakening of interest in diseases that might be peculiar to this system. This curiosity awaited the development of modern morbid anatomy and histology and in particular the thorough and frequent conduct of necropsies on cases whose clinical course had been studied. For this development of the post-mortem examination into a regular, ordered and systematic procedure we are chiefly indebted to Karl Rokitansky, 1804-1878, at Vienna and Rudolf Virchow, 1821-1902, at Würtzburg and Berlin. The growth of these two great schools of pathology in Austria and Germany challenged the earlier foundations in France and England which in their turn had succeeded Italy as leaders in these new developments in morbid anatomy. The medical literature encompassed in this wealth of new experience is extensive and its review here has been divided according to the anatomical location of the disease or obstruction. In this way the review of the literature will correspond in plan to the observations based on personally studied case reports which will be recorded later in this work.

AORTIC CONDITIONS

These will be discussed under the headings Aortic atheroma and thrombosis, Dissecting aneurysm of the aorta, Coarctation of the aorta, and Aortic surgery.

Aortic atheroma and thrombosis

The earliest reports in which aortic disease was implicated in spinal-cord ischaemia were made by the French neurologists of the late 19th century, who showed how severe arteriosclerosis could cause a neurological syndrome. The papers of Letulle (1880), of Martin (1881) and of Demange (1884) are especially noteworthy. Letulle reported a case of locomotor ataxia, in which, at necropsy, generalised arteriosclerosis was such a marked feature that the author considered this might have caused the degenerative spinal cord syndrome. Martin, in a long paper dealing with the general effects of chronic obliterative arterial disease, agreed (p. 379) with Letulle's conclusions and presented his own findings in a similar case from his own experience. The case of Demange is very well documented both by a detailed report of his clinical observations and also by a careful account of the findings at necropsy. A 75-year-old embroideress developed a paraparesis with amyotrophy and areflexia associated with dysaesthesia and disturbance of bladder function. Necropsy showed severe

generalised arteriosclerosis with conspicuous atheroma of the aorta. The spinal cord was found to contain widespread areas of degeneration scattered irregularly throughout the grey and white matter and associated with thickening of the small spinal arteries by perivascular fibrosis. The interest in this condition, begun by these early French contributions, continued in the observations of Marie and Foix (1912) who described several cases of amyotrophy in elderly patients and concluded, on the basis of the findings at necropsy, that the neurological disturbances were caused by generalised arteriosclerosis. At about this time, the concept of "intermittent claudication of the spinal cord" was formulated by Déjerine (1906) in France and later recognised in America by Hunt (1912) and by Reichert, Rytand and Bruck (1934). This syndrome of intermittent lower limb paresis related to exercise may sometimes be due to causes other than arteriosclerosis but this was thought to be the common explanation in elderly patients.

In the accounts that have been mentioned, whilst all had necropsy observations, the emphasis was on the clinical syndrome. The work of Campbell (1894) in England, and that of Nonne (1899) and Sander (1900) in Germany was specifically directed to the histological findings in the spinal cord. All these authors took advantage of the immense amount of pathological material arising from necropsies performed in

mental hospitals. The account of Campbell formed part of a larger study on the senile changes in the brain and spinal cord. Nonne described the histological findings in the spinal cord in ten elderly patients and Sander, a year later, added considerably to Nonne's observations in describing his own observations on 30 cases. It is interesting that Sander, on the basis of his histological findings, claimed to distinguish the changes due to arterio-sclerotic ischaemia from those of senile involution.

Since these early papers, the subject of spinal cord ischaemia due to arteriosclerosis has occasionally appeared in the world medical literature but never with a large number of reported cases. Kesehner and Davison (1933) found only two cases of this type in a review of cases of myelitis and myelopathy. The subject has been approached by the systematic examination of a large number of spinal cords from elderly patients dying in hospital and subjected to necropsy. This method has yielded larger numbers of cases than hitherto reported in a single paper but has had the disadvantage that the clinico-pathological correlation of the details of the cases has been less successful than in those studied individually. The accounts of Bogolepov and Brokhina (1963), and of Mannen (1963) had this drawback. Mannen in the study of 300 unselected autopsies performed in a geriatric hospital at Tokyo found 27 cases with

vascular lesions in the spinal cord. Excepting two cases of spinal cord haemorrhage, the remaining 25 cases had multiple ischaemic softenings in the spinal cord. The paper of Jellinger and Neumayer (1962) referred to a similar study conducted at Vienna. These authors reported on 21 cases, all verified at necropsy, in which a syndrome of spinal cord ischaemia was shown to be associated with arteriosclerosis. The most recent paper on this subject (Hughes and Brownell, 1966) describes five cases (detailed in this thesis) which, during life, exhibited a syndrome of paraparesis or quadriparesis with signs referable to a combined lesion of the upper and lower motor neurone. At necropsy there was severe generalised arteriosclerosis with changes in the spinal cord suggestive of chronic ischaemia. In this last paper the cases showed aortic atheroma, and in two, aortic thrombosis was also present. Aortic thrombosis and atheroma frequently coexist but in a few case reports such as those of Cook (1959) and of Hiddema, Beks, Vafi and Elema (1963) an acute spinal cord syndrome has been caused by a sudden aortic thrombosis. In the case of Brenner, Jellinger, Prosenz and Tschabitscher (1965) a similar syndrome followed a traumatic subclavian artery thrombosis.

Dissecting aneurysm of the aorta

The observation that dissecting aneurysm of the aorta

may cause a spinal-cord syndrome was first made in the nineteenth century by Swaine-Latham (1855). The first necropsy is described in the account of Coleman (1898) who found no significant abnormality in the spinal cord. In a review of the world literature of this subject and considering only the accounts with a necropsy, about 11 case reports can be readily examined. There is also a literature of the effects of dissecting aneurysm on the brain and peripheral nerves (Weisman and Adams, 1944) but these cases need not concern us here.

In reviewing these case reports it is evident that the dissection of the aorta causes more extensive spinal damage in some cases than in others. In some case-reports as in the case of Kalischer (1914) and the first case of Lange-Kosack and Kohn (1962) it is probable that death supervened before the changes in the spinal-cord became evident. This explanation does not suffice for all these instances as in the case of Moersch and Sayre (1950) in which despite a sufficient interval no changes were found.

The more usual finding is a partial necrosis of several segments of the cord and often with a selective damage to the grey matter. These were the findings in the cases reported by Reitter (1916), Thompson (1956) and Kepes (1965). In the case of Weisman and Adams (1944) there was infarction in the distribution of the anterior spinal artery whilst

that of Scott and Sancetta (1944) was exceptional in that the white matter appeared predominantly affected. Several cases have had a complete necrosis of the whole cross sectional area of the cord affecting several segments. To this group belong the case of Schwarz, Shorey and Anderson (1950), Ballantine (1952) and Hill and Vasquez (1962).

The difference in these cases, although striking in some instances, may be explained by the complicated pattern of blood supply to the spinal cord. The lesion in dissecting aneurysm may involve more or less of the aortic media and the haematoma formed may have occluded several intercostal and lumbar arteries. The number of the involved intercostal or lumbar arteries can be ascertained but the exact degree of interference with blood flow cannot usually be determined. The other complicating factor is the varying blood supply to the spinal cord from these spinal branches and in particular the large tributaries whose obstruction is so important relative to the other insignificant tributaries.

Coarctation of the aorta, first described by Morgagni in 1761, is a congenital stenosis of the isthmus of the aorta, the segment of aorta between the origin of the left subclavian artery and the position of the ductus arteriosus. Since Bonnet (1903) it has been customary to divide the cases

into "infantile" and "adult" types. In the infantile type, there is an extensive obliteration of the aortic isthmus, the ductus arteriosus remains widely patent, and because there is no compensatory anastomotic circulation, death in the perinatal period is common. In the "adult" type, the narrowing of the aorta is confined to a small segment which may be before, at, or (the usual situation) beyond the origin of the left subclavian artery. The ductus arteriosus closes and this permits an extensive anastomotic circulation to develop between the arteries supplying the upper trunk and the upper limbs, and those arising beyond the aortic constriction and which supply the lower trunk and lower limbs. These "adult" type cases have a good prognosis for life and alone concern us in a consideration of neurological complications. Coarctation of the aorta is not a common anamoly and Fawcett (1905) in reviewing 22, 316 necropsies at Guy's Hospital between 1826 and 1902 found only 18 cases. The proportion of cases which develop a spinal cord disturbance is very small. Woltman and Sheldon (1927), in reviewing the world literature, found 32 cases with neurological complications and these formed 7 per cent of the reports studied by them. Most of these reports referred to cerebral complications, often a fatal intracerebral haemorrhage or a subarachnoid haemorrhage from a ruptured congenital aneurysm. The complications affecting

the spinal cord are fewer and are of two types:

1. Those due to a reduced blood supply to the more caudal part of the spinal cord.

These complications formed the majority of the observations recorded by Tyler and Clark (1958). The symptoms and signs of paresis, sensory and sphincteric disturbance were attributed in these cases to ischaemia and hypotension of the part of the spinal cord normally supplied by arteries derived from the aorta beyond the constriction.

2. Complications due to the hypertension present in the body in arteries derived proximal to the aortic constriction.

This second group includes cases in which enlarged collateral vessels have caused compression of the spinal cord. Such cases were those of Haberer (1903), Christian and Noder (1954), Peterman, Voss and Corbin (1958), Wyburn-Mason (1943), and Blackwood (1963). There have been no necropsy reports of cases of coarctation in which the local hypertension directly caused a spinal cord syndrome but this suggestion was made in a case studied clinically by Weenink and Smilde (1964).

Aortic surgery

The twentieth century has witnessed the development

of modern vascular surgery which now includes surgical procedures in which the aorta may be occluded surgically or may be replaced by a graft. These operations and their complications now provide observations in man comparable to experiments in animals in which the aorta is obstructed. This type of experiment has a long history dating originally from the historic observation of the Danish Scientist Niels Stensen. Stensen (1667) found that a ligature tightened around the descending aorta of a dogfish paralysed the tail and that the paralysis recovered when the ligature was slackened.

The neurological complications which have followed aortic surgery were reviewed by Adams and Van Geertruyden (1956) who gathered the case reports of the various operative procedures and added cases from their own experience. Their paper is valuable in providing some estimate of the incidence of neurological complications as well as an analysis of the type of disability and its prognosis. The case reports could be grouped into four types with respect to the operation performed and these were 1. occlusion of the aorta alone, 2. occlusion of the intercostal vessels, 3. occlusion of the aorta and the intercostal arteries, 4. cases of operation on coarctation.

1. <u>Occlusion of the aorta alone.</u>

These were cases of conditions such as patent ductus

arteriosus and aortic aneurysm in which, during an operation, the aorta had to be occluded either permanently or (more usually) temporarily. There were 52 cases of this type and of these only 7 had neurological complications. In one of these seven cases (Czerny, 1879, quoted by Adams and Van Geertruyden, 1956) the aorta was permanently occluded. It is of interest that similar permanent occlusion had been performed on three other cases and these had not suffered neurological complication.

In the other six cases with neurological complications (Crafoord, cited by Ekström, 1952 4 cases; Sweet, 1950; Burgess, Freeman, Cherry and Hartwell, 1955) the aorta had been occluded for times varying from 18 minutes 50 seconds to more than 60 minutes. In all these six cases the site of the aortic occlusion was below the left subclavian artery. The times of occlusion were usually greater than in the cases without neurological complications, and in the four cases with a profound flaccid paraplegia the times of occlusion (27, 38, 49, over 60 minutes) were longer than the rest. The motor part of the neurological syndrome ranged from a moderate spastic paraparesis to a flaccid paraplegia. Sensory disturbance and paralysis of bladder and bowel were uncommon but did occur in the cases with severe paresis.

2. Occlusion of the intercostal vessels.

There were nine case-reports of this type of operation in which a shunt aorta was inserted so that the intercostal vessels were totally occluded. In only one of these cases, that of Bahnson (1953), did neurological complications ensue. In this case a shunt aorta for an aneurysm of the thoracic and the suprarenal part of the aorta occluded all the intercostal vessels and produced a paraplegia.

3. Occlusion of the aorta and the intercostal arteries.

At operation in these cases, the aorta was temporarily occluded and some or all of the intercostal arteries were occluded often by the insertion of an aortic graft. There were 18 cases of this type of which 5 cases (Lam and Aram, 1950; Cooley and De Bakey, 1955) (Eiseman and Summers, 1955; De Bakey, Cooley and Creech, 1955; Bahnson, 1955) had neurological complications. In two of these cases the disability was that of weakness in both lower limbs. In the three other cases in which an extensive occlusion of the intercostals had been performed there was a complete paraplegia.

4. Cases of operation on coaretation.

This group of eleven cases consisted of all the case-reports of this operation in which post-operative neurological complications had ensued. In these cases the neurological

deficit was often grave with complete paraplegia, sensory changes and often accompanied by bladder or rectal disturbances. In three of the cases the clinical syndrome of limb paralysis with relative sparing of sensory appreciation suggested a diagnosis of thrombosis of the anterior spinal artery.

When we turn to the case-reports of neurological complications of aortic surgery in which the spinal-cord damage has been examined at necropsy only 3 reports may be found in the literature. Pathological observations on these aortic surgery cases have been so few that a detailed consideration of these three cases is justified.

The case of Crafoord (cited by Ekström, 1952) was a boy aged 8½ years with a widely patent ductus arteriosus which was divided with clamping of the aorta. During the suturing of the divided ductus a small tear of the aorta had to be repaired and consequently the period of aortic occlusion (49 minutes) was longer than usual. On regaining consciousness from the anaesthetic the patient was found to have a flaccid paralysis and almost complete loss of sensation in both legs. He also had total paralysis of the bladder and paralytic ileus. He died 16 days after the operation. The spinal cord showed considerable destruction of the grey matter in the lower thoracic and the entire lumbar region.

The anterior horns were completely destroyed in these regions and the posterior horns partly so. The damage was mainly confined to the central area of the spinal cord with sparing of most of the white columns.

The case of Beattie, Nolan and Howe, (1953) was that of a 29-year-old man with hypertension due to coarctation of the aorta. The constriction, which was a pre-ductal coarctation just below the left subclavian, was excised and during the operation the aorta and the left subclavian were clamped for 38 minutes. The day after operation it was apparent that the patient had paralysis of the legs but tactile sensation and position sense remained intact. On the fifth post-operative day the patient died from pulmonary oedema and acute renal failure. The spinal cord showed necrosis in its caudal part but no further details were given.

The case of Hogan and Romanul (1966) was that of a 76-year-old man who was operated upon for a ruptured aneurysm of the lumbar aorta. During the aortic exposure and evacuation of haematoma, the aorta was manually compressed for 8 minutes and then clamped, below the renal arteries, for 3 hours whilst the aneurysm was resected and a Teflon bifurcation prosthesis inserted. On the morning after the operation the patient was found to have a flaccid areflexic paraparesis with a corresponding loss in the

lower limbs of sensation to light touch, pain and temperature, but with preserved appreciation of vibration and joint position. The bladder and bowel were paralysed. 24 days after the operation the patient died from renal failure terminated by pulmonary embolism. The necropsy established the patency of the aortic graft which extended from below the origin of the 1st lumbar arteries to both the common iliac arteries. The left 2nd lumbar artery had been ligated by a silk suture. The spinal cord showed a well-developed infarct affecting the central part of the cord from T12 to S5 segments. The shape of the infarcted region was that of a spindle with the upper pole situated in the grey commissure. A few segments below the upper pole the region of infarction had expanded to a round central area affecting all the grey matter and the adjacent white matter. More caudally the region became smaller but here in relation to the smaller sacral segments the infarct involved most of the cross sectional area of the spinal cord.

It is appropriate to mention here that there is one report (Hughes, 1964a) of spinal cord infarction following trauma to the aorta in a road accident. This case is presented later in this thesis and details will not be given here. In many respects the case is comparable with cases due to dissecting aneurysm of the aorta and those following

aortic surgery.

VERTEBRAL ARTERY OBSTRUCTION

Very few cases have been reported in which a lesion of one or both vertebral arteries has caused ischaemia of the spinal cord. Of the chronic disease processes, the most important are degenerative arterial disease and degenerative osteo-arthritic conditions of the spine.

Atheroma commonly affects the vertebral arteries, but according to Mitchell and Schwartz (1965 p.56), the common site is the commencement of the artery whilst the intra-foraminal portion is usually spared. It appears very rare for atheroma of the vertebral arteries to cause ischaemia of the spinal cord and Hutchinson and Yates (1951), who examined the spinal cords of 35 cases of cerebro-vascular disease, found no evidence in these cases of spinal-cord damage.

In degenerative disease of the spine, conflicting opinions are voiced as the contribution of vertebral artery compression to the cause of the myelopathy in cervical spondylosis. Sheehan, Bauer and Meyer (1960) and Maslowski (1960) considered this an important factor but other authors have not agreed. In an investigation into cervical spondylosis Hughes and Brownell (1965) found no definite evidence for vertebral artery compression in the causation of the

myelopathy.

Of the acute disease processes affecting the vertebral arteries we have to consider obstruction by thrombosis and the effects of trauma to the cervical spine. Cases with vertebral artery thrombosis have been very rare and usually, as in the case of Brenner, Jellinger, Prosenz and Tehabitscher (1965) associated with a subclavian artery thrombosis. Traumatic cases are probably more common although there have been very few cases with necropsies. One such case is that of Schneider, Thompson and Bebin (1958) who described a clinical syndrome referable to the central part of the cervical cord which was demonstrated at necropsy to be infarcted. Two more cases have been described (Hughes, 1964b) and will be referred to in this thesis.

INTERCOSTAL AND LUMBAR SPINAL ARTERIES

Obstructive disease of the intercostal and lumbar spinal arteries is rare with the exception of the aortic conditions which have been discussed earlier. These arteries are however at risk in certain surgical operations of which those giving rise of neurological complications are thoraco-lumbar sympathectomy, pneumonectomy and thoracoplasty.

There have been approximately 13 recorded cases in which the operation of thoraco-lumbar sympathectomy has

been followed by a spinal cord syndrome. Rubio (1953, quoted by Corbin, 1961) published three cases and a further case was reported by Mosberg, Voris and Duffy (1954) who also cited four other cases of Bassett (1948) and a personal communication of three further cases known to Poppen. Nathan (1956) mentioned one case in a paper concerned primarily with sensation and a single case with necropsy (described in this thesis) was reported by Hughes and Macintyre (1963). In many of these cases mentioned the clinical details are scanty and an account of the findings in the spinal cord at necropsy is only available in the cases of Mosberg et al. (1954), Nathan (1956) and Hughes and Macintyre (1963).

Case 1 of Mosberg and his colleagues was that of a 54 year old man who underwent bilateral thoraco-lumbar sympathectomy. The operation on the left side was uneventful but 10 days after the operation on the right side the patient developed mental confusion, numbness of the hands and feet and generalised muscle weakness. After a further 7 days this had progressed to a complete spinal cord syndrome with a level at T12. The patient died the following day and an autopsy was performed. The only changes found in the spinal cord were in two sections of the upper lumbar region where the architecture of the grey and white matter was indistinct and there were axonic swellings and pallor

of myelin staining. No lipid phagocytes were seen and no changes were observed in the spinal vessels. The authors considered the cause of the spinal cord disturbance to be a myelomalacia due to vascular thrombosis but this pathology was not observed in their sections.

The case reported by Nathan was that of a woman on whom a thoraco-lumbar sympathectomy was carried out in two stages with an interval of a month. During the second operation the patient became shocked and on recovery from the anaesthetic she presented a spinal-cord syndrome with a sensory level at T12 dermatome. This case was considered on clinical grounds and at necropsy 10 months later to be explained by anterior spinal artery thrombosis but no details of the necropsy are given in the paper which was chiefly concerned with disorders of sensation in a group of patients.

The case of Hughes and Macintyre (1963) is presented later in the thesis and will not be reviewed here.

There remain two other case reports without necropsies but which contribute to the subject of obstruction of intercostal vessels. Binet (personal communication to Corbin, 1961) observed a case of paraplegia which followed shortly after a left-sided pneumonectomy for tuberculosis. There was no evidence of previous arterial disease and no episode of hypotension during the operation which was considered to

have obstructed an intercostal artery giving origin to an important tributary to the anterior spinal artery. A case similar in many respects but caused by a thoracoplasty operation was described by Rouquès and Passelecq (1957). The complication of a partial cord transection followed the second stage of the thoracoplasty when the 4th, 5th, 6th and 7th ribs were resected. In neither of these two case reports was the nature and cause of the spinal cord damage ascertained at necropsy.

RADICULAR TRIBUTARIES

The radicular tributaries accompany the spinal nerve roots through the intervertebral foramina to reach the anterior and posterior spinal arteries. In their course they are vulnerable to surgical trauma, in particular an operation during which a nerve root is sectioned. Rogers (1955) quotes instances of this complication which will only occur when the damaged nerve is accompanied by a large main tributary artery.

These cases due to surgical operation are very rare and more cases are seen following malignant tumour infiltration of the spine. The syndrome of spinal-cord infarction due to obstruction of radicular tributaries is difficult to distinguish from other mechanisms of malignant paraplegia but Spiller (1925) was aware of this condition

and Corbin (1961) has recently reviewed several case reports. The case reported by Lhermitte and De Robert (1941) is typical. A 65 year old man with a carcinoma of the oesophagus developed a flaccid paraplegia with sensory loss and sphincteric paralysis. Death occurred ten days after the onset of the neurological syndrome. At necropsy there was no compression of the spinal cord which was infarcted at L1 and L2 segmental levels. There was no thrombosis of the intrinsic vessels of the spinal cord and the site of obstruction was considered to be in the extra spinal vessels.

ANTERIOR SPINAL ARTERY OBSTRUCTION

Up to the nineteenth century the acute affections of the spinal cord were grouped under the name myelitis and until the writings of Bastian (1886) a syndrome due to obstruction of the anterior spinal artery had not been recognised. Bastian was emphatic that in the spinal cord softening was frequently due to arterial obstruction by thrombosis. In this belief he was in conflict with Charcot as this extract from his book (Bastian, 1886) indicates.

> "Thus one of the common causes of ordinary degenerative or ischaemic softening as it occurs in the encephalon, is undoubtedly operative in the cord, and I must, therefore, express my strong dissent from the state-

> ment made by Charcot (Localisation, p. 41) to the effect that 'softening, secondary to arterial obstruction, whether it be due to thrombosis or to embolism are almost unknown accidents in the spinal cord'."

Bastian had support from Singer (1902) who described two cases of acute myelitis which were explained at necropsy by thrombosis in the spinal arteries which were affected by syphilitic arteritis. Soon afterwards Spiller (1908) recognised the syndrome of anterior spinal artery occlusion during life and later (Spiller, 1909) reported the confirmation of his diagnosis at necropsy.

Although the syndrome is very well known it is surprising how few cases with necropsy accounts have been published and these it is possible to review in some detail. The account of Margulis (1930) refers to three cases (cases 1, 2 and 7) in which syphilitic arteritis caused anterior spinal artery thrombosis and these cases are similar to those described earlier in the century. This emphasis on syphilis as the predisposing cause has now disappeared. In the case of Schott (1915) the thrombosis was attributed to minor trauma and this was also the cause in the report of Grinker and Guy (1927). In their case a 15 year-old boy developed thrombosis of the upper part of the anterior spinal artery apparently due to a sprain of the cervical spine with

subluxation of the cervical spine. This explanation was suggested by the authors because the syndrome had developed a few hours after yawning and vigorous upward stretching of the arms. Similar minor trauma was postulated in the case of Hughes and Brownell (1964) and this case is described in this thesis. The case of Zeitlin and Lichtenstein (1936) is unique in that the thrombosis occurred in an anterior spinal artery which was affected by atheroma. Atheroma has very rarely been reported in the anterior spinal artery and most authors (Jellinger 1966) comment on its rarity.

Whilst the syndrome of anterior spinal artery occlusion is very well known, that of obstruction to the posterior spinal vessels is almost unknown. Ullmann (1938) could only find three reported cases and in two of these the extent of spinal cord damage was much larger than the territory of the posterior spinal artery. In the case of Williamson (1895) the infarction of the spinal cord appeared to be limited to the area supplied by the posterior spinal arteries. This early report has remained without support in the literature until the publication of two cases by Perier, Demanet, Henneaux and Nunes-Vincente (1960). These authors described a case in a 47-year-old man in whom there was acute infarction in the territory of the posterior spinal arteries without any evidence of the primary cause

of the vascular obstruction. In their second case, a man of 65 years, the cause of the obstruction was demonstrated to be the blockage of the lumen of the arteries by cholesterol material which they considered to be embolic from aortic atherosclerosis. In this case and in their previous case the anterior spinal artery was normal and its territory of supply was not infarcted.

SMALL SPINAL ARTERIES

A diverse group of diseases affects small arteries and occasionally there are cases in which the small arteries of the spinal cord are particularly affected. This group contains some very interesting pathological entities but in some of these (an example is polyarteritis nodosa) the spinal cord is only affected as part of a widespread disorder of small arteries. Malamud and Foster (1942) in a review of personally studied cases of polyarteritis nodosa found that the central nervous system was involved in about 20 per cent of cases, but the spinal cord was only involved seriously in 2 per cent of cases. Other reports of polyarteritis nodosa with evidence at necropsy of spinal cord damage are those of Boyd (1940), Roger, Pourcines and Roger (1953) and Haft, Finneson, Cramer and Fiel (1957).

The condition of decompression sickness or Caisson

disease is relevant to this discussion since the disorder is apparently caused by air embolism to the spinal cord (Haymaker, 1957). This disease formerly occurred only in divers and other workers subjected to high barometric pressure in underwater caissons or similar pressurised containers, but now high-altitude aviation presents a similar hazard of rapid decompression to subatmospheric pressures. The symptoms appear shortly after rapid lowering of the barometric pressure to which the individual has become adjusted. Obese individuals are more susceptible; this was known in 1868 by Mericourt for sponge divers, confirmed in 1908 by Bogoatt and Damant for caisson workers and is now recognised in aviation decompressions (Haymaker, 1957). The cause of the disorder is the appearance of gaseous nitrogen bubbles in the tissues, blood vessels and even in the cerebrospinal fluid. These gaseous bubbles embolise, but many are trapped and absorbed in the lungs. The damage sustained by the spinal cord is probably due to nitrogen bubbles arising locally (autochthonous) and this preferential involvement of the spinal cord is of great interest.

According to Haymaker (1957) in Caisson disease the upper thoracic region of the cord is the worst affected and the brain may escape entirely. Within the cord the ischaemic lesions occur almost exclusively in the white

matter. Although any part of the white columns may be involved there are favoured locations such as the centre of each posterior column. Spinal cord involvement predominates in Caisson disease in which there is little cerebral involvement. The situation is reversed in cases of high-altitude decompression in which the brain is often seriously involved by large ischaemic lesions and the spinal cord may escape serious damage.

Of the other diseases involving small arteries specific mention will be made of syphilis, tuberculosis and sarcoidosis.

Syphilis

With the exception of cases of tabes dorsalis, the majority of cases of syphilis involving the spinal cord are of the type known as meningovascular syphilis. In these cases the meninges and small spinal vessels are involved by a granulomatous exudate to which the spinal cord damage is secondary. The part played by syphilis in causing anterior spinal artery thrombosis has been mentioned previously. The pathology of neurosyphilis has a very large literature but an important monograph was that of Heubner (1874), who described the arteritis that now bears his name. He described and illustrated a panarteritis involving adventitia, media, and intima, probably in that

sequence. Initially there is lymphocytic infiltration, later fibroblastic proliferation and finally collagenous thickening with narrowing of the lumen either concentrically or asymmetrically. At any of these stages thrombosis can occur.

Many variants of meningovascular syphilis involving the spinal cord have been described and the names of the authors form a remarkable roll-call of neurologists. Charcot and Joffroy (1869) described pachymeningitis cervicalis hypertrophica in which the dura and the leptomeninges are involved in granulomatous inflammation that unites the meningeal layers to the spinal cord in a mass of fibrous granulation tissue. In the opinion of Blackwood (1963) the cases of spinal block described by Froin (1903) were of this type having paraplegia complicated by spinal root involvement and obliteration of the subarachnoid space. The type of damage sustained in meningovascular syphilis may cause a complete transverse cord syndrome or a partial lesion may take the form of a hemisection giving a Brown-Séquard paralysis or in a central lesion may give a syringomyelia-like picture (Wilson 1954).

Tuberculosis

The involvement of vessels in tuberculous meningitis was first described in detail by Baumgarten (1881) and

this author tried to distinguish the arteritis found in tuberculosis of the meninges from that seen in meningo-vascular syphilis. Baumgarten's observations were followed by those of Hektoen (1896) and Askanazy (1910) and both these authors sought to compare and contrast these two diseases.

Winkelman and Moore (1940) in their studies of tuberculous meningitis made detailed observations on the vessels. They tried, as had many other observers, to observe features of the arteritis peculiar to tuberculosis and distinguishing it from all other types. They commented that except for the presence of the tubercle bacillus there was no feature of tuberculous arteritis specific to this disease process. They found many variations of the arterial inflammation and gave a good description of the most commonly found picture. This was the swelling of the adventitia due to proliferation of epithelioid cells and infiltration by inflammatory cells from the surrounding tuberculous exudate in the subarachnoid space. Giant cells were occasionally present in the adventitia. The media was frequently spared but otherwise was involved by spread of the inflammatory process. The subendothelial layers were usually crowded with inflammatory cells and there was sometimes fibrinoid degeneration. The damage done to the brain and spinal cord by the arteritis was particularly noted by Rigdon (1947), Smith, Vollum and

Cairns (1948), Brooks, Fletcher and Wilson (1954) and by Rowlatt (1957) and all these authors commented on and described the damage that may be sustained by the spinal cord. The damage to the spinal cord was not always attributed to obstruction by arteritis but this was in some cases the demonstrated cause.

Sarcoidosis

Sarcoidosis, a disease of unknown aetiology, is characterised pathologically by the presence in any organ or tissue of tubercles made up of epithelioid cells with giant cells but little or no necrosis. Whilst the pathological picture is similar to tuberculosis, tubercle bacilli are not present and the intracutaneous tuberculin test is persistently negative. The disease often proceeds to recovery when the pathological picture becomes that of fibrosis and hyalinisation.

In recent years it has become apparent that sarcoidosis may affect the nervous system and early reports (Colover, 1948) described involvement of the cranial and peripheral nerves. More rarely the central nervous system is affected by a granulomatous process affecting the leptomeninges and spreading to involve the brain and spinal cord. Involvement of the spinal cord is quite rare and in some of the accounts with extensive cerebral sarcoidosis the disease had not spread to the spinal cord. Cases with demonstrable spinal

cord involvement have been described by Aszkanazy (1952), Zeman (1958) and Camp and Frierson (1962). It is clear from these cases that the sarcoid granulomata are perivascular in situation both in the meninges and in the spinal cord where they follow perivascular spaces deep into the centre of the spinal cord. The granulomata were usually found in relation to the adventitia of vessels but occasionally involved the media and the intima. Sometimes the lumen was blocked either by thrombosis or actual invasion of the lumen by granulomatous inflammatory cells and in these circumstances small infarcts could occur.

VEINS

In 1926 Foix and Alajouanine described two cases under the title "La myélite nécrotique subaigue". These male patients aged 19 and 27 years developed a progressive ascending paralysis and anaesthesia. The paralysis, initially of upper motor neurone type, later became flaccid. The anaesthesia, initially dissociated in character, later became complete. The cerebrospinal fluid was remarkable in that a massive protein increase was accompanied by only a slight lymphocytosis. In both cases the course was to a fatal issue, the duration of the illness being 2 years 9 months, and 11 months. The necropsy findings in each case were distinctive. The lower thoracic, lumbar and

sacral segments of the spinal cord were affected by a large region of necrosis. The grey matter was completely necrotic but the white matter damage, although extensive, was incomplete. The histological picture of the severely affected segment was remarkable not only for the necrosis with numerous lipid phagocytes but also because of the striking vascular changes. In both cases the authors observed enlargement and much thickening of extramedullary and intramedullary vessels of the spinal cord, the veins being chiefly affected. These vascular changes they called "endomesovascularitis" and attributed to some toxic or infective agent which had simultaneously caused the parenchymal destruction. They considered that the condition was a distinct pathological entity and thought that syphilis could be excluded as a cause.

The publication of this paper was followed by a succession of reports of similar cases. The following year Van Gehuchten (1927) described a case in a 34 year old woman with a similar but more acute course, death occurring after three months. At necropsy similar vascular changes were present but also he noted perivascular lymphocytic infiltration and a small abscess in the sacral cord. Cases very similar to the original description by Foix and Alajouanine were later described by Van Bogaert, Ley and Brandes (1930); Lhermitte, Fribourg-Blanc and Kyriaco (1931);

Marinesco and Draganesco (1932); Minea (1932); Riser, Géraud and Planques (1937). Zhitomirskaya and Ovcharenko (1937) described four cases.

Greenfield and Turner (1939) described two cases of subacute necrotic myelitis, similar to those considered, together with one acute case. All their three cases had vascular hyperplastic changes. One of their subacute cases had phlebitis of the legs at the time of the onset of paraplegia. This man died from thrombosis of the left renal vein and the inferior vena cava, the clot, extending into the right auricle and ventricle. Greenfield and Turner considered this venous thrombosis coincidental but it is interesting to compare this case (case 1) with that of Mair and Folkerts (1953). These authors described a case of subacute necrotic myelitis which they ascribed to thrombophlebitis present in the lower thoracic and lumbo-sacral spinal veins. Similar findings of venous thrombosis were described briefly in two cases by Antoni (1952), and Blackwood (1963), in reviewing these cases, also came to the conclusion that thrombophlebitis of the spinal veins played an important part in causing the necrosis in the spinal cord.

The publication of the monograph by Wyburn-Mason (1943) provided a review of the whole subject of vascular abnormalities and tumours of the spinal cord and its membranes.

Wyburn-Mason in his review of the literature found about 140 cases of which he considered 120 had been adequately described. His own experience added 67 cases of which all but a few were described in detail. In the majority of these cases the angiomatous malformation had been seen at surgical operation and in many had been displayed at necropsy. The great value of Wyburn-Mason's work was the careful consideration of personally seen and reviewed cases which he arranged into groups according to a classification that he adopted. It is particularly noteworthy that he recognised an extensive venous varicosity affecting the pia and the central regions of the cord and for this type he used the term angioma racemosum venosum. He distinguished these cases from arterio-venous angiomas and cavernous angiomas. His chapter on arterio-venous angiomas is extremely interesting and in addition to citing his own cases he directs his attention to unrecognised examples of arterio-venous angiomas in the literature. His observations on his own cases of this disorder (cases 15-30) form the basis of an excellent clinical and pathological account describing the common features and also the variants that may be encountered. Haematomyelia complicated several of his own and his reviewed cases.

The recognition that a vascular abnormality of the spinal cord is of the arterio-venous type is not always easy but opinion is now growing that the majority of these

cases are of this particular type (Antoni, 1962). In the account of Bodechtel and Erbstöh (1957) these cases are considered under the heading "Die Foix-Alajouanineschе Krankheit", a title that they considered synonymous with "Myélite nécrotique subaigue" and "Angiodysgenetische Myelomalacia". These authors dealt in great detail, with their own observed and reviewed cases but were cautious as to the actual mechanism of the spinal cord disorder.

A great advance in our understanding of these cases has come from a development of angiography. Formerly these angiomatous malformations were recognised by myelography but this technique added nothing to our knowledge of the type of malformation present. Recently Djindjian and his colleagues (Djindjian, Dumesnil, Faure, Lefèbvre and Levêque, 1962; Djindjian and Fauré, 1963a, 1963b) have developed a technique for demonstrating vascular malformation of the cervical and dorso-lumbar cord by either subclavian or retrograde lumbar arteriography. This technique depends on the removal of the opacity of overlying bone structure by a cancellation of the image components common to both the preliminary and the subsequent contrast-filled radiographs.

These studies have shown that the commonest type of spinal angioma is an arterio-venous communication in which one or more of the spinal arteries forms a cluster of

vessels which drains into one or more draining veins without the blood passing in the normal way through the capillary bed of the spinal cord. The feeding artery or arteries to one of these malformations has a normal origin and direction but is enormously enlarged. If this arterial pedicle can be identified and ligated then the progressive enlargement of the malformation can be halted.

The findings of Djindjian and his colleagues have now been confirmed in other centres (Doppman and Chiro, 1964) and have gained general acceptance.

These angiographic observations, which have so elegantly demonstrated the haemodynamics of spinal angiomas, compel a reappraisal of studies made at necropsy. As we shall see the pathological findings are usually consistent with the presence of an abnormal arterio-venous communication in the spinal vessels.

CHAPTER IV

MATERIAL

The findings recorded in this thesis are based on a series of observations made in the Department of Neuropathology, Radcliffe Infirmary, Oxford. The source of the anatomical and pathological material was as follows:-

Anatomical specimens

These were obtained during the course of the routine necropsies conducted at the Radcliffe Infirmary, Oxford. No particular selection was exercised and specimens were removed for study on occasions when this was permitted by the nature of the necropsy. All the specimens were taken from adult subjects and the age group of the bulk of these was in the fifth, sixth and seventh decades. In addition to a general inspection of the vasculature of a larger number of cases a series of 40 normal adult spinal cords were examined in a standardised manner which investigated and noted the variation found in the spinal vessels. The observations and measurements detailed here were mainly made on this group of 40 specimens. The histological observations were made on two normal adult spinal cords from which multiple histological sections were cut transversely at every segmental level. Some additional observations were made on a further group of 200 consecutive

adult necropsies in which the cervical and upper thoracic cord had been examined macroscopically and microscopically. This group which had been first examined for another purpose (Hughes and Brownell, 1966b)provided a large number of histological sections of the cervical spinal cord as normally seen in adult necropsies.

For an examination of the early development of the mammalian spinal vessels serial sections of a 6 mm. pig embryo were made available to me by the Department of Human Anatomy, Oxford and the later stages were studied in human embryo material sectioned at the Department of Anatomy, Manchester University. No observations of these embryological studies are recorded in this thesis but the study was useful in the understanding of the adult blood supply.

Pathological observations

These were made on necropsies performed in the Department of Pathology at the Radcliffe Infirmary, Oxford or following the examination of tissues removed elsewhere and submitted to this department for further examination. Cases relevant to the subject of spinal cord vascular disorders have been collected by the author over a period of six years (1961-1967) and from a larger number of cases the particular case-reports and pathological observations

used in this thesis were selected. The cases were selected for their contribution to the study of obstruction at different parts of the spinal-cord blood supply. They have been arranged according to the site of this obstruction which divides the cases into the following categories:-

a. Aorta. Cases 1-4 are examples of chronic spinal cord ischaemia due to thrombosis and athero-sclerosis of the aorta. Case 5 is a case of acute spinal cord infarction due to aortic trauma.

b. Vertebral arteries. Cases 6 and 7 are examples of spinal cord infarction caused by traumatic obstruction of the vertebral arteries.

c. Intercostals. Case 8 is an example of spinal cord infarction arising from obstruction of an intercostal artery.

d. Radicular tributaries. Case 9 is an example of acute infarction of the spinal cord caused by herpes zoster affecting a radicular tributary to the spinal cord blood supply. Cases 10 to 14 are examples of obstruction of radicular tributaries by tumour infiltration in and around the spine.

e. Anterior spinal arteries. Cases 15, 16 and 17 are examples of obstruction of the anterior spinal artery by thrombosis.

f. Small spinal vessels. Cases 18, 19 and 20 are examples of spinal cord disease caused by a lesion affecting small spinal vessels. In case 18 the condition was due to meningo-vascular syphilis. In case 19 the cause of the disease was tuberculous meningitis and in case 20 the arterial disease involving the small spinal arteries was sarcoidosis.

g. Veins. Cases 21 to 25 are examples of a vascular malformation involving the spinal veins and which caused spinal cord necrosis. These cases appear to have arterio-venous aneurysms affecting the spinal cord.

METHODS

The methods of handling the anatomical specimens and examining the tissues from the pathological cases differed slightly.

Anatomical specimens

It was convenient to examine most of the anatomical specimens in the fresh state and all the series of 40 adult spinal cords were first studied in this way. The observations on the major spinal vessels were made with a hand lens but inspection was facilited by one of the following injection techniques.

(a). Indian ink injection of the spinal arteries.

This was performed by a syringe and a fine (number 22)

hypodermic needle. Initially the spinal arteries were injected at several points but with practice the following method proved simpler and more effective. The major tributary to the anterior spinal artery accompanying a lower thoracic or upper lumbar nerve root was identified and a ligature of cotton thread was applied to this root encircling the root and the arterial tributary at a point near the dural root sleeve. By gentle traction on this ligature the arterial tributary was made steady and could be entered by the hypodermic needle attached to a 10 ml. well oiled syringe containing the indian ink. With slow and steady injection it was possible to fill the whole of the anterior spinal artery and with continuing injection the ink could be made to pass through anastomotic channels into the posterior spinal arteries. Gentle digital massage assisted in filling arteries remote from the point of injection. The disadvantage of this method was that following slight trauma to any of the spinal arteries the indian ink leaked into the subarachnoid space and obscured the injection picture. It was found that specimens from young subjects were much less likely to leak in this manner.

The great advantage of this method was its simplicity and the ease withwhich the spinal arteries could be distinguished from the spinal veins. This distinction is not easy in macroscopical examination of the fresh uninjected

spinal cord. The injection also displayed the small arterial branches and the anastomotic communication between the spinal arteries. The anastomotic communications between the anterior and posterior spinal arteries could be readily identified as the injection material flowed into the anterior arteries and found its own way into posterior arterial system.

(b). Barium sulphate suspension used for injection.

Some of the specimens were injected with barium sulphate suspension, the preparation called Micropaque being used. Normally this material was used undiluted. By inserting a cannula into the vertebral arteries at the position in which they emerged through the foramen magnum into the skull it was possible to inject the whole of the cephalic part of the spinal cord arteries. An injection through a major intercostal or lumbar vessel entered from the aorta produced a similar result in the caudal part of the spinal cord. In each injection, as the material was injected, the points at which leakage occurred were secured by artery forceps. In one case, the whole arterial tree was injected by a cannula tied into the femoral artery and fed by a pressure apparatus. Micro-opaque diluted with an equal volume of water was used and at this dilution the material passed freely through the capillary network and into the venous system. By this means all the vessels of

the spinal cord could be filled and also all the feeding vessels from the aorta and subclavian artery. In this case the spine was removed and was X-rayed before removal of the spinal cord. Further X-rays of spinal cord alone showed the major spinal vessels but a much clearer picture was observed by clearing the specimen in oil of winter-green. By this technique the white matter of the cord was rendered almost translucent and the intraspinal vessels could be examined. The sulcal vessels and the manner in which they entered and branched into the grey matter and the course of the small radial vessels were seen in this way.

Anatomical observations on the small spinal vessels were made on histological sections in the transverse plane but the methods used differed in no way from those employed in the pathological studies.

Pathological observations

The methods used for the pathological observation will not be detailed since they are common to most neuropathological laboratories and have been described elsewhere (Hughes 1966). It was particularly advantageous to remove at necropsy the whole spine which was fixed in 10% formalin with the spinal cord *in situ*. By this means not only a perfectly fixed undistorted spinal cord was obtained but

the whole of the spinal vascular system was retained for dissection and examination. After two weeks fixation the spinal cord was removed by a posterior laminectomy. After a detailed examination of the spinal vessels by external inspection, the substance of the cord was examined by transverse cuts through each spinal cord segment. These blocks of tissue were then embedded in paraffin and transverse sections were cut and stained.

Histological Methods

The following staining methods were used on the majority of the blocks:-

Haematoxylin and eosin (H. & E.), haematoxylin and Van Gieson's stain (H. & V.G.), Mallory's phosphotungstic acid haematoxylin for glial fibres (P.T.A.H.), Holzer's stain for glial fibres, Weil's stain for myelin, Nissl's stain for nerve cells, and Holmes' method for nerve axons. The Marchi method was used for degenerating myelin.

In the descriptions that follow the regions of the spinal cord have been abbreviated as follows:- cervical, C; thoracic, T; lumbar, L; sacral, S.

Chapter V

ANATOMICAL OBSERVATIONS

Origin of the spinal vessels.

During the removal of the anatomical specimens at necropsy, the opportunity was taken by anatomical dissection to examine the major arteries that provide the branches which finally participate in the blood supply to the spinal cord. These major arteries may be considered as belonging to two groups, the first being those derived from the subclavian artery and the second group being those arising directly from the aorta.

The first group, those vessels derived from the subclavian artery, include the vertebral arteries, the ascending cervical branch of the thyro-cervical trunk and the superior intercostal artery derived from the costo-cervical trunk. All these arteries, of which the most important are the two vertebral arteries, send branches to the spinal cord throughout its cervical region and also to the first and sometimes to the second thoracic cord segments.

The second group of arteries are those derived directly from the aorta and these include the paired intercostal arteries of which there are from eight to nine pairs arising from the posterior aspect of the aorta. These

intercostal arteries retain most closely the situation that exists in the embryonic blood supply and it is instructive to consider their course and branches in detail (fig 6).

The intercostal artery proceeds posteriorly in relation to the vertebral body and reaches the posterior part of the intercostal space where it divides into the main intercostal artery, which then turns anteriorly, and the postero-spinal branch which itself gives rise to two branches. One of these two branches of the postero-spinal branch enters the intervertebral foramen and joins a spinal nerve root to form a radicular tributary to the main spinal cord arteries. The venous drainage has a similar arrangement to the arterial supply at least for the extra-spinal part of the blood supply.

Caudal to the origin of the intercostal arteries arise the lumbar spinal arteries and these are four or five pairs of vessels also arising from the posterior part of the aorta. These lumbar spinal arteries have similar branches to those described for the intercostal arteries and they send tributaries to the lumbar and sacral regions of the spinal cord. As we shall see there is no exact correspondence between the origin of a spinal artery and the segments of the spinal cord which it supplies. Caudal to the lumbar arteries are the ileo-lumbar arteries and the lateral sacral

arteries, and these vessels arise either from the caudal part of the aorta or from the common iliac arteries. The ileo-lumbar arteries and the lateral sacral arteries contribute very little to the blood supply of the spinal cord but the lateral sacral artery may supply the cauda equina. Each of the lumbar arteries as has been described for the intercostal vessels, gives off a spinal branch which enters the intervertebral foramen and comes into relationship with the spinal nerve roots. It then divides into an anterior and posterior spinal branch and these two vessels accompany their respective spinal nerve roots and join the anterior and the posterior spinal arteries. The single anterior spinal artery and the left and right posterior spinal arteries are longitudinal vessels (fig 7) which extend throughout most of the length of the spinal cord. They commence from branches from above arising from the intracranial part of the vertebral arteries, but as we shall see they are reinforced by the tributary vessels (fig 8a, fig 8b) accompanying the spinal nerve roots.

The spinal cord venous system (fig 9) is arranged on the same lines as the arterial system but with differences in detail which will be considered later.

Radicular tributary arteries. (figs 10, 11, 12, 13, 14, 15 and 16)

The arterial branches which accompany the anterior and posterior spinal nerve roots provide a large part of the blood supply of the spinal cord and the anterior radicular arteries accompanying the anterior spinal nerve roots and joining the anterior spinal artery are more important than the posterior tributaries concerned with the posterior aspect of the cord. Of the anterior radicular tributaries some are of much greater size and consequently of greater importance than the remainder. An artery of visible size accompanies nearly every anterior spinal nerve root but some of these provide a blood supply only for the root itself. The number, laterality and segmental position of the major anterior tributaries is of some importance and these were recorded in the anatomical study. The decision, made on macroscopic inspection, as to whether or not a particular radicular tributary was a major vessel was always easy (figs 10 and 11) in the thoracic and lumbo-sacral regions but sometimes difficult in the cervical region. From the subsequent measurements on histological sections it was clear that the size of anterior tributaries considered important always exceeded 150 microns in diameter as measured in paraffin-embedded sections.

Table I.

Specimen Number.	Position of anterior tributary arteries	Number L	R	Total
1	LT4, RT9, LL2.	2	1	3
2	LC5, RC7, LT6, LT8, RT9, LT10, RL1.	4	3	7
3	LC5, RT5, LL1.	2	1	3
4	LC6, RC7, LT2, LT10, LL2.	4	1	5
5	LC7, RT3, LT9, RT12, LL3, RS1.	3	3	6
6	RC7, LT3, RT8, LL2.	2	2	4
7	RC7, LT1, RT5, LT11, RL3.	2	3	5
8	LC8, LT3, LT10, RL3.	3	1	4
9	LC3, RC6, LC7, RC8, LT3, RT5, LT10, RL2, LS1.	5	4	9
10	RC6, LT3, LT11, RL2.	2	2	4
11	RC3, RC5, LC6, RC7, LC8, LT5, LT7, RT12, LL4.	5	4	9
12	RC7, LT4, LT9, LL1, RL5.	3	2	5
13	LC4, RC5, LC7, RT5, LT8, RT10, LL3.	4	3	7
14	LC6, RC7, LT4, LT7, RT9, LT11, RL1.	4	3	7
15	LC6, LT6, RL1.	2	1	3
16	LC1, RT7, LT10, RL4.	2	2	4
17	RC8, LT3, LT6, LT11, RL4.	3	2	5
18	LC3, LC4, RC5, LC8, RT3, LT8, RT10, LT12, LL5.	6	3	9
19	LC7, RT4, RT8, LT10.	2	2	4
20	LC6, RT4, LT7, LT9, RL1.	3	2	5
21	LC5, RT5, LT10, RS2.	2	2	4
22	RC6, LT6, LT12, LL3, RL5.	3	2	5
23	RC4, LC6, LC8, RT3, LT8, RT11, LT12, RL2.	4	4	8
24	LC7, RT3, LT6, LT12, RL2.	3	2	5
25	LC5, RT10, LL1.	2	1	3
26	RC3, LC8, RT5, LT10, RL1, LL3.	3	3	6
27	RC6, LC8, RT4, LT12, RL3.	2	3	5
28	LC5, RC6, RC7, RC8, LT1, RT4, LT10, LT12, RL1.	4	5	9
29	LC3, RC5, LC6, RC8, RT3, RT8, LT9, LT10, RS1.	4	5	9
30	LC7, RC8, LT4, RT7, LT11, RL5.	3	3	6
31	RC3, LC5, RC6, LC8, RT1, LT5, LT8, LL1, RL3.	4	4	8
32	LC6, RT3, LT10, RT12.	2	2	4
33	LC7, RC8, LT5, LT11, RL1, LL2.	4	2	6
34	LC7, LT9, RL2, LL5.	3	1	4
35	RC7, LT2, LT7, LT12, RL3.	3	2	5
36	LC4, RC5, LC6, RC8, LT3, RT6, RT8, LT10, LL2.	6	3	9
37	RC7, LT4, LT6, RT9, LS1.	3	2	5
38	LC7, RT3, LT10, RT12, LL5.	3	2	5
39	RC6, LC8, RT3, LT4, LT10, RT12, LL1.	4	3	7
40	RC5, LT5, LL3.	2	1	3
Total in 40 specimens		127	97	224

Table 1 sets out the position of the anterior tributary arteries found in the 40 spinal cords. In each specimen the largest anterior tributary was identified and the position of this is indicated in the table by underlining. The number of tributaries ranged from 3 to 9 with a mean of 5.6. The number of tributaries to the left and right were 127 (left) and 97 (right).

Table II

No. of tributaries	3	4	5	6	7	8	9
No. of specimens with each number of tributaries	5	8	11	4	4	2	6

In table II the scatter of the number of tributaries in the specimens is given. The largest number of the specimens (11) had 5 anterior tributaries and the range was from 3 tributaries to 9 tributaries.

Table III

Position of the largest anterior tributary

Segmental level.	Left.	Right.	Total.
T7	1		1
T8	1	1	2
T9	2	2	4
T10	12	2	14
T11	5	1	6
T12	4	2	6
L1	3	1	4
L2	1	1	2
L3	1		1
Totals	30	10	40

Table III is concerned with the position of the largest anterior radicular tributary which in this series was found from T7 to L3 segmental levels. The bulk of the occurrences were on roots between T9 and L1 and the commonest root was T10. There was a marked preponderance for this largest tributary to be on the left side (30 left, 10 right). The left T10 anterior root (fig 11) was particularly associated with the largest anterior radicular tributary (12 out of 40 cases). The contribution to the anterior spinal artery by these anterior radicular tributaries varies in the different regions of the spinal

cord and this variation requires consideration.

In the cervical region (fig 10) the common finding is that there are two to four medium sized tributaries and these are almost never as large as those found caudally. The number of tributaries found on the left (38) and on the right (33) was approximately the same in the cervical region when the total number in the 40 specimens was counted. In individual specimens there may be more of these large tributaries on one side than the other and in these cases the smaller number of tributaries are usually larger in calibre. A special case in the cervical region is that the anterior spinal artery may be reduplicated for some of its cervical course (fig 10). In these cases the tributaries, which tend to be more frequent, join only the nearest lateral artery that they reach.

In the thoracic region there are usually from two to four large radicular tributaries to the anterior spinal artery (fig 11). The size of these is variable, but they are usually larger than that in the cervical region. There are more tributaries accompanying the left (68) than the right (38) anterior nerve roots. It is one of these thoracic tributaries, particularly one accompanying a lower thoracic root that is the largest of all the tributaries and is given the name <u>arteria radicularis magna</u> and is also called the artery of Adamkiewicz (figs 11 & 13). The length of the thoracic cord is such that a different relationship

between these radicular tributaries and the cord exists than is seen in the cervical region. The greater length of the thoracic cord means that these few tributaries (usually two to four in number) must supply quite large regions of the spinal cord. The other feature is that the tributary arteries as they join the anterior spinal artery turn caudally and enter the spinal artery in a caudal direction and that the anterior spinal artery above the point of entry is slightly constricted (figs 8b, 10, 13). This suggests on anatomical grounds that the direction of flow from one of these tributaries is mainly downwards and that the territory supplied by it is mainly caudal to its point of entry. Another feature seen particularly in the thoracic region is that when a tributary joins the anterior spinal artery the actual point of union is often some distance (up to 3 mms.) lateral to the midline and this results in the anterior spinal artery having a zig-zag course (fig 11). In its formation the anterior spinal artery has been likened to the union of the links of a chain and nowhere is this more easily seen than in the thoracic region.

From our preliminary remarks it will be understood that somewhere in the region of the second thoracic spinal-cord segment there is a change of arterial supply. Above this point the blood supply is derived from the subclavian

artery whilst below this point it is obtained from the aorta below the origin of the subclavian artery. Despite this important difference in the source of origin of these two supplies, it is not possible by scrutinizing the spinal cord to see any change in the vasculature at this level (fig 10). It has often been stated that this point of changeover is a region where the blood supply of the spinal cord is precarious but there is little to support this in the appearance of the spinal vessels locally.

Another feature of the tributary arteries which is especially noticeable in the thoracic region is the point at which they join the anterior spinal artery (fig 14). They frequently leave the anterior nerve root in the last part of their course and in joining the anterior spinal artery pursue a path which is independent and caudal to the corresponding spinal root.

The lumbar and sacral regions will be considered together. There are usually from one to three important anterior radicular tributaries in this region and their numbers on left and right sides are approximately equal (left 20, right 25). Occasionally the largest radicular tributary of all, the arteria radicularis magna of Adamkiewicz, accompanies one of the lumbar routes, usually the first lumbar on the left side. One difference in the radicular

tributaries in the lumbar and sacral regions is that they have a long course accompanying the nerve roots. The other feature is that the major radicular tributary to this region is so large that it usually nourishes the whole of the lumbo-sacral cord and even this does not exhaust its area of supply. The injection experiments show that there is an extensive anastomosis around the cauda equina of the anterior spinal artery with the posterior spinal arteries. When one injects with ink the largest lumbar tributary the injection material flows down the anterior spinal artery but also at a later stage of the injection begins to flow quite well up the posterior spinal arteries (fig 12) and reaches finally a level much higher posteriorly than is seen anteriorly. These findings suggest that the posterior spinal arteries in the caudal part of the cord depend for their blood supply on the anterior spinal artery *via* a large lumbar or sacral tributary. A feature that is seen in many of these large tributaries is the deviation downwards as they join the anterior spinal artery and this has been remarked upon in the description of the thoracic region.

Posterior Radicular Arteries.

The posterior radicular arteries (figs 7, 12) accompany the posterior spinal nerve roots and join the posterior

spinal arteries in the same way as has been described for the anterior radicular tributary arteries. The difference is that the dependence on a few large tributaries is much less apparent in the posterior arteries. All the arteries seen are relatively small and the situation is that on many of the posterior nerve roots there are medium or small sized arteries but in some the arteries are quite insignificant or absent. To count and enumerate them in the same way as we have done in the anterior radicular arteries is not easy because of their small size (fig 7). If we consider vessels of over 100 microns in diameter as being significant tributaries there are about 20 posterior radicular tributaries and these are distributed about 5 in the cervical region, 10 to the thoracic region and the remaining number, about 5, to the lumbar and sacral regions. It is difficult to concede whether one of them is ever sufficiently large to be given the title of <u>arteria radicularis magna posterior.</u> The larger tributaries tend to be in the lower thoracic and in the lumbar region and it would be possible to choose one, usually placed between T11 and L3, as the largest posterior tributary (fig 7). These posterior tributaries join a very irregular arterial channel (the posterior spinal artery) and the whole arterial net-work on the posterior aspect of the cord is far less precise than that seen anteriorly.

Anterior Spinal Artery.

This artery (figs 7, 10, 11, 13, 14 and 17) is the most important structure in the whole vascular supply of the spinal cord and deserves special attention. It begins above by the union of the anterior spinal branches of each vertebral artery given off in the cranial cavity. These anterior spinal branches pass caudally and unite at some variable point to form the anterior spinal arteries. This point of union is usually within 2 centimetre of their origin and at about the foramen magnum. In a proportion of cases (4 specimens out of 40) the union is delayed as far as the lower cervical region (fig 10). Very rarely, and not in the series examined, the anterior spinal artery is duplicated throughout most of its length. Much more commonly, and several times in this series, parts of the anterior spinal artery are reduplicated. This tends to occur in the cervical and upper thoracic regions and was caused by an in-coming major tributary branching before its union with the main anterior spinal artery. In these places the anatomical arrangement in the adult is reminiscent of what is normally found in the embryonic spinal vessels.

The anterior spinal artery is situated in general relation to the anterior median sulcus (fig 17) but never keeps strictly to this anatomical position and pursues a

zig-zag course (fig 11), the alterations in its course being determined by the entry of radicular tributaries. The calibre of the artery varies considerably. In the series of 40 anatomical specimens it is always widest in the lumbo-sacral region (fig 11) where it often appears over 350 microns in diameter. In the cervical region (fig 10) it is often only half this size whereas in the thoracic region it is smaller still. These estimates are of the average size in various regions for the calibre increases and diminishes within each region. In table IV the figures are given for the diameter of the anterior spinal artery at every segmental level of a spinal cord. The measurements were made by a micrometer eyepiece used on paraffin-embedded transverse sections. Due to shrinkage during processing these figures are less than for an unfixed spinal cord but the comparison between different regions is valid.

It is apparent that the diameter is much larger in the lumbar and sacral region than the cervical region and that the diameter was smallest (112 microns) in the thoracic region. It is easy to see the effect of the entry of radicular tributaries for at T10 and L4 the diameter of the artery suddenly increases.

Table IV

Diameter of lumen of anterior spinal artery and sulcal arteries at consecutive segmental levels of a normal adult spinal cord.

	Diameter in microns	
Segmental level	Anterior spinal artery	Sulcal artery
C1	165	30
2	150	30
3	160	40
4	142	30
5	120	30
6	120	45
7	185	67
8	210	37
T1	245	53
2	180	30
3	142	23
4	120	15
5	120	19
6	120	23
7	120	30
8	112	15
9	112	15
10	260	23
11	200	15
T12	150	23
L1	240	23
2	195	23
3	190	30
4	340	30
5	370	30
S1	370	23
2	390	30
3	360	23
4	300	37
5	290	23

The Posterior Spinal Arteries

The size, course and distribution of the posterior spinal arteries was examined by inspection with a hand lens and the examination was facilitated by arterial injection without which it was often impossible to distinguish the posterior spinal arteries from spinal veins (figs 12 & 15).

The two posterior spinal arteries took origin from the posterior spinal branches of the vertebral artery or from the posterior inferior cerebellar arteries or rarely from a posterior radicular artery in the upper cervical region. The course of a posterior spinal artery is much less well defined than that of the anterior spinal artery and the general impression is often that of a diffuse vascular network rather than a single vessel. The artery, when it can be recognised as a single structure, is very tortuous and often moves medially or laterally away from its usual position at the point of entry of the posterior nerve roots. Frequently the arteries are discontinuous and sometimes one artery moves to supply the other side. It is rare for the position of the entering radicular tributary to be seen prominently as it frequently ends in a plexus of small arteries.

The average size of the posterior spinal arteries is

more difficult to measure than that of the anterior spinal artery but it is clear that most of the measurements are less than that found anywhere in the anterior spinal artery. The figures obtained gave the largest measurement in the cervical region (about 100 microns), the next largest region was the lumbo-sacral region where the artery measured about 75 microns, whereas in the thoracic region the measurements were usually about 50 microns. In contrast to the anterior spinal artery, the posterior spinal arteries became less noticeable in the caudal region of the spinal cord. We have previously noticed that a good anastomosis occurred between the anterior spinal artery and the posterior spinal artery around the cauda equina and that in this anastomosis the direction of blood flow appeared to be from the large anterior spinal artery into the smaller posterior spinal arterial system.

The Sulcal Arteries.

The sulcal arteries (fig 18) are the branches of the anterior spinal artery which proceed backwards in the anterior median sulcus and enter the cord in the region of the grey commissure to supply most of the grey matter (fig 19). These arteries were called sulcal arteries by Adamkiewicz but the same arteries were called central arteries by Kadyi. Here the original name given by

Adamkiewicz will be used.

The sulcal arteries cannot be examined without employing special techniques. In two spinal cords injected with barium sulphate and cleared with oil of wintergreen the majority of the sulcal arteries could be seen and an approximate count made. The spinal cords were divided into 5 cm. portions and these were examined floating in oil of wintergreen in a Petrie dish under a dissecting microscope. For particular details and photography 0.5 cm. segments were cut and viewed as transverse sections (fig 19). Further information was obtained by a series of transverse sections particularly using one spinal cord from which sections had been cut at every segmental level.

The number of sulcal arteries was similar in both the injected specimens in which approximately 200 sulcal arteries were present. The numbers of sulcal arteries differed in different regions of the spinal cord. In the eight segments of the cervical region about 70 sulcal arteries were present. The thoracic region, although very much larger, and having twelve segments each of which being longer than those in the cervical region, had only 60 sulcal arteries. In the five segments of the lumbar region, which are much smaller in length than thoracic segments,

about 60 sulcal arteries were present. This region was judged to be the richest of all in the number of sulcal arteries as compared with the amount of spinal cord supplied. The sacral region, also of small size, had approximately 20 to 25, again a very rich region of supply.

The size of the sulcal arteries was estimated by measuring their diameter with a micrometer gauge used on histological sections. The series of histological sections used was a set cut transversely at every segmental level from a whole normal spinal cord. Sometimes the diameter of the sulcal arteries could be measured in transverse section but more often a measurement in the longitudinal plane had to be used. The sulcal arteries in the cervical region and in T1 segment were the largest in diameter and their measurements ranged from 30 to 53 microns. In the thoracic region (with the exception of T1) the sulcal arteries were smaller than elsewhere and the range was found to be from 15 to 30 microns. In the lumbar and sacral regions the sulcal arteries ranges in diameter from 23 to 37 microns. These figures were larger than those found in the thoracic region but smaller than those in the cervical region. These findings reflect the greater blood supply to the cervical and lumbar enlargements of the

spinal cord as compared with intervening thoracic region. Not only are there more sulcal arteries in these regions but the caliber of the sulcal arteries is greater.

The course of the sulcal arteries from their origin from the anterior spinal artery is directly posteriorly in the anterior median sulcus except that in the thoracic region there is a slight upward inclination. Having reached the depth of the anterior median fissure the sulcal artery pierces the white matter and enters the grey commissure where it is called a sulco-commissural artery (figs 18 and 19). In most cases this name refers to the same vessel because the vessel merely changes direction into either one or the other grey column. Occasionally in the lumbar region the artery branches into two equal divisions, one to each side of the cord but this arrangement was rare even in this region and was not seen elsewhere. The common finding throughout the spinal cord was that the sulcal arteries entered alternately into the left and right grey columns. The situation in which the anterior spinal artery is duplicated was examined in the cervical cords of the 200 specimens from which histological sections were prepared. In these cases with double anterior spinal arteries the sulcal arteries frequently appeared to arise side by side one from each anterior spinal artery and to

turn into the corresponding side of the grey columns.

The area of distribution of the terminal branches of the sulcal arteries was examined in two cleared specimens (injected and rendered translucent) and also in the histological sections. In the cleared preparations it is possible to see that the sulcal arteries give off very fine small branches to supply the white matter of the anterior white column in the immediate vicinity of the anterior median fissure (fig 19). Although important for the nutrition of this region which includes the direct cortico-spinal tract these small branches are only a small part of the supply of the sulcal arteries. Having entered the grey column they ramify and supply the whole of the grey commissure and the anterior horn. They also supply the lateral horn in the thoracic region and Clarke's column in those segments in which this nucleus is present. The final twigs of the branches of these sulcal arteries (now called the sulco-commissural arteries) extend also into the white matter adjacent to the grey columns. Whilst this is always true of the anterior and lateral white columns only a few twigs penetrate into the posterior white columns which are mainly supplied from the posterior spinal arterial plexuses. A point of great importance is that the part of the lateral white column in which the pyramidal tracts

is situated appears to be always supplied in part and often to a major extent from the sulco-commissural arteries.

The Coronal Arteries.

Some of the observations on the coronal arteries of the spinal cord were made macroscopically but most were made on histological preparations. In the anatomical specimens it could be seen that the spinal cord is surrounded by a fine subpial plexus of small arteries (fig 19) which are called coronal arteries and form part of the centripetal vascular system described by Adamkiewicz. This vascular network is contributed to from several sources which include the anterior spinal artery itself and also the radicular tributaries which sometimes scarcely reach the anterior spinal artery but feed into this network of small vessels. Fed from these sources the arterial plexus ramifies on the anterior surface of the spinal cord and spreads on to the lateral surface. On the posterior aspect, a similar but less well-defined arterial plexus is present and is supplied mainly from the radicular tributaries to the posterior spinal artery and from the posterior spinal artery itself.

The Radial Arteries.

These arteries (figs 20 and 21) belong to the centripetal vascular system of Adamkiewicz and originate from the coronal vessels and proceed in a radial direction towards the centre of the spinal cord. These vessels were easily seen in the sliced segments of the cleared specimens of spinal cord, but could also be found in histological sections. These arteries were particularly long and well defined in the posterior columns (fig 20) where their course ran in connective tissue septa. These vessels correspond to the arteria fissurae of Adamkiewicz. In the posterior white columns these long penetrating vessels are of considerable importance and they also nourish most of the posterior grey horns. In the lateral white columns and in the anterior white columns (fig 21) these radial arteries are shorter. They supply some of the marginal white matter but the areas adjacent to grey matter are supplied from the terminal branches of the sulco-commissural arteries as described earlier.

Small Intramedullary Arteries and Capillaries.

The situation, direction, and size of the small intramedullary arteries and capillaries was seen in histological sections. It is apparent that there is a much richer vascular network in the grey matter by comparison with the

white matter (fig 19), and that this profuse network is mainly derived from the sulco-commissural arteries arising from the anterior spinal artery. The exception to this is in the region of the posterior horn which receives its blood supply (less than that of the anterior horn) from the posterior spinal arteries and their penetrating branches.

Spinal Veins.

The spinal veins were first examined in the anatomical specimens with a hand lens (fig 9). It was found impossible to study them in an uninjected preparation but when the spinal arteries were filled with Indian ink the veins were easily distinguished.

The most prominent feature of the spinal venous system and one which is in complete contrast to the spinal arteries is that the veins are most prominent on the posterior aspect of the spinal cord. The venous network is very irregular and there is considerable anastomosis of large venous trunks. There is however a single large median posterior vein (fig 22) applied to the posterior aspect of the cord in the region of the posterior median septum and this vessel appears to have no arterial counterpart. It receives draining veins from the posterior columns and part of the posterior horns.

The anterior spinal vein (fig 17) accompanies the

anterior spinal artery and receives small sulcal veins in a similar manner to the sulcal arteries arising from the anterior spinal artery. The area of drainage of these sulcal veins could not be assessed accurately. They appear to drain part of the anterior white columns and most of the grey commissure and anterior grey horn.

Both the anterior spinal veins and the median posterior vein are themselves drained by radicular veins which are in relation to anterior or posterior spinal nerve roots. They are commoner than the corresponding radicular arteries but like them some are especially large. These large veins may be termed radicular draining veins. They were sometimes accompanying major radicular arterial tributaries but often were independently situated and accompanying nerve roots with only small radicular arteries.

The venous network on the lateral aspect of the spinal cord includes circumferential vessels which may be termed coronal veins. These coronal veins drain into the anterior spinal veins and also into two fairly constant posterior veins one on each side and in relation to the medial aspect of the posterior root entry zone. These large posterior veins drain into posterior radicular veins.

CHAPTER VI

CASE REPORTS

Case 1. S.C.

HISTORY.

A woman aged 82 years, was admitted to a geriatric hospital on June 1, 1961. She was known to have ischemic heart disease with attacks of cardiac failure, but her present complaint was of gradually progressive weakness in both legs for about six months. She had become almost bedridden, and for a few weeks had been incontinent of urine at night.

EXAMINATION.

On examination there was a moderately severe paraparesis with brisk tendon reflexes and extensor plantar reflexes, but sensation was not impaired. In the upper limbs, power, reflexes, and sensation were normal, but there was slight wasting of the small muscles of both hands.

INVESTIGATIONS.

The blood pressure was 200/100 mm Hg. A lumbar puncture produced clear fluid under normal pressure; protein was 35 mg/100 ml, and there were 150 RBCs per c.mm. An X-ray of the spine showed degenerative changes in the cervical region with diminished disk spaces at C4-5 and

C5-6. A blood count was normal, and the blood Wassermann reaction was negative.

COURSE.

A diagnosis of myelopathy due to cervical spondylosis was made, and the patient was discharged home on June 23rd without any specific treatment. In October 1961 she was again admitted to a geriatric ward because she could no longer be cared for at home. Her paresis had become worse, and she had also developed congestive cardiac failure with auricular fibrillation.

MODE OF DEATH.

She died on February 2nd, 1962 after slow deterioration, a little over a year after the onset of her symptoms.

GENERAL NECROPSY FINDINGS.

Terminal changes included early pressure sores over both heels and severe bilateral bronchopneumonia. The thyroid was diffusely enlarged and the gallbladder was distended due to the impaction at the neck of a single large gallstone.

Cardio-vascular system.

The coronary arteries were affected by extensive atheroma causing severe narrowing of the descending branch of the left coronary artery. The scar of an old anterior

myocardial infarct was present with some mural thrombus remaining attached to the endocardium. The abdominal aorta was affected throughout by severe atheroma, and there was a recent flat mural thrombus adherent alongside the origin of the renal arteries with slight extension of the clot into the opening of the right renal artery.

Nervous System.

Brain. Weight. 1070 grams.

External appearance.

The brain was small and gave the impression of generalized atrophy. The vessels of the base of the brain showed an extreme degree of atheroma which affected the vertebral arteries, the basilar artery, and the internal carotid arteries.

Coronal slices.

On coronal slicing, the lateral ventricles and the third ventricle appeared symmetrically enlarged, probably due to the moderate cerebral atrophy. There were many small pinhead cavities suggestive of vascular lesions and one at the junction of the cortex and white matter of the right insula was calcified.

Brain stem. }
Cerebellum. }

There was atrophy of the lower pons and medulla. The cerebellum also appeared rather small but was otherwise

normal.

SPINAL CORD.

Meninges.

The dura mater appeared normal, but the leptomeninges were opaque and thickened from T3 down to T12 on the posterior aspect of the cord. There was no thickening elsewhere, and the cauda equina was not involved by adhesions.

Vessels.

The anterior spinal artery was patent throughout and showed no tract of atheroma. There were prominent veins on the posterior aspect of the cord, but these appeared within normal limits.

External appearance.

The spinal cord itself showed a slight dent on the anterior aspect of C6 segment corresponding to a cervical spondylotic protrusion, but apart from this post-mortem moulding of the cord, there was no evidence of any pressure effect.

Transverse cuts.

Transverse cuts through the cord at each segment showed a normal cervical cord, but the thoracic cord seemed rather atrophied with some greyish areas in the lateral and posterior columns possibly concerned with Wallerian degeneration.

Neither the anterior nor the posterior nerve roots appeared atrophied.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 23-34).

White matter.

Three types of change were seen in the white columns.

1. Wallerian degeneration. (figs 23, 27, 28).

The myelin stains showed Wallerian degeneration present in the posterior columns in the cervical and upper thoracic regions and in the corticospinal tracts in the lumbosacral cord.

2. Large spongy areas of diffuse degeneration (figs 24, 25, 26, 29)

In the thoracic cord, beginning at T6, there was conspicuous and widespread myelin and fibre loss in irregular areas of varying size present in all three white columns. The lateral white columns were the worse affected, and in this situation the lesions were conspicuous at the periphery of the cord in the distribution of the small branches of the coronal arteries. The central part of the white columns was similarly affected, but in less degree. Very numerous corpora amylacea were present scattered throughout the white matter (figs 30, 31).

3. Small focal areas of necrosis (fig 31).

Occasional small focal areas similar in nature to the large spongy areas were present. In many regions the

severe myelin degeneration obscured these focal areas which were more easily seen in the less affected segments.

Grey matter.

Three types of change were seen in the grey columns.

1. Small focal areas of necrosis (fig 33).

The grey matter was normal in the cervical and upper thoracic regions. In T6 segment and in all more caudal segments there were focal areas of necrosis similar in size and appearance to those seen in the white matter.

2. Depletion of neurones with gliosis (fig 34).

The anterior horns showed severe neuronal depletion with gliosis and abundant corpora amylacea.

3. Ischaemic changes in surviving neurones (fig 34).

The remaining neurones in the anterior horns often showed shrinkage and pyknosis.

Spinal nerve roots.

The anterior nerve roots in lumbar and sacral segments were depleted of nerve fibres.

Meninges.

Moderate leptomeningeal fibrosis was present throughout the spinal cord.

SUMMARY OF CASE 1.

1. An 82 year old woman, in congestive cardiac failure from arteriosclerotic heart disease and hypertension,

developed a severe paraparesis with slight weakness of the hands.

2. Death occurred from bilateral bronchopneumonia a year after the commencement of the neurological disease.

3. At necropsy an old myocardial infarct with mural thrombus was found and the aorta was affected by severe atheroma with ante-mortem thrombus in the abdominal aorta.

4. Histological examination of the spinal cord showed changes in the white and grey matter which suggested the effects of acute and chronic ischaemia.

Case 2. B.A.

HISTORY.

A woman aged 65 years, was admitted to the Neurosurgical Department at the Radcliffe Infirmary on June 23, 1963. The history was that two years previously she had had several falls following which she noticed weakness of her left leg. The weakness increased, and some months later her right leg also became weak and she developed incontinence of urine. Later, she developed pains in the neck and shoulder and her hands and arms became weak. For about nine months she had been completely bedfast and had suffered considerable pain in her back and legs. One year before her admission to the Radcliffe Infirmary, she had been investigated at Worcester where she was found to have a carcinoma of the right breast. This was removed by a radical mastectomy, and at no time was there any clinical or radiological evidence of metastatic tumor.

EXAMINATION.

On examination on June 23, 1963, there were no abnormal signs outside the nervous system. Blood pressure was 140/75 mm Hg. There were no abnormalities in the cranial nerves and the upper limbs. In the lower limbs there was wasting of buttocks, thighs, and calves, and scarcely any voluntary movement was possible. Knee and ankle jerks and plantar reflexes were absent on both sides. Sensation in all forms

was diminished below C5 on the left side of the body.

INVESTIGATIONS.

A lumbar puncture produced clear CSF under normal pressure. There were no cells, and the protein was 85 mg/100 ml. The Wassermann and Khan reactions were negative in the blood and CSF, and the blood count was normal. A chest X-ray showed some cardiac enlargement; a myelogram showed no block, but severe degenerative changes were seen in the X-ray of the cervical and lumbar spine. There were no obvious tumor deposits to be seen. Electromyography showed changes that were considered to indicate a severe neuropathy and were consistent with multiple root involvement. A muscle biopsy showed atrophy with the pattern of a progressive denervation.

COURSE.

The patient was discharged on July 11th, 1963 without a definite diagnosis having been made. She was subsequently cared for in a hospital in the Worcester region where she died in February, 1964 2½ years after the onset of her neurological illness.

GENERAL NECROPSY FINDINGS.

Bilateral bronchopneumonia was present and was considered to be the proximate cause of death. There was no evidence of any malignant tumor either throughout the body or in the

region of the old right mastectomy operation.

Cardio-vascular system.

The coronary vessels were affected by atheroma, and severe generalized atherosclerosis was present throughout the body.

Nervous system.

Brain. (Described in the fresh state and not preserved)

The cerebrum showed generalized atrophy. The brain stem and cerebellum appeared normal.

SPINAL CORD.

Meninges. Normal.

Vessels. Normal.

External appearance.

The only abnormality seen was slight generalised atrophy.

Transverse cuts.

These showed greyness in the posterior and lateral columns suggestive of Wallerian degeneration.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 35, 36, 37)

White matter.

Two types of change were seen in the white columns.

1. Wallerian degeneration.

The myelin stains showed severe Wallerian degeneration seen in the posterior columns of the cervical region (figs

35, 36) and in the corticospinal tracts in the lumbosacral region. Large numbers of corpora amylacea were present in the degenerate areas.

2. Large spongy areas of diffuse degeneration.

From the upper thoracic region downwards there was depletion of nerve fibers and myelin with an irregular distribution but present in all the white columns. The detail of the degeneration was that of spongy areas with a loose glial network and abundant corpora amylacea. A few focal areas of degeneration were present but these were difficult to make out among the profound diffuse degeneration.

Grey matter.

Three types of change were seen in the grey matter.

1. Small focal areas of necrosis.

The grey matter in the lower thoracic, lumbar and sacral regions had small foci of necrosis often surrounding a small arteriole. These were seen in anterior and posterior horns as well as in the grey commissure.

2. Depletion of neurones with gliosis.

The anterior horns showed severe depletion of neurone cell bodies from the lower thoracic, lumbar and sacral regions. The grey matter in these areas showed gliosis and abundant corpora amylacea.

3. Ischaemic changes in surviving neurones.

The remaining neurones in the anterior horns often showed shrinkage and pyknosis.

Spinal nerve roots.

The anterior spinal nerve roots of the lower thoracic, lumbar and sacral regions were atrophied, fibrosed and depleted of nerve fibres.

Spinal Vessels.

The anterior spinal artery and the other major spinal vessels were normal. Within the spinal cord there was capillary proliferation with perivascular phagocytes in some areas.

Meninges.

The leptomeninges showed connective tissue thickening throughout the spinal cord.

SUMMARY OF CASE 2.

1. A 65 year old woman developed a paraparesis which progressed to a quadriparesis with sensory changes and bladder paresis.

2. Death occurred from bilateral bronchopneumonia 2½ years after the onset of the neurological illness.

3. At necropsy severe generalised atherosclerosis was found.

4. Histological examination of the spinal cord showed changes in the white and grey matter suggestive of acute and chronic ischaemia.

Case 3. A.S.

HISTORY.

This lady was a housewife who was aged 67 years at the time of her death. She had a long history of arthritis, having been, from 1950 onwards, partially crippled because of osteoarthritis in her hips and knees. In March 1960, when she was seen as an out-patient, her chief complaints were weakness of the legs, difficulty in balancing, and incontinence of urine, all of which she had had for two months. In addition, she complained of dyspnoea on mild exertion and swelling of the legs.

EXAMINATION.

On examination she had the facies and the hair appearance of myxoedema. Her blood pressure was 137/75 mm Hg. The neurological state was a mild paraparesis with brisk tendon reflexes in the lower limbs. Her plantar responses were flexor, and her abdominal reflexes were present. The cranial nerves were normal, and there were no abnormal neurological signs in the upper limbs.

INVESTIGATIONS.

The blood count was normal. The serum cholesterol was 280mg/100 ml. A lumbar puncture (performed later in 1962) produced cerebrospinal fluid contaminated by blood but under normal pressure. This contained numerous red blood

cells but no excess of white cells; the protein content could not be estimated and the Wassermann reaction was not done. An X-ray of the cervical spine showed severe degenerative changes.

COURSE.

The spondylotic changes seen in the cervical spine led to the diagnosis of myelopathy due to cervical spondylosis and this was treated by the immobilization of the neck in a collar and a course of physiotherapy. The patient continued with this moderate degree of paraparesis, able to pursue limited activities at home, until November 1961, when she had to be urgently admitted to hospital following a fall into the fire during which she burned her leg. In April 1962, still in hospital and having skin grafting to her burnt areas, she was found to have a carcinoma of the right breast which was removed by a total mastectomy in May 1962. Following this operation, she never became ambulant in spite of intensive physiotherapy. Her paraparesis became more marked; there was now less spasticity in the lower limbs; the hyperreflexia of the tendon reflexes had abated; and the left ankle reflex could not be elicited.

In July 1962 she was transferred to a geriatric hospital for terminal care.

MODE OF DEATH.

The patient died of a respiratory infection in January 1963 3½ years after the onset of her paraparesis.

GENERAL NECROPSY FINDINGS.

Terminal changes included large pressure sores involving the sacral and trochanteric regions. One lymph node in the right axilla was distended with secondary carcinoma; but apart from this local lymphatic spread, there was no evidence of tumor dissemination. Bilateral bronchopneumonia was present with pleurisy and pulmonary abscesses. A single mixed stone was present in the gallbladder. The thyroid gland showed moderate diffuse enlargement and a 2 cm. diameter cortical adenoma was present in the right adrenal gland. The spine was affected by spondylosis which narrowed the cervical region of the spinal canal adjacent to C4-5, C5-6, C6-7 intervertebral disks.

Cardiovascular system.

The coronary vessels were severely narrowed with atheroma, but there was no obvious infarction seen in the heart. The aorta was severely affected by atheroma (fig 38), which involved particularly the abdominal region where there was calcification, ulceration, and adherent antemortem thrombus. The orifices of some of the intercostal and lumbar arteries were completely buried beneath the ulcerated

plaques of atheroma.

Nervous system.

Brain. Weight 1200 grams.

External appearance.

The brain appeared moderately atrophied with greyish thickening of the leptomeninges over the vertices and at the base of the brain. The vessels of the circle of Willis were normal in arrangement and showed moderate atheroma.

Coronal slices.

These confirmed the moderate generalised atrophy which was associated with dilated lateral and third ventricles. The atrophy appeared consistent with the atheroma affecting the major cerebral vessels.

Brain stem.)
Cerebellum.) No abnormality was seen.

Histology.

A celloidin section from the left cerebral hemisphere at P1 coronal plane showed mild cerebral atrophy with enlarged perivascular spaces in the grey and white matter. The pons, medulla and cerebellum were normal.

SPINAL CORD.

Meninges. Normal.

Vessels. Normal. No trace of atheroma could be seen and no evidence of occlusion could be discerned with the hand lens.

External appearance.

Three anterior indentations marked the spinal cord at C5-6, C6-7 and C8 levels and corresponded to the protrusions at the disc spaces. Otherwise the only obvious abnormality was slight generalised atrophy.

Transverse cuts.

These showed greyness in the posterior columns maximal in the cervical region.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD.

White matter.

Three types of change were seen in the white columns.

1. Wallerian degeneration.

Long tract degeneration was seen in the fasciculi gracilis and cuneatus and in the spino-cerebellar tracts. This degeneration was most evident in the cervical region.

2. Large spongy areas of diffuse degeneration.

A spongy state was present in the white columns of the lower thoracic, lumbar and sacral regions. At large magnification these areas were seen to consist of a loose glial network from which the majority of the myelin and axons had disappeared. Corpora amylacea were abundant in these areas.

3. Small focal areas of necrosis.

Occasional small focal areas similar in nature to the

large spongy areas were seen.

Grey matter.

Two types of change were seen in the grey columns.

1. Depletion of neurones with gliosis.

Depletion of neurone cell bodies, most obvious in the anterior horns, was seen in the lower thoracic and lumbo-sacral regions of the spinal cord. The Holzer stain showed fibrous gliosis in these areas.

2. Ischaemic changes in surviving neurones.

Some of the surviving neurone cell bodies, again in the caudal parts of the spinal cord, showed pyknosis of the nuclei and shrinkage of the cell body.

Spinal nerve roots.

The anterior spinal nerve roots of the lumbar and sacral regions often showed atrophy with depletion of nerve fibres.

Spinal vessels.

No abnormality was seen in the anterior spinal artery or in the other major spinal vessels. The small intra-spinal arteries and capillaries showed mural thickening with an increase in acellular connective tissue both in the wall of the vessel and as a condensation of loose connective tissue in the perivascular space.

Meninges.

The leptomeninges showed moderate acellular connective

tissue thickening.

SUMMARY OF CASE 3.

1. A 67 year old housewife developed a chronic paraparesis with bladder and bowel changes. The paresis, initially of upper motor neurone type later showed lower motor neurone features.

2. Death occurred from acute bilateral bronchopneumonia 3½ years after the commencement of the neurological illness.

3. At necropsy the abdominal aorta was severely affected by atheroma with calcification and mural thrombosis.

4. Histological examination of the spinal cord showed changes in the white and grey matter suggestive of acute and chronic ischaemia.

Case 4. A.D.

HISTORY.

This man aged 77, was admitted to an Oxford geriatric hospital on September 13, 1963. His chief complaints were breathlessness and cough for two to three months and gradual weakness of all four limbs for eight to ten months. Recently he had been unable to walk, and he had been bedridden for several weeks. His previous medical history included the operation of partial gastrectomy for peptic ulcer 18 years ago. Eight years ago he had had an attack of herpes zoster involving the left shoulder and the trunk, and following this attack, he had suffered considerable neuralgic pain in the affected areas.

EXAMINATION.

On examination he was orthopneic and slightly cyanosed with signs of consolidation at both lung bases. The blood pressure was 140/85 mm Hg. and there was slight ankle oedema with jugular venous congestion. In the central nervous system, the results of an examination of the cranial nerves were normal. Muscle wasting was present in the trunk and all four limbs but affecting mainly the legs, which showed marked loss of power and fasciculation of the muscles. Tendon reflexes in upper and lower limbs were present and equal, and the plantar responses were equivocal. All

forms of sensation were entirely normal.

INVESTIGATIONS.

A lumbar puncture produced clear cerebro-spinal-fluid under normal pressure; protein was 25 mg/100 ml; there were no cells, and the Wassermann reaction was negative. A blood film showed slight iron deficiency of the RBCs; the haemoglobin level was 79%. The serum cyanocobalamin (Vitamin B_{12}) level was 250 µµg/ml.

COURSE.

The patient was considered to have an acute broncho-pneumonia superimposed on a chronic chest infection and combined with early congestive cardiac failure. His paresis and muscle wasting were thought to be due either to motor neurone disease or to a myelopathy related to the old herpes zoster infection. He was treated with antibiotics and mercurial diuretics and at first he improved slightly but about ten days after admission, his condition began to deteriorate.

MODE OF DEATH.

The patient died of his respiratory infection on September 24th, 1963. The duration of his neurological illness was approximately 10 months.

GENERAL NECROPSY FINDINGS.

Terminal bilateral bronchopneumonia was present in both lungs which were affected by emphysema and chronic bronchitis. Bilateral clubbing of the fingers was present. The left shoulder was scarred by old herpes zoster lesions in the distribution of the left C7 dermatome.

Cardiovascular System.

The heart was moderately enlarged due to slight left ventricular hypertrophy and moderate dilatation of both ventricles. The aorta (fig 39), throughout its entire length, was affected by severe atheromatous ulceration with antemortem thrombus adherent to the atheromatous areas. The abdominal aorta was the part most severely affected, and near the bifurcation there was a large aneurysmal dilatation. The atheroma continued into both the iliac arteries which were extremely tortuous, and the remaining arteries were also affected by atheroma which involved the carotid and vertebral arteries. No thrombus was found in any vessel apart from the aorta. The great veins were examined and found to be normal.

Nervous system.

Brain. Weight 1390 grams.

External appearance.

The brain appeared moderately atrophied with patulous sulci and some thickening of the leptomeninges over the

vertices. The arteries of the circle of Willis showed large flecks of atheroma and both internal carotid arteries were narrowed down to half their lumen.

Coronal slices.

These showed a symmetrical cerebrum with dilated lateral and third ventricles apparently compensatory to loss of brain substance. There were cribriform areas in both the white and grey matter, and this was particularly noticeable in the temporal lobes. A few larger focal softenings were present, one being in the corpus callosum. The extreme degree of atheroma of the major cerebral arteries was apparent everywhere in the coronal slices.

Brain stem.)
) The brain stem and cerebellum showed
Cerebellum.) minor changes similar to those in the cerebrum.

SPINAL CORD.

Meninges.

The dura mater was normal. The leptomeninges showed slight opacity.

Vessels.

The major spinal vessels appeared normal, and there was no trace of atheroma in the anterior spinal artery.

External appearance.

The spinal cord itself did not appear atrophied but the anterior nerve roots were small in comparison with

the normal posterior roots.

Transverse cuts.

These were normal apart from a suspicion of greyness in the posterior columns.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD.

White matter.

Three types of change were seen in the white columns.

1. Wallerian degeneration.

Wallerian degeneration was present in the gracile and cuneate fasciculi and in the spinocerebellar tracts. This change was most prominent in the upper cord down to C4 level, after which it became less distinct due to the general degeneration in the cord.

2. Large spongy areas of diffuse degeneration.

Below C4 the white matter showed a generalized spongy state present in every section examined and affecting all the white columns.

3. Small focal areas of necrosis.

In addition to this generalised spongy state, there were small foci of necrosis suggestive of micro-infarcts, and these were also seen at random in every white column. Although apparently of vascular origin, they bore no relation to any particular arterial territory.

Grey matter.

Three types of change were seen in the grey columns.

1. Small focal areas of necrosis.

The grey matter was affected by small foci of necrosis seen in the anterior and posterior horns and in the grey commissure. These were exactly similar to the lesions in the white matter, differing only in their location.

2. Depletion of neurones with gliosis.

In the anterior horns there was severe depletion of neurones, frequently indicated by empty spaces surrounded by oligodendroglial nuclei.

3. Ischaemic changes in surviving neurones.

The remaining neurones in the anterior horns frequently showed shrinkage of the cell body and pyknosis of the nucleus.

Spinal nerve roots and ganglia.

The anterior nerve roots were atrophied and depleted of nerve fibres. The posterior root ganglia were examined, and a healed herpetic scar was found in the left C7 posterior root ganglia, but this lesion appeared to have no connection with the generalized pathology in the spinal cord.

Spinal vessels.

No abnormality was seen in the anterior spinal artery or in the other major spinal vessels. The capillaries and

small arteries in the spinal cord showed acellular mural thickening.

Meninges.

The leptomeninges showed moderate to severe connective tissue thickening.

Muscles.

Numerous voluntary muscles were sectioned, and denervation atrophy was found in the left and right biceps, the right deltoid muscle, the right thenar and hypothenar, and the right gastrocnemius muscles.

SUMMARY OF CASE 4.

1. A 77 year old man, in congestive cardiac failure from arteriosclerotic heart disease, developed a chronic paraparesis.

2. Death occurred from bilateral bronchopneumonia 10 months after the commencement of the neurological illness.

3. At necropsy the whole aorta was affected by atheromatous ulceration and the abdominal aorta contained ante-mortem thrombus.

4. Histological examination of the spinal cord showed changes in the white and grey matter which suggested the effects of acute and chronic ischaemia.

COMMENT ON CASES 1-4.

Cases 1-4 were so similar in their clinical and pathological findings that they may be considered together.

The clinical picture in each of these cases was that of an elderly subject suffering from extensive arterio-sclerotic degenerative disease which became complicated by the development of a chronic neurological syndrome. This complicating syndrome was chiefly manifest as a chronic paraparesis with the features (increased tone, exaggerated tendon reflexes, absent superficial reflexes, and Babinski plantar responses) characteristic of a so-called upper motor neurone lesion. Superimposed upon these signs were others (flaccidity, diminution of tendon reflexes, and absent plantar reflexes) due to involvement of the lower motor neurone. The coincidence of these two types of neurological involvement resulted in a complex clinical picture. The clinical course of the neurological syndrome sometimes clarified the clinical signs and when, as in case 3, neurological examinations had been made at intervals it was clear that the sequence was usually that of a spastic upper motor neurone paresis which progressed into a flaccid lower motor neurone paresis. Added to this picture of chronic paraparesis was a disturbance of bladder and bowel function. Sensory changes were rare.

The necropsy findings confirmed the presence of extensive arteriosclerosis with particular emphasis on atheroma of the aorta and in three cases mural thrombus in the abdominal aorta. The appearance of the spinal cord in each case was that of atrophy with microscopical changes which were interpreted as due to ischaemia involving both white and grey matter.

The findings in the spinal cord white matter included small focal areas of necrosis, large spongy areas of diffuse degeneration, and Wallerian degeneration of long tracts. In the grey matter there were small focal areas of necrosis, but the grey matter also showed gliosis with depletion of neurones and ischaemic changes in those neurone cell bodies still present.

These four cases appeared to be examples of a chronic spinal cord degeneration associated with generalised arteriosclerosis, aortic atheroma, and aortic thrombosis. In the absence of any other spinal cord disease the cause of the degenerative disorder must be sought in the severe degenerative vascular pathology.

Case 5. E.B.

HISTORY.

This 62 year old housewife was brought to the accident department of a hospital in Reading. The patient had suffered an accident in which she had, while driving her car, crashed into the front of a shop. She was knocked unconscious for a short period of time, probably no longer than a few minutes. On regaining consciousness she was able to walk to a nearby house and was then brought in to the hospital by ambulance. Her complaints on arrival at the Accident Department were of pain in the chest, in the left knee and in the chin.

EXAMINATION.

On examination, the patient was conscious and orientated. There was no motor or sensory loss and the reflexes were present and equal. The blood pressure was 120/80mm. and the pulse was 100. There was a two inch laceration of the chin, several of the lower teeth were loose, and the left upper thorax was tender. The remainder of the examination revealed nothing unusual.

INVESTIGATIONS.

The initial investigations included X-rays which showed no fracture of the skull and only degenerative joint disease in an X-ray of the left knee. The chest X-rays showed

increased opacity of the left base of the lung and fractures of the second, third and fourth left ribs at their anterior ends.

COURSE.

On the second day in hospital and about 20 hours after the accident, the patient suffered a fall in blood pressure to 100/20 and her pulse increased to 120. She had a further chest X-ray and this showed an obvious left hemothorax. A thoracentesis was attempted and 75 ccs of blood removed. She was transfused with plasma and whole blood. The patient's condition continued to deteriorate despite the transfusion and an emergency left thorocotomy was performed. At this operation 2 litres of blood was removed from the pleural space and during this procedure it was noticed that the mediastinal tissues were infiltrated with blood and there was a 2.5 cm. tear in the pleura over the aorta just above the diaphragm. During and immediately after this operation 5 pints of whole blood were given and during this time the blood pressure varied between 65/0 to 90/60 mm. Following the fifth pint of blood the patient's blood pressure rose to 110/60 to 120/70 mm. level. There was a transitory oliguria which lasted 24 hours and there was also a paralytic ileus lasting three days.

On the afternoon of the fifth day following her

accident, the patient was sitting up in bed reading, but that evening she complained to a nurse about difficulty in moving her legs. The following morning when she was examined she was found to have a complete paraplegia with a sensory level at T3.

FURTHER INVESTIGATIONS.

An X-ray of the thoracic spine showed no fracture and a thoracic myelogram demonstrated no block in the flow of the myodil. The cerebrospinal fluid was examined and it contained 2,100 red cells per cu. mm. 8 white cells per cu. mm. a protein of 85 mgms. per 100 ml, chloride 96 m.eq. per litre and glucose 65 mg. per 100 ml. On the fifth day following surgery a small area of thrombophlebitis developed in the right leg at the site of the cut-down for the blood transfusion.

MODE OF DEATH.

On the morning of the seventh day the patient suffered a sudden fall in blood pressure, she became comatose and fifteen minutes after this she died.

GENERAL NECROPSY FINDINGS.

The external examination showed the lacerations, contusions, and fractures commented upon in the account of the clinical examination.

Cardio-vascular system.

The heart showed no abnormality. The thoracic aorta showed considerable adventitial haematoma which surrounded and compressed the intercostal arteries, involving the second, third, fourth and fifth intercostal arteries. The intimal surface of the aorta showed a large transverse tear which practically encircled the aorta at a level 4 cms. below the origin of the left subclavian artery. There was no dissection of the tunica media and all the appearances were those of a traumatic tear rather than a spontaneous dissection of a ruptured aneurysm of the aorta.

Nervous system.

Only the spinal cord from C6 to T7 segmental levels had been submitted for examination.

SPINAL CORD.

Meninges.

The dura mater and pia-arachnoid were normal.

Vessels.

The anterior spinal artery appeared quite bloodless from T2 downwards. It received major tributaries accompanying left C5 and right C6 anterior nerve roots. The spinal veins appeared normal.

External appearance.

The spinal cord from T3 to T7 was soft and distorted.

Transverse cuts.

Transverse cuts through each spinal segment showed a round softened area in the posterior columns at C7. This was not apparent in C8 and T1 but began again in T2. The segments T3 and T4 showed softening involving the whole cross sectional area of the spinal cord. The softened area then diminished caudally but was still present at T7.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 40, 41).

Transverse sections were taken from C7, C8, T1, T2, T3 and T4 segments. The changes varied at different segmental levels which will be described.

C7. In the midline of the posterior columns was a well-demarcated oval area, in which the myelin and axon fibres were swollen and fragmented. Polymorphs were present in the margin of the area but few lipid phagocytes had formed. These appearances were those of early infarction.

C8, T1 and T2. In these segments the sections showed capillary proliferation, and a spongy state of the myelin with swollen axons. The neurones showed pyknotic nuclei and shrunken cell bodies. These abnormal findings increased caudally.

T3 and T4. In both these segments there was infarction

involving the whole diameter of the spinal cord. Neurones were absent and the myelin and axons were broken up. There was a perivascular polymorph reaction but only a few lipid phagocytes had as yet appeared although the destruction of tissue was extensive.

SUMMARY OF CASE 5.

1. A 62 year old housewife had a road accident which resulted in fractured ribs, haemothorax and a tear of the aorta just above the diaphragm.

2. On the fifth day after the accident she developed a paraplegia with a sensory level at T3 segmental dermatome.

3. Death occurred on the seventh day following the accident and two days after the onset of the paraplegia.

4. At necropsy a traumatic intramural haematoma of the aorta was demonstrated and this had compressed the second, third, fourth and fifth intercostal arteries.

5. Histological examination of the spinal cord showed extensive acute infarction at C7 and below T3 with ischaemic changes in C8, T1 and T2 segments.

COMMENT ON CASE 5.

This case is one of traumatic intramural haematoma of the aorta causing spinal cord infarction.

In the clinical account of this case it is clear that the patient, despite a severe motor accident with multiple rib fractures, was able to walk soon after the accident and on examination in hospital showed no evidence of any neurological injury. The involvement of the spinal cord came on the fifth day with the development of a syndrome that soon progressed to a complete paraplegia with a sensory level at T3 dermatome. At necropsy the cause of the obstruction to the spinal vascular system was shown to be a haematoma of the thoracic aorta which surrounded and compressed the second, third, fourth and fifth intercostal arteries. The spinal cord was infarcted from T2 to T7 with a smaller region of infarction at C7.

Whilst the spinal cord infarction in this case seems clearly related to the aortic pathology it is interesting to consider the time relationship of its late development five days after the trauma. It is possible but unlikely that the lesion had developed somewhat earlier and during the course of the extensive resuscitation measures and the thoracotomy on the second day in hospital that the neurological state in the lower limbs was not seen. It is likely that

the state of oligemic shock with blood pressures ranging between 65/0 to 90/60 mm. Hg. caused the effects of the intercostal arterial blockage to be intensified and during this period the infarction occurred. It is significant that there was at the same time an oliguria and a paralytic ileus which also may be explained by the period of hypotension and oligaemic shock.

Case 6. S.E.

HISTORY.

A 52 year old factory worker was knocked down by a car whilst crossing the road. He sustained multiple injuries including scalp lacerations, a compound fracture of the left humerus, a fracture of the right clavicle and a large haematoma of the left thigh. Signs of intra-abdominal bleeding became apparent and at laparotomy a ruptured spleen was removed.

EXAMINATION.

His neurological examination on admission had been limited by confusion and oligaemic shock, but no localising neurological signs had been found. Twelve hours after his admission, following splenectomy and adequate blood transfusion, his general condition had improved and permitted a full neurological examination. He now had evidence of a lesion affecting the cervical cord with bilateral sensory loss and paresis below C8. A left Horner's syndrome was also present.

INVESTIGATIONS.

X-rays of the cervical spine showed no fracture or displacement. The fractures of the left humerus and the right clavicle were confirmed.

COURSE.

Two days after his accident the patient's condition gave rise to the suspicion of a respiratory infection, and the following day he became cyanosed with irregular breathing. He died that day three days after the accident and two days after the development of the neurological syndrome.

GENERAL NECROPSY FINDINGS.

The examination showed the lacerations and fractures commented upon in the account of the clinical examination. In the abdomen the splenectomy site was normal but there was a large retroperitoneal haematoma behind and round the left kidney and left adrenal. The lungs were affected by early bronchopneumonia.

Cardio-vascular system.

The heart showed myocardial ischaemia associated with coronary sclerosis. The aorta showed only moderate atheroma and no evidence of injury.

Cervical spine.

The prevertebral muscles were infiltrated with haematoma and covered by a thin film of blood clot. Removal of this blood clot showed a gross tear through the C5-6 intervertebral disc (figs 42, 43). This tear ran roughly transversely but with a wavy contour corresponding to the upper surface of C6 vertebral body. The anterior longitudinal

(prevertebral) ligament was also torn as were the capsular ligaments of the C5-6 intervertebral joints. Both these joints were loose and the facets could be moved on one another but no fractures were associated with this joint subluxation. Consequent on the disc and capsular ligament tears, the spine was abnormally hinged at C5-6, where the upper portion was permitted to angle backwards.

Spinal canal.

The spinal canal was examined from the posterior aspect by removal of the laminae. No haematoma was present within the canal, which showed no gross deformity when the spine was kept straight. If the upper portion was pressed backwards, angulation occurred up to 40 degrees backwards from the normal anatomical position. The abnormal angulation hinged on the posterior longitudinal ligament which was intact.

Vertebral arteries.

After dissection of the cervical spine the vertebral arteries could be seen as they passed through the region of the intervertebral disc tear. Both were markedly kinked when angulation of the spine occurred. In addition to this the left vertebral artery was partially torn (fig 43) with some old blood clot surrounding the tear as a nodule 0.3 cm. in diameter. The patency of each vertebral artery was investigated by fluid injection. The injection (by

syringe) was made into the commencement of the vertebral artery and the outflow observed at its termination. With the cervical spine in the normal anatomical position the vertebral flow was normal but even slight hyperextension (and abnormal hinging due to the disc tear) caused obstruction of the flow of fluid.

Nervous system.

Brain. Weight 1224 grams.

External appearance.

The brain showed mild cerebral swelling with a minor contusion to the left temporal lobe on its lateral aspect near the temporal pole. This contused area, 1.5 cm. in diameter, was the only evidence of trauma. The arteries comprising the circle of Willis were abnormal in that both posterior communicating arteries were large so that the blood flow to the posterior cerebral arteries was from the internal carotid arteries.

Coronal slices.

These displayed a moderately swollen cerebrum with compressed lateral and third ventricles.

SPINAL CORD.

Meninges. Normal.

Vessels.

The anterior spinal artery at C5, 6 and 7 was blood-

less, though normally filled above and below this level. On the posterior aspect the veins were empty over C5, 6 and 7 though very prominent below this down to the cauda equina.

External appearance.

The spinal cord showed slight swelling affecting C5, 6 and 7 segments (figs 44, 45).

Transverse cuts.

These showed a normal appearance down to C4 where there was a small softened area in the posterior columns. This enlarged in C5 and C6 and then contracted in size in segment C7. No obvious abnormality was seen in C8 and T1.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 46, 47).

Transverse sections were taken at every segmental level from C1 to T2 and from T6, T10, L1 and S2 segments. The changes varied at different segmental levels which will be described.

C1, C2, C3, C4 (upper). These segments showed moderate congestion and capillary proliferation. The neurones of the grey matter were depleted and those remaining were shrunken. These changes increased down the spinal cord and by the upper part of C4 had become on the verge of infarction.

C4 Lower, C5 upper, C5 lower, C6 upper, C6 lower. These segments contained a cone-shaped region of infarction first seen as a round area of necrosis (1 mm. in diameter) in the posterior columns immediately posterior to the grey commissure (fig 46). In upper C5 this area enlarged and in lower C5 and both C6 sections (upper and lower) a large area of necrosis was present, involving most of the central part of the posterior columns and the grey matter (fig 47). The grey matter was very hyperaemic and in C6 all the neurones were destroyed.

C7, C8, T1, T2, T6, T10, L1, S2. Only a trace of hyperaemia was present in C7 segment and below this the spinal cord was not remarkable.

SUMMARY OF CASE 6.

1. A man of 52 sustained multiple injuries in a road accident.

2. The following day he developed a neurological syndrome indicating a cervical spinal cord lesion.

3. X-rays showed no fracture or displacement of the cervical spine.

4. Death occurred from respiratory failure three days after the accident and two days after the onset of neurological signs.

5. At necropsy a tear through the C5-6 intervertebral disc had kinked both vertebral arteries.

6. Histological examination of the spinal cord showed recent infarction of C4, C5 and C6 segments with ischaemic changes in neighbouring segments.

Case 7. J.C.

HISTORY.

An 81 year old man, previously in good general health, fell downstairs one evening. He was shaken but apparently unhurt and he retired to bed. During the night he wished to get out of bed to pass water but was unable to do so because of right sided weakness. His general practitioner, called during the night, considered he might have a cerebro-vascular accident but it was curious that, despite his right hemiparesis, he had no disturbance of consciousness or speech. His admission to the Radcliffe Infirmary, Oxford was arranged for the following day.

EXAMINATION.

The examination on admission showed an obese man with a blood pressure of 190/100 mm. He now had a tetraparesis but no sensory loss was found. A few hours later he had gross lower motor neurone paresis in the distribution of C6 and C7 and diminution of all sensation below C6. Both plantar reflexes were upgoing and he was incontinent of urine.

INVESTIGATIONS.

An X-ray showed no fracture of the cervical spine but there was slight backward shift of C6 with respect to C5 vertebra.

COURSE.

He was put to bed with a sponge-rubber collar and during the next 24 hours there was no change in his neurological state. However the following day, the third after his fall, his tetraplegia was more profound and his sensory level had certainly ascended and now involving the C5 dermatome. A lumbar puncture showed slightly yellow fluid but there was still no evidence of spinal block. Because of the progression of the cervical cord lesion a laminectomy was performed.

OPERATIVE FINDINGS.

The spinous processes and laminae of C3-7 were removed showing a thin film of extra-dural blood. On incising the dura the subarachnoid space was seen to be of normal size and when the arachnoid was opened the cord itself looked normal. It was in no way bruised or displaced and there was a copious flow of spinal fluid. Anteriorly there was no evidence of intervertebral disc protrusions nor of any other pressure on the cord. Two denticulate ligaments were divided to have a better look at the front of the spinal cord but again it appeared quite normal. The laminectomy wound was closed in the usual manner.

POST-OPERATIVE COURSE.

Immediately after his operation there was no significant

neurological change but, in the course of a month, power returned to his lower limbs and to his upper limbs with the exception of the lower motor neurone weakness in the C8-T1 distribution. Sensation recovered leaving patchy sensory loss below C7.

MODE OF DEATH.

He had several episodes of auricular fibrillation, attacks of bronchopneumonia and persistent urinary infection which led to his death in a geriatric hospital four months after his accident.

GENERAL NECROPSY FINDINGS.

The general findings at necropsy were acute bronchopneumonia, multiple pulmonary infarcts and cystitis with bilateral pyelonephritis.

Cervical spine.

The laminae of C3-7 vertebrae were absent, being replaced by a thick connective tissue scar of the previous laminectomy operation. Overlying the spinal cord at C7 was a 5 cm. sutured incision in the dura mater. The spinal cord was removed and the specimen was now cut sagittally, revealing a tear through C5-6 intervertebral disc, this dividing the spine into two portions which could be moved on one another but naturally lay in their normal anatomical relationships (fig 48). No fracture was present, but the

intervertebral joints uniting C5-C6 were abnormally mobile with tearing of the capsular ligaments. The posterior longitudinal ligament was intact.

Spinal canal.

There was no haematoma in the spinal canal which appeared completely normal when the cervical spine was kept straight. If the spine was moved it was possible to make an angle at the tear through the C5-6 disc the hinge of the angulated specimen being the intact posterior longitudinal ligament.

Vertebral arteries.

The course of the vertebral artery was investigated (fig 49) and on both sides there was kinking which could be made worse by extending the spine. Both vertebrals were injected with fluid whose passage could be stopped by extending the spine, the procedure and findings being identical with those in Case 6.

Nervous system.

Brain. Weight 1210 grams.

External appearance.

The brain appeared normal in size and general proportions. The vessels of the circle of Willis showed fibrous thickening, a little atheroma but no occlusion. The anatomical arrangement of the circle of Willis was normal with normal communicating arteries.

Coronal slices.

These showed a symmetrical cerebrum with slight dilatation of the lateral ventricles. In the posterior part of the hemispheres there were lesions suggesting old infarction on both sides in the boundary territory between the middle and posterior cerebral arteries. Histological sections showed these areas to be replaced by a spongy gliosis with considerable loss of brain tissue.

Brain stem. }
Cerebellum. } Normal.

SPINAL CORD.

Meninges.

The dural thickening due to the laminectomy operation has already been described. The pia-arachnoid was normal.

Vessels.

The anterior spinal artery appeared normal and in the cervical region received major tributaries accompanying the right C4 and the left C6 anterior nerve roots. The spinal veins appeared normal.

External appearance. }
Transverse cuts. } The only abnormality was slight atrophy and yellowish discolouration seen from C6 to T1 externally and on transverse slicing.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 50, 51, 52).

Transverse sections were taken at every segmental level from C2 to T2 and from T6, T12 and L2. The changes varied at different segmental levels which will be described.

C2. The neurones, and nerve roots were normal. Myelin and nerve fibre loss was marked in the gracile fasciculi, and in the anterior and posterior spino-cerebellar tracts. The appearances suggested Wallerian degeneration above a moderately complete cord lesion.

C3, C4, C5. In addition to the changes seen in C2, these segments showed capillary proliferation with fibrosis. A few shrunken neurones were present in the anterior horns among many normal neurone bodies.

C6, C7, C8, T1. These segments showed generalised myelin and fibre loss (fig 50) with astrocytic gliosis and prominent corpora amylacea. The anterior horns were slightly depleted of neurones but more striking was the presence of small shrunken pyknotic neurones (fig 51). Capillary proliferation was marked with connective tissue hyaline thickening around the new vessels. These changes were also present in the anterior median sulcus and the leptomeninges (fig 52).

T2, T6, T12, L2. These segments showed only mild ischaemic changes but Wallerian degeneration was seen in the pyramidal tracts.

SUMMARY OF CASE 7.

1. An 81 year old man fell downstairs and within a few hours developed a progressive lower cervical spinal-cord syndrome.

2. X-rays showed no fracture or displacement of the cervical spine and at laminectomy the spinal canal appeared quite normal.

3. Necropsy, four months later, showed tearing of the C5-6 intervertebral disc with kinking of both vertebral arteries.

4. The spinal cord from C3-T1 showed evidence of ischaemia also seen in the brain in the boundary zone between the posterior and middle cerebral artery territories.

COMMENT ON CASES 6 AND 7.

Cases 6 and 7 are similar in their clinical and pathological findings and may be considered together.

They both appear to be examples of spinal cord ischaemia caused by traumatic obstruction of the vertebral arteries. In both cases, following an accident, the cervical spine was injured but when X-rayed during life showed no fracture and very little evidence of displacement. In case 7 a posterior laminectomy from T3 to T7 confirmed that the spinal canal was normal to inspection. Both cases had developed a progressive lower cervical spinal cord syndrome but in case 6, due to multiple associated injuries, death occurred on the third day after the accident whereas case 7 survived until 4 months after the trauma. At necropsy the nature of the injury in both cases was a tear through the C5 to 6 intervertebral disc and this had caused injury to both vertebral arteries. Examination of the spinal cord showed recent infarction in case 6 and chronic ischaemic changes in case 7 in each case the lower cervical region being principally affected.

Case 8. V.G.

HISTORY.

This lady, a bank clerk, was 41 years of age at the time of her death. The history was that 10 years previously she had developed malignant hypertension and in 1950 her blood pressure level was in the range 240/130 to 260/150. She had complained of attacks of unconsciousness lasting a few minutes, occipital headaches, dyspnoea on exertion and swelling of the ankles. It was considered that all these symptoms were due to the effect of her considerable hypertension and for this reason she was admitted to a hospital in London for thoraco-lumbar-sympathectomy. The left sympathetic chain, from T2 to L2 plus the splanchnic nerves was extirpated at the uneventful first stage. Three months later the right sympathetic chain from T1 to L2 plus the splanchnic nerves were removed through a thoracotomy opening with resection of the ninth rib. The full notes of this operation show that there were no obvious technical problems and the records of the blood pressure throughout the operation showed that it did not fall to lower levels than is usual. On recovery from the general anaesthetic it was apparent that she had weakness and sensory disturbance in both lower limbs.

EXAMINATION.

A full neurological examination the day after the onset of the paraparesis showed that she now had an almost complete paraplegia from the level of T9 spinal cord segment downwards. The only movement seen was a little in the left leg. She had lost control of both bladder and bowel.

INVESTIGATIONS.

Lumbar puncture produced fluid under a pressure of 150 mms. of CSF but the cell count and protein levels and biochemistry were completely normal. An X-ray of her spine was normal.

After several weeks the paraplegia gradually improved to the level of weakness which eventually was mainly evident in the right leg. By the time of her discharge four months after her sympathectomy operation she had improved to the degree that she could walk with the use of a caliper on the right leg. She still had a spastic paraparesis evident on clinical testing in both limbs and she was still without perception in the lower limbs of pain, temperature, and vibration, but with considerable perception of touch and joint movement. Over the subsequent ten years her neurological picture remained unchanged but her blood pressure slowly increased.

MODE OF DEATH.

Her last admission was to the Radcliffe Infirmary, Oxford because of a subarachnoid haemorrhage which proved fatal after a few days.

GENERAL NECROPSY FINDINGS.

The general necropsy findings were left ventricular hypertrophy, fibrous pleural adhesions and shrunken kidneys (right more than left). Sections showed changes of hypertension with evidence of prior chronic pyelonephritis.

Nervous System.

Brain.

The rupture of a congenital berry aneurysm on the left anterior cerebral artery had caused such extensive subarachnoid bleeding as to be the immediate cause of death.

SPINAL CORD.(figs 53, 54, 55).

Meninges.

The meninges were chiefly abnormal in that they were moderately opaque and that the subarachnoid space was filled with recent blood clot.

Vessels.

The vessels of the spinal cord were examined in detail. The anterior spinal artery was joined by large radicular arteries which accompanied the left C3, right C8, left T1,

and left L2 anterior nerve roots. The left L2 branch was especially large (fig 55) but above this there was no major tributary to the anterior spinal artery until that which accompanied the left T1 anterior nerve root. The veins appeared prominent but their pattern was not abnormal.

External appearance.

The spinal cord itself showed a shrunken appearance from T6 spinal cord segment to L1 spinal cord segment. This was accompanied by a greyish discoloration particularly seen on the anterior aspect of the spinal cord (fig 53).

Transverse cuts.

Transverse slicing through the cord at various segmental levels confirmed this grossly shrunken appearance from T6 to L1 and showed that the anterior part of the cord was that chiefly affected (fig 54). Above and below this region there was greyness due to Wallerian degeneration.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 56-59).

Transverse sections were taken from C5, C8, T1 and all segments to T12, L1 and all segments to L5, and S2. The changes varied at different segmental levels and these will be described.

C5, C8, T1, T2, T3, T4. The sections C5, C8, and T1 to T4 showed similar abnormal appearances (fig 56). There

was leptomeningeal thickening with some recent subarachnoid blood. Myelin and fibres were lost from the posterior columns and in the anterior and posterior spino-cerebellar tracts due to upward Wallerian degeneration above a profound cord lesions. At these levels the anterior horn showed no neuronal depletion and the nerve roots were normal. The vessels showed no evidence of occlusion.

T5, T6, T7, T8, T9, T10, T11, T12, L1. The sections from T5 to L1 showed the region of spinal cord damage (figs 57, 59). Its upper limit was seen in T5 in which the anterior horns showed few neurones which were intermingled with some astrocytic gliosis. The main damage to the spinal cord was from T6 to T12 and in these segments there was severe depletion or complete absence of neurones from the anterior horn (fig 59). The anterior and lateral white columns were shrunken and the normal tissue had been replaced by dense astrocytic gliosis. All the anterior nerve roots from these segments showed severe atrophy with loss of both myelin and fibres. There was considerable lepto-meningeal thickening. None of the vessels seen, either arteries or veins, showed any evidence of occlusion. The lesion ended caudally in L1 where the anterior horn showed depletion of neurones with gliosis.

L2, L3, L4, L5 and S2. The sections of L2, L3, L4, L5, and of S2 showed no evidence of direct damage to the cord but pyramidal tract degeneration with myelin and fibre loss due to downward Wallerian degeneration (fig 58).

SUMMARY OF CASE 8.

1. A 41 year old woman died 10 years after spinal cord infarction sustained during an operation of thoraco-lumbar sympathectomy.

2. At necropsy a large gliotic scar, in the situation of former spinal cord infarction, affected the anterior two thirds of the segments T6 to T12.

3. The clinical history and pathological findings suggested that a major tributary to the anterior spinal artery had been obstructed during the operation of right thoraco-lumbar sympathectomy with resection of the right ninth rib.

COMMENT ON CASE 8.

This case is an example of spinal cord infarction caused by obstruction to an intercostal artery. This complication was the immediate sequel of a thoracotomy with the resection of the right ninth rib and it is likely that the right ninth intercostal artery was occluded during this procedure although one cannot dismiss the possibility that some other intercostal vessel was ligated during the extirpation of the sympathetic chain. The post-mortem examination of the spinal cord showed an extensive region of atrophy corresponding to the region of former spinal cord infarction. In its longitudinal extent this ranged from T6 to T12 and this would correspond to the area of a supply coming from a major tributary at about T9 level. One interesting feature was that the cross-sectional area of the lesion in the spinal cord exactly corresponded to that of an obstruction to the anterior spinal artery although this structure, examined at several levels, was not itself thrombosed or in any way abnormal.

Case 9. M.M.

HISTORY.

This 81 year old woman developed a typical herpes zoster vesicular erruption around the posterior aspect of her right shoulder. A few days later she developed weakness of both arms and legs with extensor plantar responses.

EXAMINATION.

On admission to a geriatric hospital in Aylesbury her condition was at the stage when there was weakness of the limbs on the left side but the following day weakness of the right arm developed and then weakness of the right leg. By this time both plantar responses had become extensor. In addition she had developed sensory impairment involving the whole of the trunk with an upper sensory level in the distribution of the upper cervical dermatomes. Her mental state was normal and there was no abnormality of her cranial nerves.

INVESTIGATIONS.

A lumbar puncture was performed and this showed a normal number of cells and no elevation of the protein. An electrocardiogram showed slight ST elevation in the leads over the sacral area and for this reason it was thought she might in addition to her other complainte have a recent

cardiac infarction.

COURSE AND MODE OF DEATH.

Her breathing was hampered by intercostal paresis and she developed a pneumonia. She died 4 days after her admission and seven days after the onset of her neurological syndrome.

GENERAL NECROPSY FINDINGS.

Bilateral bronchopneumonia was present. The heart contained a recent cardiac infarct with mural thrombus and emboli had passed into the pulmonary and renal arteries. There was no thrombus in the aorta and no evidence of blockage of any of the arterial tributaries arising from the aorta and supplying the spinal cord. Both vertebral arteries were patent.

Nervous system.

Brain. Weight 1165 grams.

External appearance.

The meninges were normal. The cerebral arteries showed fibrous thickening but no significant atheroma. There was an area of softening with a haemorrhagic blush in the right occipital lobe.

Coronal slices.

These displayed on the right side an area of haemorrhagic infarction of the cortex of the precuneus and this

state continued backwards to the occipital pole. This infarction was in the territory of the most posterior part of the anterior cerebral artery. Histological sections from the cerebrum showed an area of infarction at the stage of abundant polymorphs but with some myelin breakdown with many lipid phagocytes. Neurones were destroyed within the infarcted area. A small cortical artery seen in cross section contained a round discreet thrombus.

Brain stem.)
Cerebellum.) Normal.

SPINAL CORD.

Meninges. Normal.

Vessels. These appeared macroscopically normal.

External appearance.

The spinal cord from segments C5 to T1 seemed slightly soft and discoloured.

Transverse cuts.

Transverse slicing through the cord at various segmental levels confirmed the softness and showed that the discoloration seen externally was due to congestion.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 60, 61).

Transverse sections were taken from C2 to T3 and L2 segments. The changes varied at different segmental levels

which will be described.

C2, C3, C5.

Grey matter. This showed moderate but definite capillary proliferation present throughout the grey matter. The neurones were mainly normal but some seemed shrunken in appearance. The white matter appeared normal in connective tissue, myelin and axon stains. The nerve roots were normal and the major spinal cord vessels were patent and normal.

C7, C8 and T1 (figs 60, 61).

Grey matter. Vascular proliferation was very pronounced in these three segments. There were many new capillaries which were accompanied by some large distended veins. The anterior horn (particularly in C8) was markedly depleted of neurones. The neurone cell bodies remaining were often shrunken and were often surrounded by reactive astrocytes. Only an occasional lipid phagocyte was seen.

White matter. This showed pallor in the myelin stains particularly evident on low-power inspection. At higher magnification this pallor was seen to correspond with swollen myelin tubes.

Nerve roots. The anterior nerve roots showed degeneration of the myelin and swelling and fragmentation of the axons. the posterior nerve roots were much less affected. The meninges were normal apart from slight connective tissue fibrosis of the leptomeninges. The major spinal cord

vessels were patent and appeared normal.

T3 and L2. No abnormality was seen in these segments.

SUMMARY OF CASE 9.

1. A woman of 81 developed herpes zoster associated with a spinal cord syndrome.

2. At necropsy, seven days after the onset of her neurological syndrome, a state of recent infarction was found in the spinal cord from C7 to T1.

3. The major spinal vessels were patent and the distribution of the infarction suggested an obstruction to a radicular artery accompanying a nerve root between C7 and T1.

COMMENT ON CASE 9.

This case is an example of spinal cord infarction associated with herpes zoster affecting the posterior root ganglia of the lower cervical region on the right side. The history suggested this sequence because the neurological syndrome, a spastic quadriparesis, developed a few days after the herpes infection.

The findings at necropsy demonstrate the tendency to intravascular thrombosis present in this disease. There was a recent myocardial infarct with mural thrombus and embolism to the pulmonary and renal arteries. Further evidence of thrombosis was found in the brain where the most posterior part of the right anterior cerebral artery was occluded. Histological examination of this thrombus suggested that it had been formed in situ.

The spinal cord showed recent infarction from C7 to T1 segmental levels and the distribution of this infarction was compatible with an effect of the herpes zoster lesions, exerted on radicular tributary vessels accompanying the spinal nerve roots.

There was no evidence to suggest that emboli in the aorta or vertebral arteries had contributed to the spinal cord ischaemia.

Case 10. R.H.

HISTORY.

This 81 year old housewife presented with a history of generalised lymphadenopathy beginning December, 1960. A biopsy of a superficial enlarged left supraclavicular lymph node in March, 1961 showed the changes of a lymphoblastic reticulosarcoma. She was treated with deep X-ray therapy to her enlarged nodes in the axillae and groins. On 9.5.61 she was admitted to the Churchill Hospital, Oxford, now complaining of paralysis of both legs of a week's duration.

EXAMINATION.

She was an ill lady with enlarged axillary and inguinal lymph nodes, a right pleural effusion and an ascites with hepatomegaly. Her neurological state was that she had a complete flaccid paraplegia with a loss of all forms of sensation below a level at T8-9 dermatome. She was incontinent of urine and faeces.

INVESTIGATIONS.

X-rays of the spine showed osteoporosis but no evidence of bony tumour deposits. Lumbar puncture produced a xanthochromic fluid with a protein of 270 mgms/100 ml. but no abnormal cells.

COURSE.

External radiation therapy to the lower thoracic spine was begun but not completed. Her general condition steadily deteriorated.

MODE OF DEATH.

Her gradual deterioration was ended by a sudden collapse and death on 25.5.61, about 3 weeks following the onset of her paraplegia.

GENERAL NECROPSY FINDINGS.

The immediate cause of death was pulmonary embolism from thrombosed leg veins. In the anterior mediastinum a large mass of growth distended the retrosternal tissues. Tumour was also present covering the parietal pleura on both sides and markedly distending the paraaortic glands in the abdomen. Tumour was spreading diffusely in the mesentery of the small and large bowels.

Nervous system.

Brain. Weight 1275 grams.

External appearance.

Slight atrophy with moderate opacity of the leptomeninges and flecks of atheroma in the cerebral arteries.

Coronal slices.

The overall impression was of slight generalised atrophy.

Brain stem. } Normal.
Cerebellum. }

Spinal column.

The spine was dissected after fixation. The spinal canal was opened by laminectomy, the spinal cord was removed and then the whole spinal column was sawn sagittally. This showed a film of soft greyish tumour situated extra-durally adjacent to the T6, T7 and T8 vertebrae. There were no tumour deposits inside the vertebral bodies.

Transverse cuts.

Transverse slicing showed that the spinal cord was normal down to T8 cord segment which looked rather grey and was definitely soft to palpation. This abnormality expanded in T10 segment where the soft area was how easily seen and was situated in the midline of the posterior columns. By T11 the posterior third of the cord was soft and through the whole of T12 segment the whole cross sectional area of the cord felt soft and was discoloured grey. The softening in L1 was confined to the posterior columns and this was so in L2. Caudal to this the spinal cord appeared normal.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 62-67).

Transverse sections were prepared from T1, T7, T8, T9, T10, T11, T12, L1 and L2 spinal cord segmental levels. The appearances varied in the segmental levels which will be described.

T1, T7, T8, T9. The spinal cord at T1, T7, T8, T9 showed little change either in grey or white matter. A section

at T8 level showed extradural tumour with the histological appearances of reticulosarcoma (fig 61).

T10, T11, T12, L1. In T10, T11, T12 and L1 there was a necrotic process first evident as a round area in the posterior columns of T10 (fig 62, 65). This expanded in T11 and T12 (fig 63, 66) and then tapered ending in a round area in the posterior columns of L1 (fig 64). The affected region was that of a haemorrhagic necrosis replaced by lipid phagocytes. Many axonic swellings could be seen. The grey matter was wholly destroyed in T12, severely affected in T11, but mainly preserved in T10 and L1.

L2. The spinal cord at this segmental level showed only minor changes.

SUMMARY OF CASE 10.

1. An 81 year old woman developed a reticulosarcoma causing lymph node enlargement in the neck, axillae, groins, mediastinum and abdomen.

2. Her illness was complicated by the rapid development of a complete flaccid paraplegia with sensory loss and bladder and bowel paralysis.

3. Death occurred from pulmonary embolism 3 weeks following the onset of her paraplegia.

4. Necropsy showed extensive tumour infiltration around the spinal column but no evidence of cord compression by tumour.

5. The spinal cord was infarcted from T10 to L1 segmental levels.

Case 11. S.A.

HISTORY.

This 67 year old man was admitted to the Churchill Hospital, Oxford, as an emergency on 17.9.59. His complaint was of weakness and numbness of the legs which had been coming on gradually for about 3 weeks. For about the same period he had had difficulty in passing water. He had suffered from back pain for about 3 years and this pain which was worse on walking and moving, was aggravated by coughing. For many years, he had had a bad chest with a productive cough which had recently become worse and had become accompanied by breathlessness.

EXAMINATION.

On examination, he was an ill looking man who was very dyspnoeic and wheezy, coughing and producing a purulent creamy sputum. The chest showed very poor movement with scattered rhonchi in all areas. The liver edge was palpable five finger breadths and this was thought to be pathological.

In the nervous system his cranial nerves were normal as were his upper limbs. In the trunk there was weakness of the abdominal and back muscles and diminution in all forms of sensation below a level of T7. The abdominal reflexes were absent. The legs showed a complete flaccid paralysis accompanied by loss of all forms of sensation. The knee jerks were absent and the ankle jerks on both sides were

only barely elicitable. No plantar responses could be elicited.

INVESTIGATIONS.

The C.S.F. obtained by lumbar puncture was slightly xanthochromic, had a protein of 600 mgms. per 100 ml., and a cell count of 11 of which 2 were polymorphs, six were lymphocytes, and 3 were macrophages. No malignant cells were seen and the Lange reaction was normal. An X-ray of the chest showed an opacity in the right upper zone probably in the posterior apical segment.

COURSE.

This patient was referred to the Neurosurgical Department at the Radcliffe Infirmary but at the time of referral he was too ill for any surgical intervention and his subsequent course was that he deteriorated rapidly and died on 25.9.59. He had survived four weeks since the onset of his neurological illness.

GENERAL NECROPSY FINDINGS.

A large carcinoma of the right main bronchus was present and this had given rise to peribronchial lymph node infiltration and metastatic deposits in the liver, pancreas, ribs and spine.

Nervous system.

Brain. Weight 1570 grams.

External appearance.
Coronal slices. } The cerebrum showed moderate atrophy associated with atheroma of the major cerebral arteries.

Brain stem.
Cerebellum. } Normal.

Spinal column.

After fixation the spine was examined by laminectomy and sawing in the sagittal plane and this showed extensive tumour deposition in the vertebral bodies particularly in the lumbar region. Tumour tissue was also found in the spinal canal as a thin film outside the theca in the lower thoracic and lumbar regions. This tumour had caused no compression or narrowing of the spinal canal but it was infiltrating the intervertebral foramina.

SPINAL CORD.

Meninges.

The dura was normal apart from a film of malignant tumour outside the dura mainly around the lumbar enlargement. On opening the dura mater no tumour was seen within the theca. The leptomeninges were normal.

Vessels.

The major vessels of the spinal cord appeared normal.

External appearance.

The spinal cord appeared congested and felt a little soft in the mid-thoracic region.

Transverse cuts.

Transverse slicing through the spinal cord showed a normal appearance down to the level T5. Here on cut section the lateral and anterior white columns looked unnaturally grey. At level T8 the whole cord was rather soft in consistency and appeared to have suffered some type of haemorrhagic infarction. Below the level of T9 or T10 the cord looked normal on transverse section including the area in the lumbar region. There was no evidence whatsoever of cord compression by tumour.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 68, 69).

Transverse sections were prepared from C6, T4-T10, L3 and S2 spinal-cord segments. The appearances varied at different segmental levels which will be described individually.

C6, T4, T5. In these sections early Wallerian degeneration could be seen in the posterior columns.

T6-T10. The sections taken showed tumour infiltration present extradurally adjacent to the thoracic, lumbar, and sacral regions in the cord. No tumour was present within the spinal meninges and the cord itself was free from tumour.

From the T6 segment downwards the whole cross section of the cord was infarcted with large areas of myelin destruction and complete disappearance of the central grey matter. These appearances were profound at T8 and continued through T9 spinal cord segment with lesser changes in T10. Scanty perivascular polymorph infiltration was present in the infarcted region. These appearances suggested infarction but without any local cause found in the spinal vessels.

L3, S2. Moderate ischaemic changes were seen at L3. At S2 the main change was early Wallerian degeneration in the cortico-spinal tracts.

SUMMARY OF CASE 11.

1. A 67 year old man developed carcinoma of the right main bronchus with secondary deposits including tumours in the spinal column.

2. Within a period of 4 weeks he developed a fatal syndrome of flaccid paralysis and total loss of sensation of both lower limbs and the trunk.

3. At autopsy the spine showed extensive tumour infiltration but no tumour was present intradurally or inside the spinal cord.

4. Histological examination showed a state of infarction of the spinal cord below the mid thoracic region.

Case 12. H.K.

HISTORY.

This 88 year old housewife presented with a history of girdle pain in the mid-thoracic region for the previous 6 weeks. She had been admitted to a medical ward and during this admission had developed paraplegia with urinary incontinence and a sensory level at the fourth thoracic dermatome.

EXAMINATION.

On examination there was a flaccid paralysis of the lower limbs in which no reflexes could be elicited. There was complete loss of all sensation on both sides of the body up to T4 dermatome. The abdominal reflexes were absent and plantar stimulation produced a withdrawal reflex on both sides.

INVESTIGATIONS.

X-rays were normal apart from a partial collapse of the fourth thoracic vertebra. Lumbar puncture produced a spinal fluid with a protein of 560 mgms. per 100 ml, and 5 cells, all of which were lymphocytes. The Lange and the Wassermann reactions were normal. These findings suggested a paraplegia from some type of infiltrating tumour.

COURSE.

On 1.10.59 a laminectomy was performed on T2, 3, 4 and 5 vertebrae and this showed very soft bone infiltrated by tumour which was also present in the extra-thecal space. The histological examination of this material showed a reticulosarcoma. Tumour was present in the extrathecal space only. None was seen intrathecally, nor was there any compression of the spinal cord. Following the operation a course of radiotherapy was arranged after which the patient was transferred to a geriatric hospital.

MODE OF DEATH.

The patient's gradual deterioration with decubitus ulcers and urinary troubles was cut short by a sudden collapse and death on 15.11.59, seven weeks after the onset of her paraplegia.

GENERAL NECROPSY FINDINGS.

The tumour proved to be a reticulosacroma (fig 70) involving the peribronchial and para-aortic lymph nodes and extensively infiltrating the thoracic spine. The immediate cause of death was acute cardiac infarction due to thrombosis of the descending intraventricular brand of the left coronary artery.

Nervous system.

Brain. Weight 1225 grams.

External appearance. }
Coronal slices. } The cerebrum was moderately atrophied due to cerebral atherosclerosis.

Brain stem. }
Cerebellum. } Normal.

Spinal column.

After fixation the spinal canal was opened by posterior laminectomy and the spinal cord was removed. On sawing the spine sagittaly tumour deposits were present in many of the vertebral bodies. The fourth thoracic vertebral bodies was partially collapsed by tumour infiltration but no angulation had been caused. The spinal canal was in several places coated by tumour as a thin extradural layer and this was particularly evident in the upper thoracic region. The laminae and spines of the second, third, fourth and fifth thoracic vertebrae were deficient due to the exploratory operation.

SPINAL CORD.

Meninges.

The dura mater appeared normal and had no adherent tumour. The leptomeninges were also normal.

Vessels.

There was no abnormality of the major vessels of the spinal cord.

External appearance.

The external surface of the spinal cord appeared normal and no softness could be detected.

Transverse cuts.

Transverse cuts through the spinal cord showed only a slight indistinctness of the margin between the grey and white matter in the thoracic region. There was no distortion of the spinal cord and no evidence whatsoever of compression by tumour.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 71-73).

Transverse sections were prepared from C7 and T4-T10 segmental levels. The appearances varied at different segmental levels which will be described.

C7. In these sections Wallerian degeneration was seen in the posterior columns as an early degeneration of myelin and axons.

T4-T10. Slight changes were seen at T4 and T5. At T6 and below the cord showed spongy degeneration with swelling of myelin sheaths (figs 71, 72, 73). Many axons were missing and others were fragmented and showed axonic swellings. The neurone cell bodies showed chromatolysis and pyknosis of the nuclei. All these changes suggested an ischaemic affect on the spinal cord. The appearances were those of

partial infarction but in none of the vessels in the spinal cord was any explanation of this evident.

SUMMARY OF CASE 12.

1. An 88 year old housewife developed a reticulosarcoma involving the mediastinal and paraaortic lymph nodes and extensively infiltrating in and around the thoracic spine.

2. Beginning with girdle pains a syndrome of flaccid paraplegia, urinary incontinence, and loss of sensation below the T4 thoracic segment developed.

3. Death occurred from a myocardial infarction seven weeks after the onset of the paraplegia.

4. At necropsy the thoracic spine was extensively infiltrated by tumour which was not however causing spinal cord compression.

5. Histological examination of the spinal cord showed a state of recent infarction of the lower thoracic region.

Case 13. L.F.

HISTORY.

This woman was 77 years at the time of her death. Her clinical history began seven months before her death when she developed a tumour in her right thigh which was removed and found on histological examination to be a fibrosarcoma. For four months after this operation the patient was well and with no symptoms. She then began to complain of pain in the back between the shoulders. This pain gradually became worse and then spread down the spine and around the ribs. A fortnight before her last admission to hospital she noticed that both legs were weak, and on the day of her admission to hospital her legs had become very much worse and the power was so slight that she could scarcely move them. In addition she complained that her legs felt numb and that for the previous day she had been incontinent of urine.

EXAMINATION.

On examination in hospital she was found to be an ill woman in congestive cardiac failure. Her cerebration was normal, there was no abnormality of her cranial nerves and her upper limbs were normal in all respects. Both lower limbs were completely paralysed with absent abdominal reflexes, bilateral Babinski responses, and exaggerated

tendon reflexes in the knee and ankle. She had diminution of all modes of sensation below T7 dermatome.

INVESTIGATIONS.

She had a moderate anaemia and X-rays showed metastatic tumour deposits in her spine. Her general condition was so poor that further investigations such as a myelogram were deferred and in fact were never carried out.

COURSE.

Her condition progressed with ascent of her sensory level to T5 and the conversion of her spastic paraparesis into a complete flaccid and areflexic paralysis of the lower trunk and lower limbs.

MODE OF DEATH.

She developed a chest infection from which she died one month after admission and seven months after the commencement of her illness with a tumour in her thigh. Her neurological illness had lasted six weeks.

GENERAL NECROPSY FINDINGS.

Terminal changes included bilateral bronchopneumonia and bilateral acute cystitis with pyelonephritis. The remaining findings concerned the distribution of tumour throughout the body. The right thigh was explored beneath the region of the former operation and a large ill-defined

firm white tumour was present measuring approximately 5 x 4 x 3 cms. and involving the muscle and fascia of the upper part of the thigh. There was no encroachment on the femur but the inguinal lymph nodes on the right side contained tumour deposits. Extensive tumour deposits were found throughout both lungs, in the sub-mucosa of the stomach, and in the ribs. The remaining tumour was in and around the spine.

Nervous system.

Brain. Weight 1,220 grams.

External appearance.
Coronal slices.
Brain stem.
Cerebellum.
Spinal column.

Normal, no evidence of tumour deposits.

The spine was dissected after fixation. Numerous nodules of firm white tumour tissue were present throughout the spine and were also seen as sheets of tumour spreading in the paravertebral tissues. After opening the spinal canal and removing the spinal cord the spinal column was sawn sagittaly and this showed many tumour deposits situated in the vertebral bodies. The bodies of T6, T7, T8, and T10 were extensively involved by tumour with some collapse of the bone and wedging of the vertebral bodies. The vertebral

bodies of L1 and L2 were also infiltrated by tumour. It was likely that many other tumour deposits were present in the remaining vertebral bodies. The spinal canal showed only slight deformity caused by the collapsed vertebral body of T7 and in this position the tumour was spreading into the epidural space (figs 74, 75).

SPINAL CORD.

Meninges.

Tumour coated the dura mater over the T9 segment of the cord. Apart from this there was no tumour involving the dura and none within the dural sac. The leptomeninges appeared normal.

Vessels.

The major vessels of the spinal cord were normal without any evidence of local obstructions.

External appearance.

The only abnormality seen externally was a little congestion of the lower thoracic cord which appeared soft.

Transverse cuts.

Transverse slicing through the spinal cord showed a normal appearance as far as T6 spinal cord segment where there was some softening and discolouration which continued down into the lumbar cord.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 76-78).

Sections were taken at C3, C6, T2, T4, T6, T9, T11, L1, L4 and S2 segmental levels. The appearances changed at different levels which will be described.

C3, C6. At these segmental levels Wallerian degeneration was apparent in the posterior white columns.

T2, T4. At segmental levels T2 and T4, in addition to the posterior column degeneration there was some pallor and sponginess of the white matter and microscopical ischaemic changes in the neurones of the grey matter.

T6, T9, T11. At T6 segmental level the whole cross sectional area of the cord was infarcted with marked congestion of vessels and necrosis of neurones and white matter which failed to stain (fig 76). This region of infarction continued to T9 (fig 77) and was also seen at T11. The anterior spinal artery was normal throughout as were the vessels in the position of the posterior spinal arteries. The veins showed some dilatation. The appearances suggested an extensive infarction (fig 78) but the cause of this was not demonstrable inside the spinal cord. An examination of the spinal nerve roots in the intervertebral foramina showed them to be everywhere embedded in tumour and it appeared that obstruction to small radicular tributaries

passing through the intervertebral foramina had occurred.

L1, L4 and S2. The changes of infarction were less in L1 and in L4 and S2 segments the main finding was ischaemic changes in neurone cell bodies.

SUMMARY OF CASE 13.

1. A 77 year old woman developed a fibrosarcoma of the thigh with metastases to the lungs, ribs, and spinal column.

2. She then developed a spinal cord syndrome which progressed to an areflexic flaccid paralysis and loss of sensation in the lower limbs and lower trunk.

3. Death occurred from bilateral bronchopneumonia and urinary infection six weeks after the onset of the neurological syndrome.

4. At necropsy the primary fibrosarcoma of the thigh with secondary metastases were seen and tumour was particularly evident in and around the spinal column.

5. An extensive infarction affected the spinal cord in the lower thoracic region.

Case 14. L.S.

HISTORY.

This 72 year old housewife, one year before her death, had a carcinoma of the left breast which was treated by a left radical mastectomy followed by a course of radiotherapy. She remained free from symptoms of tumour infiltration until 14 weeks before her last admission to hospital. She then complained of pain in the back which progressed and was felt in most of the spinal column and also the ribs. After three weeks of pain she developed weakness of both legs and two days later this had progressed to a state where she was unable to walk. Eleven days before her death she was admitted to hospital for investigation.

EXAMINATION.

On examination it was found that she had a complete flaccid paralysis of both legs and trunk. The knee and ankle jerks were absent and the plantar responses were extensor. She had lost all forms of sensation below a level in the region of the seventh thoracic dermatome.

COURSE.

Shortly after admission to hospital she developed a temperature of 101 degrees F. and this was accompanied by signs of pulmonary and urinary infection. She also developed acute pulmonary congestion possibly due to myo-

cardial ischaemic fibrosis. Her general condition continued to deteriorate and she died two days later. She had survived the onset of her neurological illness by 12 weeks.

GENERAL NECROPSY FINDINGS.

A recent myocardial infarction was present in the posterior half of the interventricular septum. The coronary arteries were patent but showed severe atheroma. Cystitis and bilateral pyelonephritis were present. The right breast showed no evidence of a tumour and there was no recurrence in the left breast or in the axillary lymph nodes. The only tumour found was in and around the spine.

Nervous system.

Brain. Weight 1110 grams.

External appearance. }
Coronal slices. } The brain externally and on coronal slicing showed moderate atrophy associated with atheroma of the main cerebral arteries. There was no evidence of metastatic tumour deposits.

Spinal column.

The spine was removed intact and fixed with the spinal cord *in situ*. The spinal canal was opened, the spinal cord was removed and then the spinal column was sawn in the sagittal plane. This showed that all the vertebral bodies were soft and many were extensively invaded by tumour.

Tumour particularly affected the C7, C8 and T1 vertebral bodies and here there was slight angulation resulting in a kyphos. There was no tumour in the spinal cord but the outside of the spine was plastered with tumour which in particular could be seen around the intervertebral foramina through which the spinal roots emerges. Sections of the vertebrae showed infiltration by a spheroidal-celled carcinoma with a fibrous stroma (fig 79).

SPINAL CORD.

Meninges. The meninges were entirely normal.

Vessels.

The anterior spinal vessels adjacent to C8, T1 and T2 spinal cord segments were flattened by slight pressure due to the kyphosis of the spinal column (fig 80).

External appearance.

The anterior aspect of the spinal cord showed a shallow impression at T1 corresponding with the kyphos of the vertebral column.

Transverse cuts.

Transverse slicing through the spinal cord showed a normal appearance as far as T1 spinal cord segment. In T1 segment and to a greater extent in T2 and T3, there was softening in the anterior and lateral columns and this was worse on the right side. Below these levels the spinal cord appeared macroscopically normal.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 81, 82).

Transverse sections were cut at the following segmental levels:- C8, T1 (upper and lower), T2, T3, T4, T8, L1, and S1 segments. The appearances varied in different segments which will be separately described.

C8. In C8 segment Wallerian degeneration could be seen in the posterior columns. The anterior roots had lost some nerve fibres and the anterior horns contained a few neurones showing central chromatolysis.

T1 upper and lower. In T1 segment myelin and axon destruction was apparent and there were many lipid phagocytes. The anterior white columns and the grey matter were particularly affected.

T2 and T3 (fig 81). At T2 and T3 spinal cord segments little normal nervous tissue remained. The myelin was pale from swelling of the myelin tubes or replaced by a spongy degeneration with many axonic swellings (fig 82). The anterior spinal nerve roots showed severe depletion of fibres and only a few neurone cell bodies had survived in the anterior horns. The appearances were those of infarction with many new capillaries and abundant lipid phagocytes.

T4. At T4 segmental level similar but less severe changes were present to those described in T2 and T3.

T8, L1 and S1. In these segments the principal change was Wallerian degeneration in both cortico-spinal tracts.

SUMMARY OF CASE 14.

1. A woman of 72 developed a carcinoma of the left breast which was treated by a radical mastectomy and by radiotherapy.

2. One year later she began to experience pains in the back and these symptoms progressed and developed into a complete flaccid paraplegia with a sensory loss below T7.

3. Death occurred from myocardial infarction 12 weeks after the onset of her neurological illness.

4. At necropsy the only tumour present was secondary carcinoma in and around the spinal column. Vertebral collapse, kyphosis and pressure on the anterior spinal artery was demonstrated.

5. Histological examination of the spinal cord showed a state of infarction affecting the T1-T4 spinal cord segments.

COMMENT ON CASES 10-14.

These five cases are examples of paraplegia developing in malignant disease. They have been selected and grouped together because they illustrate a type of spinal cord infarction which is caused by extensive malignant infiltration in and around the spine.

All five cases have the common clinical features of a flaccid paralysis and loss of all sensation below a level in the thoracic region. At necropsy the explanation of this neurological syndrome was seen to be extensive infarction of the spinal cord without evidence of compression by tumour infiltration or angulation of the spine (except for slight angulation in case 14). Extensive tumour infiltration surrounded the radicular tributary vessels supplying the spinal cord vessels and it was at this point that the vascular obstruction was caused. In case 14 an additional complicating factor was that pressure on the anterior spinal vessels was demonstrated.

Case 15. W.B.

HISTORY.

This man, a retired electrical engineer, was 65 years old at the time of his death. The history of his terminal illness was that one month before his death he began to complain of a cramp-like pain in the left arm which spread to the back of the neck. Subsequently he felt a pain down the right arm. The following day he noticed that the grip in his right arm was weak and he particularly noticed that that morning he was unable to shave satisfactorily. This disability in his right arm came on quite rapidly and twenty minutes later he found that both his legs were weak and also that he had some numbness over the right side of his abdomen. About this time also he noticed that he was unable to pass urine. He was admitted that day to a hospital in South Wales.

EXAMINATION.

On examination he was found to have normal cranial nerve function but weakness of the upper and lower limbs which was of a localised distribution. The weakness in the upper limbs affected particularly the wrist movement and the finger movements whilst that in the lower limbs affected particularly hip flexion. The tendon reflexes in the upper and lower limbs were absent but the plantar responses were probably flexor. Sensory testing showed a diminution

of sensation to pin prick below a level in the mid-thoracic region. His retention of urine was also noted.

COURSE.

Three days after the onset of his paralysis his state had progressed to an almost complete paralysis of all four limbs. He now had loss of sensation up to the C4 sensory level. A tracheostomy was performed and he was put on artificial respiration and in this state was transferred to Oxford. It was 14 days since the onset of his neurological illness. On arrival at the Churchill Hospital, Oxford the patient was in considerable respiratory difficulty with purulent secretion that could be aspirated from his tracheostomy. His neurological state was that of normal cranial nerves but now a flaccid paralysis of all four limbs with the exception of a little movement of the fingers of the right hand and the right leg. The plantar responses were absent. There was now a sensory level in the high cervical region at about C4.

INVESTIGATIONS.

The investigations that were performed were several chest X-rays which showed consolidation in the right upper zone and a myelogram which showed free flow up to the skull and no evidence of any block in spinal theca. A lumbar puncture produced cerebrospinal fluid under normal pressure

with three white cells, a protein of 40 mgms. per 100 ml. and a glucose level of 73 mgms/100 ml. The white cell count was 16,000/c.mm.

MODE OF DEATH.

The subsequent course was that the neurological state was static but the respiratory difficulty increased and it proved impossible to ventilate him adequately due to the progressing bronchopneumonia. There was no response to intensive physiotherapy and treatment with several antibiotics and he died 4 days after admission to the Churchill Hospital, Oxford and one month after the beginning of his illness.

GENERAL NECROPSY FINDINGS.

An advanced bronchopneumonia affected particularly the right lung, but also the left lung. The trachea and both main bronchi contained a large quantity of muco-purulent material.

Nervous system.

Brain. Weight 1,100 grams.

External appearance.

Externally there was some evidence of atrophy with widening of the sulci. The vessels of the circle of Willis were healthy with practically no atheroma.

Coronal slices.

These showed a symmetrical cerebrum with no other abnormality other than mild atrophy.

SPINAL CORD.

Meninges.

The dura mater appeared normal as did the leptomeninges.

Vessels.

The anterior spinal artery appeared macroscopically normal but the spinal veins appeared prominent.

External appearance.

Slight softness was apparent in the cervical region but otherwise the spinal cord appeared normal.

Transverse cuts.

On transverse slicing, beginning at C3 segmental level, there was an area of softening, mainly affecting the grey commissure and grey columns. By C4 segmental level this area had expanded to involve the white matter particularly that of the left lateral column. By C5 segmental level the softening involved most of the spinal cord cross sectional area but again more on the left. The softened process affecting the cord ended at C7 as a softened state in the left anterior horn. There was some possible change at C8 but at T1 and below the cord appeared absolutely normal.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 83-92).

Transverse sections were prepared from every segmental level. The findings differed markedly throughout the spinal cord.

C1, C2. At C1 segmental level the only change seen was commencing Wallerian degeneration in some fibres of the posterior columns. At C2 segmental level the grey matter showed ischaemic changes in the neurone cell bodies with some clusters of lipid phagocytes in the adjoining white matter.

C3, C4, C5, C6, C7, C8. In these six segments a region of frank infarction had destroyed about one third of the cross-sectional area of the cord. The distribution of the infarcted area is best seen in the figures (figs 83-88). The infarcted zone always included the grey matter which was usually totally destroyed. The white matter was always involved but in an irregular manner with large extensions sometimes to one lateral column (as in C3, C4, C5, C6, C8) and sometimes into one anterior column (C4, C5, C7, C8). The asymmetry of the region of infarction was striking. The spinal arteries were carefully examined in all the sections. A large thrombus was found at C3 segmental level in the anterior spinal artery (fig 90) which was almost entirely blocked. A smaller thrombus

was seen in a sulcal artery at C4 (fig 92). The infarcted area was full of lipid phagocytes, proliferated capillaries and some acute inflammatory cells. The spinal veins were moderately dilated.

T1, T2. In both these segments the grey matter showed ischaemia and at T1 there were small infarcted areas in the left anterior white column.

T3-T12, L1-L5, S1-S5: These segments showed early Wallerian degeneration in both cortico-spinal tracts.

SUMMARY OF CASE 15.

1. A 65 year old man whilst shaving noticed weakness of his right arm which spread to his left arm and his legs and was accompanied by impairment of sensation below the cervical region and paralysis of bladder function. His condition progressed to a complete areflexic flaccid paralysis of all four limbs with corresponding sensory disturbance.

2. Death occurred one month later from respiratory infection.

3. At necropsy extensive infarction was found in the cervical region of the spinal cord in the distribution

of the anterior spinal artery which contained ante-mortem thrombus.

Case 16. A.F.

HISTORY.

A 70 year old woman suddenly developed pain between the shoulders while dressing in the morning; the pain radiated up the back of the neck and head. At the same time, she experienced numbness and tingling in her hands, and within a few minutes weakness in both arms developed. She was admitted to the hospital on the same day.

EXAMINATION.

On examination she was found to have a flaccid paresis of the arms where there were diminished tendon reflexes, the right side being more sluggish than the left. Sensation in the upper limbs was normal except for diminution of perception to pinprick along the ulnar borders of the hands; temperature sensation was not tested. In the lower limbs, power and sensation were normal, tendon reflexes were present and equal, and plantar reflexes flexor. Examination of the cranial nerves was normal, pulse was 76 counts per minute, blood pressure was 170/100, and no abnormal physical signs were detected in any other system.

INVESTIGATIONS.

An X-ray of the cervical spine, performed on the day of admission, showed degenerative spondylotic changes but no evidence of fracture or dislocation. An electrocardiogram

was normal as was the blood count and the erythrocyte sedimentation rate.

COURSE.

During the course of the same day, the patient's legs became weak, and she was unable to stand. At 5.30 a.m. on the following morning her pulse was barely palpable, and her systolic blood pressure had dropped to readings between 90 and 110 mm. Hg. She was cyanosed and was noted to be using accessory muscles for respiration while the intercostal muscles were not moving. She died at 9.30 a.m., approximately twenty-four hours after the onset of her symptoms.

GENERAL NECROPSY FINDINGS.

A necropsy was performed at the King Edward Memorial Hospital, Ealing, by Dr. W.S. Killpack, who found extensive bilateral pulmonary collapse but no other significant abnormalities except in the spine. He kindly submitted the spine and the spinal cord for examination.

Spinal column.

From T5 to T7 there was kyphosis with slight scoliosis with a convexity to the right and severe spondylosis affecting most of the spinal column.

Spinal canal.

The spinal canal in the thoracic region and below was not remarkable, and the thoracic kyphoscoliosis had caused

no untoward effect on the spinal cord. In the cervical region there were spondylotic bulges in association with the C3 to C4, C4 to C5, and C5 to C6 intervertebral disks; the first 2 of these had low transverse ridges, and the C5 and C6 disk had 2 symmetrical lateral eminences projecting backward into the spinal canal. The patency of both vertebral arteries was demonstrated by fluid injection, and on dissection they were seen to be free from atheroma and had widely patent lumens.

Nervous system.

Brain.

This had been examined in the fresh state and had not subsequently been preserved. No significant abnormality had been noted.

SPINAL CORD.

Meninges.

These appeared normal.

Vessels.

The spinal arteries were examined macroscopically but no abnormality was seen. The spinal veins appeared slightly dilated in the upper part of the spinal cord.

External appearance.

The spinal cord was indented at C4 to C5, C5 to C6, and C6 to C7 segmental levels; these three indentations corresponded to the spondylotic protrusions associated with

the C3 to C4, C4 to C5, and C5 to C6 intervertebral disks.

Transverse cuts.

These showed softening and white discoloration from about C5 down to C8. At these segmental levels the demarcation between grey and white matter was observed.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 93-103).

Transverse sections were prepared through the spinal cord at the following segmental levels: C2, C3, C4, C4-C5, C5, C5-C6, C6, C6-C7, C7, C8, T1, and T2.

C2, C3. There were no changes in C2 but C3 the grey matter showed a suspicion of ischaemia and there were collections of lipid phagocytes in the white matter adjacent to the grey columns.

C4 - T1. From C4 down to T1 (figs 93-98) there was a continuous zone of infarction symmetrically placed within the distribution of the anterior spinal artery. The extent of the infarct may best be seen in the figures. The whole of the anterior white columns, together with the adjacent areas of the lateral and posterior white columns, was affected. Of the grey matter, the infarction involved the anterior horns and most of the grey commissure. In all the segmental levels from C5 down to C8, recent ante-mortem thrombus was present in the anterior spinal artery (figs 99, 100), an occasional sulcal artery (C5) (fig 101),

and an occasional small vessel in the grey commissure (C6). The changes in the infarcted region everywhere were recent (figs 102, 103) and comparable to the age of the arterial thrombus which was well developed and attached to the vessel wall but not organised by fibrous tissue.

T2. The spinal cord was normal at this segmental level.

SUMMARY OF CASE 16.

1. A 70 year old woman whilst dressing developed a neurological syndrome central in the cervical cord.

2. Death occurred from respiratory paralysis 24 hours after the onset of symptoms.

3. At necropsy there was infarction of the anterior part of the spinal cord from C4 down to T1 and this was caused by thrombus in the anterior spinal artery and its branches.

4. The severe cervical spondylosis present corresponded to the position of the arterial obstruction and may have been the precipitating cause of the anterior spinal artery thrombosis.

Case 17. S.T.

HISTORY.

This 75 year old woman had complained of backache for two years but was otherwise in good health up to 3½ weeks before admission to hospital. She had suddenly developed severe backache whilst walking to the toilet in the middle of the night. The pain radiated round the abdomen and down the back of both legs and feet. She did not fall. Since the abrupt onset of pain she began feeling numbness and weakness of both legs. She was constipated and incontinent of urine. Her eyesight and hearing were normal. She was admitted to Cowley Road Hospital, Oxford, on 6.3.51.

EXAMINATION.

She was an obese lady with slight dyspnoea. Temperature 98°F., pulse 72, regular. Heart normal, B.P. 180/90. Her superficial pulses were present. In the nervous system the cranial nerves and upper limbs were normal.

Lower Limbs.

A flaccid paraplegia was present and paralysis of the lower abdominal muscles. All forms of sensation were lost below T9 on the right and T10 on the left, except preservation of touch sensation on the left in the area of L4. A hyperaesthetic zone was present at T9. The lower abdominal, plantar, knee and ankle reflexes were absent.

INVESTIGATIONS.

A lumbar puncture performed six days after admission obtained clear C.S.F. at a pressure of 120 mms. of C.S.F. The Queckenstedt's test was normal. Cells 2/c.mm. Protein 180 mgm./100 ml. Sugar normal. Lange normal. The Wassermann reaction and Kahn reaction were negative and also were negative on testing a sample of blood.

COURSE.

She was treated with chemotherapy and local attention to pressure areas. Her general condition could not be maintained and she died on 21.3.51, six weeks after the onset of her illness.

GENERAL NECROPSY FINDINGS.

Pressure sores, bilateral bronchopneumonia and chronic pyelonephritis were present.

Cardiovascular system.

The heart was enlarged with moderate hypertrophy of the left ventricle and marked dilatation of the right ventricle. The heart valves appeared normal and there was no source of embolism. The coronary vessels were patent. The aorta showed a few patches of atheroma in its thoracic and abdominal portions. The venous system appeared natural.

Nervous system.

Brain. Weight 980 grams.

External appearance.

The leptomeninges showed considerable opacity in the parasagittal region. The brain appeared small and the frontal lobes appeared atrophied.

Coronal slices.

These confirmed the general appearance of cerebral atrophy but were otherwise unremarkable.

Brain stem.)
Cerebellum.) Normal.

SPINAL CORD.

Meninges.

Several calcified areas were present in the arachnoid over the posterior surface of the cord.

Vessels.

No occlusion of a major spinal vessel could be seen macroscopically but the arteries and veins over the lower thoracic and lumbar regions appeared congested.

Transverse cuts.

These displayed a normal looking cord down to the T11 spinal cord segment. Here the anterior and lateral columns looked rather grey and the demarcation between grey and white matter was indistinct. This appearance continued to be seen as far as the mid-lumbar region below which there was yellowing of the white matter and a haemorrhagic

appearance. The lower lumbar cord was soft and possibly necrotic.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 104-107).

Only the blocks from C6, T7, T9, T11 and L1 segmental levels were available and these were recut and stained.

C6, T7, T9. These segments showed Wallerian degeneration well seen in the spino-cerebellar tracts and in a moderate degree in the posterior columns.

T11, L1. At both these segmental levels there was a large zone of infarction occupying an irregular and asymmetrical part (about half) of the cross-sectional area of the cord (fig. 104). The infarcted area was mainly within the anterior half of the cord and involved most of the anterior white columns and a large area of the lateral white columns. The grey commissure was totally infarcted as were the anterior grey horns but the posterior grey horns were spared. The anterior spinal artery at T11 (fig 105) contained a large ante-mortem thrombus almost completely occupying the lumen. At L1 a portion of thrombus was present in a sulco-commissural artery in the grey commissure within the region of infarction, (figs 106, 107), which consisted of lipid phagocytes, proliferated capillaries and some acute inflammatory cells.

SUMMARY OF CASE 17.

1. A 75 year old woman developed with a dramatic acute onset severe back pain with dysaesthesia and paresis of the legs.

2. This progressed to a flaccid paraplegia and almost complete anaesthesia below the T9 dermatome.

3. Death 6 weeks later was from bronchopneumonia and pressure sores.

4. At necropsy the cord was found to be extensively infarcted due to an ante-mortem thrombus in the anterior spinal artery.

COMMENT ON CASES 15-17.

These three cases are examples of spinal cord infarction caused by thrombosis in the anterior spinal artery. In cases 15 and 16 the upper part of the spinal artery was affected whilst in case 17 the caudal part of this vessel was obstructed. In all three cases the onset of the neurological syndrome occurred with dramatic suddenness and there was rapid development to a complete flaccid paralysis corresponding to the affected spinal-cord segments. All the patients were elderly and in case 16 cervical spondylosis was present and was thought to have initiated the anterior spinal artery thrombosis. The necropsies showed the distribution of the infarcted area which was of irregular extent and affecting sometimes more the left and sometimes more the right of the spinal cord. The examination of the spinal vessels showed that the amount of thrombus present was also variable and thrombus was seen both in the anterior spinal artery and in many of the sulcal branches.

Case 18. J.J.

HISTORY and EXAMINATION.

This man was 64 at the time of his death. His terminal illness was ushered in by a productive cough and breathlessness. A chest X-ray showed a large hilar mass on the left side and investigations showed this to be carcinoma of the bronchus. In addition to this respiratory pathology he had a neurological syndrome of long duration which was associated with weakness and wasting of the muscles of his arms and legs particularly the left hand. In his previous medical history he was known to have had syphilis many years before and this had been treated in its primary stage.

MODE OF DEATH.

His death was from acute bronchopneumonia superimposed upon his carcinoma of the bronchus.

GENERAL NECROPSY FINDINGS.

The general findings were those of a carcinoma of the left main bronchus with involvement of the neighbouring lymph glands. In addition bilateral bronchopneumonia was present.

Nervous system.

Brain.

The brain was examined in the fresh state and was not preserved. Moderate cerebral atrophy and leptomeningeal

thickening were noted.

Spinal column.

The spinal cord had been fixed within the spine. Examination of the spine showed severe degenerative disc disease affecting C2-3, 3-4, 4-5, 5-6, and 6-7 intervertebral discs. From all these discs spondylotic protrusions projected into the spinal canal and those associated with C2-3, C3-4 and C4-5 discs narrowed the antero-posterior diameter of the canal by at least 0.5 cm.

SPINAL CORD.

Meninges.

The dura mater was normal. The leptomeninges were thickened and opaque throughout the length of the spinal cord.

Vessels.

The anterior spinal artery was flattened at several points by the spondylotic protrusions previously mentioned. The spinal veins were prominent on both the anterior and posterior surfaces of the cord.

External appearance.

The whole of the spinal cord appeared moderately atrophied. It was flattened antero-posteriorly and further indented by transverse depressions over C3-4, C4-5, C5, C6-7. These indentations corresponded to the protrusions

associated with the discs. The thoracic cord had a small midline indentation at T7 due to a midline spondylotic protrusion.

Transverse cuts.

These confirmed the atrophy and the distortion of the spinal cord by the cervical spondylosis.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD. (figs 108-114).

Transverse sections were taken from the spinal cord at the following segmental levels :- C2, 3, 4, 5, 6, 6-7, 7, 7-8, 8, T1, 7, L1.

Leptomeninges. In all the sections there was marked leptomeningeal fibrosis (figs 109, 110, 111) filling the anterior median sulcus and binding the leptomeninges to the spinal cord. Small numbers of lymphocytes were scattered throughout the connective tissue fibrosis which otherwise was acellular and suggested a very chronic process.

Vessels. The large and small arteries both within the cord and among the thickened leptomeninges showed concentric mural thickening by fibrous tissue (figs 112, 113). The numerous capillaries (fig 113) in the spinal cord were surrounded by a condensation of fibrous tissue suggestive of former vascular proliferation. Most of the spinal veins were dilated.

Grey Matter. Loss of anterior horn neurones was evident in several sections (fig 114) and in C3, C4 and T7 they were almost entirely absent.

White Matter. Wallerian degeneration was present in the posterior columns of C2, and in the pyramidal tracts of the caudal segments. Marked myelin loss throughout most of the diameter of the cord was present in C3 and C4 with only the anterior white column being spared. Distortion of the cord outline in C3, C4 and C6 corresponded to the position of the cervical spondylotic protrusions.

SUMMARY OF CASE 18.

1. A 64 year old man died of bronchopneumonia superimposed on a carcinoma of the left main bronchus.

2. In early adult life he had contracted syphilis for which he had had a course of treatment.

3. For many years preceeding his death he exhibited a neurological syndrome associated with weakness and wasting of the limbs.

4. At necropsy severe bony and cartilagenous changes of cervical spondylosis were observed.

5. Histological examination of the spinal cord showed evidence of former meningo-vascular syphilis with the

features of syphilitic amyotrophy.

Case 19. S.K.

HISTORY.

A 20 year old Austrian au-pair girl, one week after her arrival in England, developed an illness which subsequently proved to be tuberculous meningitis. She also had evidence of generalised tuberculosis since her chest X-ray showed miliary tuberculosis and she had evidence of tuberculous endometritis. Her initial treatment was at the Atkinson Morley Hospital but after 1 month she was transferred to the Tuberculous Meningitis Unit at Oxford.

EXAMINATION.

On examination she had a complete paraplegia and this was thought to be due to localised tuberculosis affecting the thoracic region of the spinal cord. She was treated with streptomycin and isoniazid. Initially there was some improvement but then she began gradually to lose ground and was finally in a state of severe toxaemia.

MODE OF DEATH.

She was found dead in bed four months after admission to the Tuberculous Meningitis Unit at Oxford and five months after her first admission to hospital.

GENERAL NECROPSY FINDINGS.

Permission for necropsy was limited to examination

of the brain and spinal cord. Externally the body was that of a lean girl with two pressure sores, one over the sacrum and the other over the left greater trochanter.

Nervous system.

Brain. Weight 1,226 grams.

External appearance.

The brain was generally swollen. There was thick greyish exudate at the base and there were miliary tubercles everywhere in the leptomeninges.

Coronal slices.

On slicing the brain, the lateral, third and fourth ventricles were dilated due to obstruction at the base of the brain.

Histology.

Histological sections showed thick exudate around the mamillary bodies and in both Sylvian fissures. This exudate was made up of lymphocytes and macrophages with only a few giant cells. The vessels at the base of the brain were buried in exudate and showed endarteritis. Ischemic foci were present in the substance of the brain in relation to the endarteritic vessels. Sections stained for acid fast bacilli showed large numbers in every slide examined.

SPINAL CORD.

The dura mater was distended from top to bottom by

exudate surrounding the cord. The root sleeves of the dura mater were also swollen and, in some of these, yellowish exudate could be seen. It was quite impossible to cut and reflect the dura mater in the usual way and so the spinal cord was examined further by transverse slicing through the cord within the dura. These slices showed that the cord was surrounded by an exudate in the subarachnoid space which was greyish in colour and particularly marked posteriorly. The effect on the spinal cord itself was related to the quantity of exudate. At C6 segmental level the cord was almost intact apart from some softness around the grey commissure. At T4 segmental level there was definite softness involving most of the posterior columns and also affecting all the grey matter. By T7 segmental level, the whole substance of the spinal cord was rather soft. More caudally, at T11 segmental level, the cord was soft but here the exudate, situated posteriorly, had flattened the contour of the cord. This exudate in the lower thoracic region and below was very extensive and included within the exudate was a cystic cavity 1 cm. in diameter and filled with altered blood. This cavity which extended from about T5 down almost to the conus medullaris was probably the loculated area in which intrathecal therapy had been attempted. The transverse slices through the cauda equina showed all the nerve roots stuck together and buried

in greyish exudate.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD. (figs 115-121).

Transverse sections were taken at C6, T4, T7, T11 and S2 segmental levels and in each case the section included the dura mater around the spinal cord.

C6, T4, T7, T11, S2. At all these segmental levels the spinal cord was surrounded by thick tuberculous granulation tissue in the subarachnoid space (figs 115-117). This exudate was most pronounced posteriorly where it obliterated the space apart from a cystic cleft running down from the cervical region down to the cauda equina. The nerve roots of the cauda equina were entirely buried in exudate. The spinal cord itself showed a remarkable degree of ischaemic necrosis (fig 118), seen at all the levels examined but particularly severe in the lower thoracic regions. All the small spinal vessels (fig 120) buried in the exudate in the subarachnoid space showed marked endarteritis and this change also affected the larger vessels (figs 119, 121). Histological slides stained for acid fast bacilli showed many acid-fast bacilli in every segmental level examined.

SUMMARY OF CASE 19.

1. A 20 year old girl died 5 months after contracting tuberculosis of the lungs, uterus, and central nervous system.

2. At necropsy tuberculosis was found throughout the central nervous system with particular localisation to the subarachnoid space around the lower spinal cord.

3. The whole of the thoracic and lumbosacral part of the spinal cord was infarcted due to tuberculous endarteritis affecting the majority of the spinal vessels in the subarachnoid space in these regions.

Case 20. B.J.

HISTORY.

This man was 30 years of age at the time of his death. His last illness began at the age of 27 when he noticed increasing unsteadiness which on one occasion led to his falling off a bus. He also complained of backache and aching in the limbs, of lassitude and progressive weakness, first of his legs and then in his arms. In particular he had noticed difficulty in getting up and down stairs and even in rising out of a chair. The grip of his hand was only moderately impaired but he found it very difficult to lift objects up above shoulder level. In addition to these neurological symptoms he complained of constipation and difficulty in emptying his bladder. After these symptoms had been present for 6 months without remission, he was referred, because of his bladder trouble, to a surgical clinic in South Wales where he was found to have retention of urine with a distended bladder palpable above the umbilicus.

EXAMINATION.

He was found to be a dull lethargic young man with a moderate pyrexia. His skin was dry and there was scaling with some hyperkeratosis of the soles of the feet. His abdomen was distended with a palpable colon and an enlarged bladder.

The neurological findings were as follows:- The right pupil was normal with normal reactions, but the left pupil was small and unreactive with ptosis and a small palpebral fissure together with limited movements of the eye in most directions. He had a left palatal palsy and laryngoscopy showed impaired movement of both vocal cords which were considered to be paralysed. The remainder of the cranial nerves were normal. Widespread muscle atrophy was present without fasciculation and involved chiefly the proximal limb girdle muscles and the small muscles of the hands. All the tendon reflexes were constantly absent and both plantar responses were extensor. The abdominal reflexes were sometimes present but occasionally could not be elicited. The jaw jerk was normal. He was grossly ataxic and joint position sense was totally absent in the toes and impaired at the ankle. There was also impairment of superficial modalities of sensation and of vibration sense as high as the knee. No sensory level could be found over the trunk and no sensory loss was present in the upper limbs.

INVESTIGATIONS.

Repeated blood cultures were negative. Blood count showed no particular abnormality apart from a mild normochromic anaemia varying between 11 and 12 grams %

haemoglobin. Urine examination showed persistent infection with a variety of organisms. Chest X-ray showed enlargement of the hilar lymph nodes but no abnormality in the lung fields. X-rays of the skull and of the skeleton were normal. Agglutination tests for viruses, leptospira, and enteric organisms were normal. Serum proteins were normal and the electrophoretic patterns on several occasions were normal. A search for L.E. cells was constantly negative. The E.S.R. was elevated and the highest recorded was 24 mms. in 1 hour. Blood sugars, blood urea, and electrolytes were always in the normal range. The blood W.R. and Kahn reactions were negative as was the treponemal immobilisation test.

The spinal fluid was examined on five separate occasions and on all examinations the pressure was normal with a normal manometric pattern. The fluid was clear except on a second admission a year later when it was slightly Xanthochromic on one occasion. The cells ranged from 0 to 52 white cells per cu. mm. and the cells were almost entirely lymphocytes. The protein ranged from 75 to 160 mgms.% and the C.S.F. sugar ranged from 31 (on two occasions) to 56 mgms./100 ml. The Lange curves were all normal and the Wassermann reaction was negative. Cultures of the C.S.F. including cultures for acid-fast bacilli and guinea pig innoculation were always negative.

A muscle biopsy showed changes considered typical of

sarcoidosis. The Kveim test was strongly positive. The muscles were examined by electromyography and this showed active denervation changes.

COURSE.

Sarcoidosis was diagnosed and several courses of A.C.T.H. and steroids were given. There was only slight initial improvement and the subsequent progress was that of general deterioration particularly in the neurological picture. The bladder control remained impaired and a suprapubic cystostomy with a permanent indwelling catheter had to be performed. He was at one time discharged home but soon had to be readmitted to a local hospital in Chepstow and there he remained as a chronic long stay patient.

MODE OF DEATH.

In an attempt to alleviate his urinary problem a reconstruction operation was performed with a bladder constructed out of a portion of ileum. The intention was to try to transplant both the ureters into the intestine but he died suddenly before this could be performed. His neurological illness had been present without remission for 3 years.

GENERAL NECROPSY FINDINGS.

The general necropsy findings included a peritonitis

due to the operations on the bladder and intestines. The lungs showed congestion, collapse and obstructive bronchitis. The histological sections of the lungs showed small tubercles of sarcoidosis and these included epithelioid cells, giant cells and a large number of lymphocytes. The remaining viscera were normal, apart from a few small lymphocytic foci in the liver.

Nervous System.

Brain.

External appearance.

Coronal slices.

Externally the brain gave the impression of mild cerebral atrophy. Coronal slices showed moderate ventricular dilatation and some evidence of exudate in the subarachnoid space.

Histological examination.

Histological sections showed a sub-arachnoid exudate as a localised collection in many places around the cerebrum but particularly involving the region around the insula (fig 122). The exudate consisted of a filling of the space with protein fluid, connective tissue proliferation, and a cellular infiltration partly of lymphocytes but with interspersed large macrophages. Scattered around the cerebrum, usually in the pia-arachnoid but sometimes attached to the outer arachnoid layer was small granulomatous sarcoid

nodules. About 70 to 80 of these were seen in a celloidin hemisphere section, the greatest concentration being in the insula. The majority of these sarcoid tubercles were in and around the subarachnoid space but several were in the cerebral cortex, particularly the cortex of the insula and these intracerebral lesions were always within perivascular spaces. A few lesions were seen in the hypothalamus and hypocampus and these were also superficially placed. All these sarcoid granulomata measured up to 1 mm. in diameter. They usually had a central multinucleated giant cell surrounded by epithelioid-like cells with many accompanying lymphocytes and a good deal of connective tissue in each sarcoid nodule. The only necrosis seen was that within the multinucleated giant cell.

SPINAL CORD.

Meninges.

The dura mater was normal. The leptomeninges showed opacity with a suspicion of subarachnoid exudate.

Vessels.

The major spinal arteries were normal. The spinal veins were prominent.

External appearance.

The spinal cord was mildly atrophied and there was some general discolouration. The main abnormality seen externally

was that the spinal roots were thickened and often adherent to the meninges.

Transverse cuts.

On transverse slicing through the spinal cord the boundary between the grey and white matter was indistinct. Sometimes a small grey-white area could be seen in the grey commissure.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD. (figs 123-127).

Paraffin blocks were available from C7, T3, T10, and L2 segments. Sections were cut and stained from these four levels.

C7, T3, T10, L2. There was gross pathology evident at all these segmental levels (figs 123, 124) with Wallerian degeneration in the posterior columns and added pyramidal tract degeneration seen in the lumbar region. There was a similar exudate to that seen in the brain but the sarcoid nodules were larger and they tended to extend into the cord alongside blood vessels both along the radial blood vessels in the white matter and along sulcal arteries into the grey commissure (figs 125, 126). The other distinction of the granulomata was that as well as being larger they appeared to be older and have more fibrous tissue than the cerebral granulomata.

A very marked feature was the involvement of all the

spinal nerve roots in sarcoid granulation tissue with multinucleated giant cells, inflammatory exudate, and fibrosis (figs 123, 124). The posterior nerve roots were the worst affected but the anterior roots were also severely affected. The spinal cord itself, apart from the granulomata present in the perivascular spaces, showed evidence of ischemia both in the grey and the white matter. There were many small foci of degeneration (fig 127) but frank infarction was absent.

SUMMARY OF CASE 20.

1. A 30 year old man died 3 years after the onset of a neurological syndrome characterised by marked ataxia and paresis of all four limbs, bladder and bowel.

2. Sarcoidosis had been diagnosed during life and was confirmed at necropsy which demonstrated sarcoid changes in the lungs and in the central nervous system.

3. Sarcoid granulomata were present in the brain and were situated in the sub-arachnoid space and intra-cerebrally along perivascular spaces.

4. The spinal cord was extensively involved in sarcoid granulation tissue which was present in the subarachnoid space and within the cord along perivascular spaces. The spinal nerve roots were particularly involved in the disease.

COMMENT ON CASES 18-20.

These three cases have been selected because they show spinal cord ischaemia or infarction caused by an arteritis in case 18 from syphilis, in case 19 from tuberculosis and in case 20 from sarcoidosis. The three cases show interesting contrasts. The case of meningovascular syphilis (case 18) shows an atrophic state of the spinal cord affecting grey and white matter and associated with long standing arterial lesions now evident as hyaline thickening around the major spinal arteries, the arterioles and the capillaries.

In case 19 the major spinal vessels and the small spinal branches are affected by an acute progressing arteritis due to tuberculous exudate by which these vessels are surrounded.

Case 20 shows sarcoidosis affecting the spinal cord. The disease is evident as small granulomata situated perivascularly and locally destroying the spinal cord but causing much less ischaemia than in the case of syphilis or tuberculosis.

Case 21. F.R.

HISTORY.

This man was 64 at the time of his death. He presented at the Radcliffe Infirmary in October, 1960 complaining that over the past year he had experienced pain in the lower part of his back and that this had increased in severity. This backache was at times very severe and it was constantly present when he was standing up but when he was able to lie down the pain usually disappeared. After several months of this pain he began to notice that his legs were slowly becoming weaker. At first the weakness of his legs was only noticed about once a week when they would give way under him and cause him to fall but later he became aware of slight weakness all the time. Fifteen weeks before his admission to the Radcliffe Infirmary his complaints had progressed to such an extent that he had to give up his occupation as a driver at Morris Motors. Eight to nine weeks before admission to hospital his symptoms had undergone a sudden deterioration. He had gone to bed one evening suffering from his normal severe aching back and when he got up in the morning he noticed several changes. The pain had now spread outside his back and he felt numbness of both his legs and bladder disturbance and constipation. The radiation of the pain now affected his knees and the outside of both his legs. All these symptoms brought him

first to the out-patient department and then to be admitted to the Neurosurgical ward at the Radcliffe Infirmary.

EXAMINATION.

On examination he was found to be normal mentally and in the cranial nerves, upper limbs and trunk. The lower limbs were abnormal in that power was generally decreased in all muscle groups and also slightly decreased in the buttocks. The patient was able to walk without assistance but tended to walk slowly and to drag the right foot. There was some wasting of the calves and probably of the quadriceps. The tendon reflexes were normal in the arms but the knee jerks and the ankle jerks were brisk and the plantar responses were extensor. A moderate degree of ankle clonus was present. Sensory testing showed loss of sensation to pin prick over L4, L5 and S2 areas on both sides. The S1 dermatome appeared normal. Loss of temperature sensation was noticed in a similar distribution but vibration sense was normal. Joint position sense was moderately diminished in both feet. In the general examination the blood pressure was 160/100 and the respiratory system showed some slight emphysema.

INVESTIGATIONS.

Lumbar puncture obtained clear C.S.F. under normal

pressure and without evidence of block. The fluid contained a protein of 80 mgms./100 ml. and 3 lymphocytes/ cu. mm. The X-rays of the spine showed spondylosis and some spondylo-listhesis at L5/S1. A lumbar myelogram was performed and this showed partial obstruction and distortion of the myodil column at the level of T11 to T12 and these appearances were thought to be due to some type of angiomatous malformation.

COURSE.

On 10.10.60 a laminectomy was performed from T10 to L1 and the dura was opened. The subarachnoid space was very capacious and it was possible to see abnormal spinal vessels through the arachnoid, in particular one at T11 to 12 segmental level. On opening the arachnoid it was clear that the abnormal vessels continued upwards and downwards as far as could be visualised. Nothing further was done and the dura was closed. Post-operatively there was little change in the neurological deficit and the patient was discharged home and attendance at the Physical Medicine Department arranged.

MODE OF DEATH.

He was seen at the out-patients department when there was little change and then a year later was admitted to Cowley Road Hospital with considerable deterioration and

with a pulmonary infection from which he died on 25.11.61 two years after the onset of his neurological disease.

GENERAL NECROPSY FINDINGS.

Both lungs were affected by bronchopneumonia superimposed on chronic bronchitis and emphysema. Pressure ulcers were present due to decubitus. A small benign adenoma was present in the left suprarenal gland.

Nervous system.

Brain. Weight 1,376 grams.

External appearance.)
Coronal slices.) Normal.

Brain stem.)
Cerebellum.) Normal.

SPINAL CORD (figs 128, 129).

Meninges.

The dura mater was thickened at the site of the laminectomy affecting T12, L1, L2 and L3 vertebra where three sutures united the dura longitudinally. The arachnoid mater showed slight glistening opacity with adherence to the dura mater posteriorly.

Vessels (figs 128, 129).

The anterior spinal artery was patent throughout, of normal calibre, and not obviously entering the abnormal angiomatous malformation. The large tributaries to the

anterior spinal artery were identified and these accompanied the left C5, the left T3, and the right L1 anterior spinal nerve roots. The spinal veins were examined and the major draining venous tributaries were arranged normally. They were slightly dilated but apart from this distension could be considered within normal limits. The roots of the cauda equina all had tiny vessels along the course of the root and these suggested a dilatation of normally very fine vascular channels. In addition to the normal spinal cord vessels a large coiled mass of dilated abnormal vessels (fig 129), blue in colour and distended with blood extended from T11 to L4 on the posterior aspect of the spinal cord. On inspection and some dissection it appeared to be one large long convoluted vessel and was seen to be external to and additional to the normal venous system.

Transverse cuts.

Transverse slicing across the spinal cord at various segmental levels showed that the cervical cord and the thoracic cord down to T8 were grossly normal. The T9 segment showed softness and discolouration of the grey and white matter and this abnormal appearance continued down to about L1 segment. The lower lumbar cord and the sacral cord were grossly normal.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 130-137).

Transverse sections were taken from the C7, T3, T7, T11, L1 and S4 segments.

C7, T3, and T7 (fig 130). These segments showed Wallerian degeneration corresponding to a total cord transection below.

T11, L1 and S4 (figs 131, 132). In these segments the leptomeninges showed moderate connective tissue thickening. The spinal cord itself showed varying degrees of necrosis which was most severe at T11, moderately involved the cord at L1 and showed changes at S4. In the necrotic areas neurones were destroyed and were totally absent from T11 in which the grey matter was completely destroyed. In these segments vessels of various types were observed.

1. Arteries (figs 133, 134). These appeared of normal histological structure and position. The anterior spinal artery was normally situated throughout and there were similar normal vessels in suitable positions for posterior spinal arteries.

Veins (fig 135). These were numerous, dilated and with thickened walls but situated normally on the posterior aspect of the cord and anteriorly adjacent to the anterior spinal artery. The distinction between veins and arteries was facilitated by staining for elastic (figs 134, 135).

Abnormal large vessels. The abnormal vessels in the posterior aspect of the cord, constituting the vascular malformation, had the histological appearance of thickened veins.

Capillaries (figs 136, 137). Within the spinal cord were very numerous and often abnormal capillaries frequently with thick hyaline walls.

To summarise the vessel changes, the spinal cord vessels consisted of a normal anterior and posterior arterial system, spinal veins which were normal but dilated, an abnormal (possibly anastomotic) vessel on the posterior aspect of the cord with the appearance of a thick walled vein, and abnormal capillaries within the cord and which were possibly a secondary phenomenon.

SUMMARY OF CASE 21.

1. A 62 year old man developed a neurological syndrome of spastic paraparesis, sensory disturbance, and paralysis of bladder and bowel.

2. An angiomatous malformation was diagnosed by myelography and visualised at laminectomy.

3. The neurological syndrome progressed and 2 years after its commencement he died from respiratory infection and pressure sores.

4. At necropsy the spinal vessels consisted of:-

(a) A normal spinal arterial system.

(b) A normally situated but dilated spinal venous system.

(c) A large, long convoluted vessel which appeared to be an arterio-venous communication.

(d) Large number of thick walled capillaries.

Case 22. W.S.

HISTORY.

This 85 year old man presented at the out-patients department of the Cowley Road Hospital, Oxford on 5.2.57. He gave a two years history of progressive weakness with pains and numbness. The paresis and dysaesthesiae began in the legs and slowly progressed for eighteen months after which the arms became affected.

EXAMINATION.

The heart was clinically normal and the blood pressure 145/85. In the respiratory system there were signs of chronic bronchitis and in the urinary system evidence of chronic urinary retention and benign hypertrophy of the prostate gland. In the nervous system the cranial nerves were normal. In the upper limbs there was bilateral weakness of the hands with wasting of the interossei and minimal sensory loss. In the lower limbs there was bilateral weakness of the legs accompanied by increased tone except for the right foot which was flaccid. Sensation to pin prick and cotton wool was impaired on the lateral aspect of the right leg and foot. The joint and vibration sense were absent in the ankle. The left biceps and supinator reflex were absent, but those on the right side were present as were both the triceps reflexes. The knee

and ankle reflexes were absent on both sides as were the abdominal reflexes and the plantar reflexes.

INVESTIGATIONS.

Lumbar puncture produced a clear colourless spinal fluid of 70 mms. pressure. Three lymphocytes per cu. mm. and 90 mgms. protein per 100 ml. were present. The Lange was negative and the Wassermann reaction was negative. Examination of the spinal fluid on three other occasions showed a normal cell count with moderate protein elevation. Gastric analysis showed free acid present and a vitamin B12 assay in the serum showed 220 micro micrograms per ml. (within normal limits).

COURSE.

During the next few months there was no improvement in the neurological state. He required extensive nursing care first at the nursing home and then by admission to Cowley Road Hospital on 30.7.57. He developed a urinary infection which responded to antibiotics and anaemia which was treated by blood transfusion. A few days before his death he developed bronchopneumonia from which he died on 15.11.57. The total duration of his illness was 2 years 9 months.

GENERAL NECROPSY FINDINGS.

The cause of death was acute bilateral bronchopneumonia. Both kidneys showed pyonephrosis associated with cystitis and urinary retention due to hypertrophy of the prostate gland. The other organs were not remarkable.

Nervous system.

Brain.

External appearance.

The leptomeninges and the vessels were normal for age. The brain appeared rather small with moderate convolutional atrophy.

Coronal slices.

These showed mild symmetrical ventricular dilatation and generalised atrophy of the cortex.

Brain stem.)
Cerebellum.) Normal.

SPINAL CORD (figs 139, 140).

Meninges.

The dura appeared normal. The arachnoid mater showed an opaque granular appearance particularly affecting the lumbo-sacral cord and the cauda equina.

Vessels.

On opening the dura the most striking feature was an engorged, very tortuous, apparently unbranched vein running

over the posterior aspect of the thoracic cord extending from just above the lumbar enlargement up to about T7 segmental level. Grossly abnormal vessels, tortuous and distended, ran along many of the roots of the cauda equina (fig 140). These vessels could be classified, on close scrutiny, into three groups. Firstly, an anterior and posterior spinal artery system which was normal apart from slight dilatation. Secondly a venous system which was in situation and number of vessels but abnormal in being greatly enlarged in calibre. Thirdly, and most prominent throughout the sections was the large tortuous vein-like channel on the posterior and lateral aspect of the cord. As this vessel was cut in various planes it often gave the spurious appearance of multiple abnormal venous channels. This vein appeared to be an abnormal communication between the spinal arterial system and the spinal venous system although the actual communication was not demonstrated.

Within the substance of the spinal cord were many abnormal vessels being large in calibre and having thickened hyaline and often calcified walls. These vessels were present particularly in the grey matter and appeared to be abnormally altered capillaries or veins. In the grey matter the anterior horn cells were often seen almost intact

in the midst of these abnormal vessels. There was considerable myelin degeneration in all the white columns with a few small necrotic areas. The nerve roots showed degeneration of the anterior roots and some of the roots were accompanied by distended vessels with thickened walls.

Transverse cuts.

Transverse slicing through the spinal cord in the thoracic and lumbar region showed moderate atrophy and brown discolouration which observed the margin between grey and white matter.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 141-144).

Transverse sections were taken at C7, T3, T7, L2 and S1 segmental levels. The changes differed at the various levels examined which will be described.

C7, T3, T7. These segments showed severe Wallerian degeneration corresponding to severe cord destruction below. The spinal vessels were distended but the changes were minimal compared with those caudally.

L2, S1 (figs 141, 142). In both these segments the cord showed extensive necrosis associated with profound abnormalities of the vessels.

The anterior (fig 144) and posterior spinal arteries were normal apart from slight dilatation. The spinal veins were normal in situation and number of vessels but abnormal

in being greatly enlarged in calibre and having thick "arterialised" walls (fig 144). The most abnormal feature was a large tortuous vessel situated on the posterior aspect of the cord, and having the histological structure of an arterialised vein. This abnormal vessel appeared to be a communication between the spinal arterial and spinal venous systems.

Within the substance of the spinal cord were many abnormal small vessels with thickened, hyaline and often calcified walls (fig 143). These were particularly present in the grey matter and appeared to be altered capillaries. Necrosis was taking place both in the grey and white matter but in the grey matter anterior horn neurones were often present in the midst of the abnormal vessels. The anterior nerve roots of these L2 and S1 segments showed fibre degeneration which was also seen in the sciatic nerves.

SUMMARY OF CASE 22.

1. A 85 year old man presented with a history of progressive paresis and dysaesthesiae, beginning in the legs and then extending to the arms.

2. Death occurred from bronchopneumonia 2 years and 9 months after the onset of the neurological symptoms.

3. At necropsy the spinal cord was found to be involved by an extensive angiomatous malformation consisting

mainly of a single convoluted vein situated on the posterior aspect of the spinal cord.

4. Histological examination showed necrosis of the spinal cord affecting both grey and white matter which were occupied by many small vessels which were abnormal in having thickened hyaline and often calcified walls.

Case 23. T.J.

HISTORY.

This man was 70 years of age at the time of his death. The history of his last illness began in 1955 when he found that he was unable to pass urine properly and could in fact only pass it when he was sitting down. This difficulty continued for several years and in February, 1959 and again in October, 1959 he had an operation of transurethral resection of the prostate gland which did not give any improvement. It subsequently transpired that these urinary troubles were the start of the neurological syndrome which continued 6 months later by the commencement of pain in the lower part of his back and down both legs as far as the toes. There was also numbness and a cold feeling in the buttocks and in the perineum. These symptoms were particularly accentuated by activity, even by walking 200 yards, and they would gradually subside with rest. Within a year of the onset of his first sensory symptoms he noticed weakness of the legs beginning with the right leg and by 1958 his symptoms were such as to cause him severe disability. He was often kept awake at night by his backache and from involuntary spasms of his legs which came on abruptly and gradually died away followed by increased pain in his back, and often by an urgent desire to pass urine.

EXAMINATION.

On examination at his first presentation at a neurological centre in South Wales in 1960, the only abnormal findings were in his nervous system. He walked slowly with his stick and had a slow spastic gait on a slightly wide base. There was gross atrophy of both lower limbs involving the buttocks, thighs and all the muscles below the knees. The degree of wasting was rather more advanced on the left than on the right and all the muscles showed fasciculation. The upper limbs reflexes were normal. The upper abdominal reflexes were present and equal, the lower abdominal reflexes and the cremasteric reflexes were absent. The right knee, adductor, hamstring, and ankle jerks were all recorded as being just present at this time, but all very sluggish with comparison to the upper limb reflexes. All four of the tendon jerks were absent on the left side and both plantar responses were extensor. In the sensory examination, light touch, pain and temperature sensation were absent from the knees distally and over the saddle area and from the backs of the limbs involving L4 root area. Joint position sense was impaired in all toes, more severely on the left than the right but was normal at the ankles and at other joints proximally. Vibration sense was impaired as high as the iliac crests on both sides but was not absent.

INVESTIGATIONS.

A chest X-ray was normal. Cervical, dorsal and lumbo-sacral spine X-rays showed minor degenerative changes at many levels. A lumbar puncture showed a clear colourless fluid with a resting pressure of 85 mms. and a free rise to 210 mms. and a normal fall to 90 mms. The fluid contained no increase of cells, 45 mgms. of protein per 100 ml. and the Lange and the Wassermann reactions were negative. The blood Kahn and W.R. were negative. A myelogram was carried out on the 3rd February, 1960. Some streaking of the contrast medium in the lower thoracic region suggested an angioma and the screening was repeated on the 6th February, 1960 but finally it was concluded that there was no evidence of a malformation. Any other form of compressing lesion was excluded by these two examinations.

COURSE.

During the next 12 months the patient's symptoms continued and became gradually worse. The pain in his lower back, down the backs of both legs and into the perineum became continuous, bladder control worse and he was frequently incontinent of urine. His nights were disturbed by pain and burning sensation and pins and needles sensation in his feet. On 16.3.61 he was readmitted to hospital for

reinvestigation. Repeat of spinal X-rays showed no change and a lumbar puncture which was repeated showed normal findings. Re-screening of the residual myodil on this occasion showed no abnormality. In October, 1961 he was again readmitted to hospital because of increasing pain in his back and legs, almost total loss of bladder control and an extreme degree of constipation. Further progression of wasting of all the muscles of his lower limbs was noted with continuous fasciculation. The knee and ankle jerks were now all lost and the plantars completely unresponsive. The degree of sensory loss had progressed, joint position sense was present at the ankles but all other modalities, touch, pain, temperature and vibration sensation were lost in the root areas L4 and distally. Myelography was again carried out but no abnormality was found. An exploratory laminectomy carried out in Swansea on 4.12.61 did not show any compressing lesion and it was concluded that the spinal cord had suffered some type of vascular lesion.

MODE OF DEATH.

His symptoms continued following this admission and at subsequent reviews at out-patients a slow progression in his neurological state was noted. He eventually died in April, 1965 in a hospital to which he was admitted for terminal nursing care. His neurological illness had

extended over 10 years.

GENERAL NECROPSY FINDINGS.

Bed sores were present on the sacrum and both heels. Both lungs showed advanced bronchopneumonia.

Nervous system.

Brain. The brain was examined in the fresh state and was not preserved. It appeared normal on external examination and as seen in coronal slices.

SPINAL CORD.

Meninges.

The dura mater was normal apart from a healed sutured surgical incision posteriorly over the lumbo-sacral region. The leptomeninges showed thickening and opacity throughout the cord but particularly evident posteriorly and in the caudal areas. There were adhesions to the dura and to the spinal cord.

Vessels.

The leptomeningeal thickening, opacity and adhesions made observation of the vessels difficult, but it was evident that abnormal vessels were present posteriorly around the lumbosacral cord and that the anterior spinal artery seemed normal throughout.

Transverse cuts.

The spinal cord itself was normal in the cervical and

upper thoracic regions but in the lower thoracic segmental level and below and extending as far as the conus the spinal cord was softened and had on transverse slicing an abnormal yellowish brown discolouration. It was difficult to see the demarcation between the grey and white matter.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 145-148).

Transverse sections were examined at C5, T1, T10 and L2 segmental levels. The findings differed in these levels which will be separately described.

C5, T1 (fig 145). These two sections showed Wallerian degeneration seen in the posterior columns and in the spino-cerebellar tracts and these appearances were those expected above a severe cord lesion. Otherwise the grey and the white matter were normal. There were no changes here in the spinal arteries and the spinal veins were normal apart from slight dilatation seen in T1.

T10, L2 (fig 147). Similar abnormal changes were present in both these segmental levels. The spinal cord had suffered almost total necrosis which involved both the grey and the white matter and the only surviving areas were parts of the anterior horn and the adjacent white matter. Among the cord necrosis were very numerous large and small blood vessels with hyalinised walls (fig 146). There was

evidence of small amounts of bleeding with a good deal of hemosiderin deposited around the vessels. Outside the spinal cord were numerous abnormal vessels making the whole vasculature extremely complex. In detail the following observations could be made on these vessels which were made up as follows:-

1. A normal anterior spinal artery (fig 148).
2. An enlarged spinal venous system composed of hypertrophied veins with thick hyalinised walls. The anterior spinal vein appeared to have been thrombosed and recanalised (fig 148).
3. A large convoluted vessel on the posterior aspect of the spinal cord. This abnormal vessel appeared to be an arterialised vein.
4. Very large numbers of abnormal intramedullary vessels having thickened hyaline walls.

SUMMARY OF CASE 23.

1. A 70 year old man in the last 10 years of his life suffered a neurological syndrome characterised by paraparesis, sensory disturbance in his legs, and progressive difficulty with his bladder and bowel.

2. He died of bronchopneumonia and at autopsy a necrotic and atrophied state of his spinal cord in the lower thoracic and lumbar region was found.

3. The major spinal vessels were abnormal in that a large convoluted vessel on the posterior aspect of the cord appeared to be an arterialised vein.

4. Histological examination of the spinal cord showed necrosis affecting the grey and the white matter which contained many small vessels with thick hyalined walls.

Case 24. F.M.

HISTORY.

This man was 80 years of age at the time of his death. His last illness began in 1964 when he began to be unsteady in his gait. He had also noticed that both legs were weak and he had some numbness of sensation around the buttocks. His bladder was also disturbed and because he was incontinent of urine an enlarged prostate gland was treated without improving his urinary incontinence. By the time that he was seen by the Neurosurgical Department at Oxford he had been bedridden for nine months and had developed large pressure sores over the sacrum and the heels.

EXAMINATION.

His blood pressure was 140/75. The only physical signs were in the nervous system. His cranial nerves were normal and there were no abnormalities in the upper limbs. In the lower limbs there was a lower motor neurone weakness of both legs with wasting, more marked on the right than on the left. All the tendon jerks in the legs were absent apart from a right knee jerk. No plantar responses could be elicited. The sensory examination showed complete analgesia over the saddle area with some sensory impairment in both legs. There were large pressure sores over both buttocks, over the sacrum and over both heels.

INVESTIGATIONS.

He had a moderate hypochromic anaemia with a haemoglobin of 64%. The E.S.R. was 60 mm. in 1 hour. The urine contained protein, pus cells and grew on culture a mixed growth including coliform and proteus organisms.

A spinal puncture obtained a clear colourless fluid under normal pressure with a total protein of 65 mgms per 100 ml. No cells were present and the biochemical examinations were normal. A myelogram was carried out and this showed a free flow up the spinal canal to the skull and a free flow downwards to the caudal sac. No abnormality was seen.

COURSE.

The patient was discharged to High Wycombe General Hospital where there was no change in the neurological state up to the time of his death on 29.7.1966.

GENERAL NECROPSY FINDINGS.

Large pressure sores were present and changes of chronic cystitis and bilateral pyelonephritis.

Nervous system.

Brain. The brain was examined externally and cut in the fresh state. The cerebral vessels showed atheroma and on slicing the brain there was moderate atrophy with a diffuse loss of white matter and thinning of the cerebral

cortex.

SPINAL CORD.

Meninges.

The dura mater was normal. The leptomeninges showed thickening and opacity throughout the cord and particularly evident in the caudal region. Slight adhesions bound the leptomeninges to the spinal cord.

Vessels.

The spinal vessels were normal in the cervical region and in the upper half of the thoracic region. From about T7 downwards there was obvious enlargement of the spinal vessels and on close inspection it was apparent that posteriorly there was a large convoluted vessel suggestive of a vein running longitudinally down the cord as far as the cauda equina. The spinal arteries appeared normal and the spinal venous system was normal apart from considerable dilatation of all its channels.

Transverse cuts.

In the cervical and upper thoracic region transverse slicing through the cord showed Wallerian degeneration in the posterior columns evident as a greyish discolouration. In the lower thoracic region and in the lumbo-sacral enlargement transverse slicing showed a yellowish-brown discolouration which obscured the demarcation between the

grey and the white matter.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD (figs 149-155).

Transverse sections were examined at C4, T1, T5, T9, L1, and L5 segmental levels. The findings differed in these levels which will be separately described.

C4, T1 (fig 149). In these two sections there was Wallerian degeneration seen in the posterior columns and in the spino-cerebellar tracts. This degeneration was marked in degree and indicated a severe cord lesion below. The spinal vessels were normal in these two segments but the leptomeninges showed moderate acellular thickening.

T5, T9, L1, L5 (figs 150, 151, 152).

Abnormal changes were seen at all these segmental levels. They were least in T9 and greatest in L5 segments. The spinal cord had suffered necrosis which involved both the grey and the white matter (fig 153). In the lumbar segments this cord necrosis was almost complete and within the necrotic tissue were very numerous large and small blood vessels with hyalinised walls (fig 154). Some of the small vessels were encrusted with hemosiderin suggesting minor haemorrhage. Outside the spinal cord there were many abnormal vessels making the whole vasculature complex in appearance. After the different components of the spinal vessels had been separately examined it was possible to state that the vessels

were made up as follows:-

1. A normal anterior spinal artery.

2. A grossly enlarged spinal venous system with veins which were normal in position but very much enlarged and having thick hyalinised walls.

3. A large convoluted vessel on the posterior aspect of the spinal cord and sometimes cut many times because of its convolutions. This abnormal vessel appeared to be an arterialised vein (fig 155).

4. Very large numbers of abnormal intramedullary vessels of capillary size and larger and having thick hyalinised walls (fig 154).

SUMMARY OF CASE 24.

1. An 80 year old man in the last two years of his life developed a neurological syndrome characterised by paraplegia with sensory disturbances in his lower limbs and paralysis of his bladder.

2. Death occurred from pressure sores and cystitis with pyelonephritis.

3. The major spinal vessels were abnormal in that the normal spinal venous system was grossly distended with hypertrophied veins. A large convoluted vessel on the posterior aspect of the spinal cord appeared to

be an arterialised vein.

4. Histological examination of the spinal cord showed necrosis affecting the grey and the white matter both of which contained many small vessels with thick hyalinised walls.

Case 25. T.L.

HISTORY.

This man was 64 at the time of his death. He presented at the Radcliffe Infirmary in January, 1958 complaining of vague backache for about three years and weakness of the legs for the past 18 months. His paraparesis developed and in December, 1957 he became unable to walk. About this time he also lost control of bladder function and feeling of his bowel action.

EXAMINATION.

No abnormality was detected outside his nervous system. The cranial nerves and upper limbs were normal. In the lower limbs there was a profound paraplegia of flaccid type with absent tendon, abdominal and plantar reflexes. There was a sensory level at L2 on both sides below which there was impaired appreciation of pinpricks, light touch, vibration and temperature sense.

INVESTIGATIONS.

X-rays of the spine were normal. A lumbar puncture produced clear fluid with normal pressure but with 120 mgms. per 100 ml. of protein. There were no cells and the biochemistry was normal. A myelogram was performed and this showed abnormal findings suggestive of an angiomatous malformation situated in the lower thoracic region of the

spinal cord.

COURSE.

On 1.2.1958 a thoraco-lumbar laminectomy was performed by Mr. Pennybacker who removed the spinal processes and laminae of T11, T12, L1 and L2 vertebrae. On opening the dura the spinal cord was found to be obscured by a tangle of serpiginous blood vessels lying in clumps and clusters on the posterior aspect of the cord and especially numerous opposite approximately T10 and 11. Nothing further was done, the dura was closed and the operation terminated. The subsequent history was that the man was discharged back to Leicester Royal Infirmary where he survived several months dying in September, 1958. The duration of his neurological disease was approximately 3½ years.

GENERAL NECROPSY FINDINGS.

The immediate cause of death was acute bilateral bronchopneumonia. Pressure sores, cystitis and pyelonephritis were present.

Nervous system.

Brain.

External appearance.

The meninges over the vertex were opaque and moderately thickened. Cortical atrophy was apparent particularly in the frontal lobes. The vessels at the base of the brain showed

atheroma.

Coronal slices.

These confirmed the cerebral atrophy. The lateral ventricles were enlarged and the cortical ribbon appeared rather thin.

Brain stem. } Normal.
Cerebellum. }

SPINAL CORD.

Meninges.

The dura mater was normal except for the old healed surgical incision in the midline posteriorly over the lumbar region. The leptomeninges were opaque, moderately thickened, and adherent both to the dura and to the cord in the region of the surgical operation.

Vessels.

The anterior spinal artery was sometimes obscured by other vessels but it appeared normal throughout. Many large thin-walled vessels were seen and their identification was difficult. It appeared that on the anterior surface of the spinal cord there was a gross distension of the normal spinal veins from the level T9 downwards. On the posterior aspect of the spinal cord there appeared to be, in addition to the hypertrophied normal veins, a large convoluted vessel from T10 level downwards.

Transverse cuts.

In the cervical and upper thoracic regions, transverse cuts showed whiteness in the posterior columns, suggestive of Wallerian degeneration. From about T10 downwards there was yellowish discolouration and in the lumbo-sacral region the cord appeared definitely necrotic.

HISTOLOGICAL FINDINGS IN THE SPINAL CORD. (figs 156, 157, 158).

Transverse sections were examined at C8, T6, T10, L1 and S3 segmental levels. The findings differed in these levels which will be described separately.

C8, T6. The posterior columns showed profound Wallerian degeneration, which was also seen in the spino-cerebellar tracts. These appearances were those expected above a severe lesion of the lower spinal cord. The spinal arteries were normal and the spinal veins showed only slight dilatation at T6.

T10, L1, S3 (figs 156, 157). Similar abnormal changes were present in these segmental levels but the amount of change varied from a slight disturbance at T10, moderate damage at L1 and profound necrosis at S3. The necrosis affected grey and white matter and was associated with numerous large and small blood vessels with thickened hyalinised walls (fig 158). Haemosiderin deposition was seen around many of the small blood vessels and indicated

intramedullary bleeding. The vessels outside the spinal cord were complex but the abnormalities could be summarised as follows:-

1. A normal anterior spinal artery.
2. An enlarged spinal venous system which was normal in its anatomical situation.
3. A large abnormal vessel, probably an arterialised vein, situated on the posterior aspect of the spinal cord.
4. Abnormal intramedullary vessels with thickened hyalinised walls.

SUMMARY OF CASE 25.

1. A 64 year old man in the last 3 years of his life developed a neurological syndrome of paraparesis, sensory disturbance in the legs, and paralysis of bladder and bowel.

2. A laminectomy operation showed a serpiginous tangle of abnormal blood vessels posteriorly and extending from the lower thoracic region to the conus medullaris.

3. Death occurred from bronchopneumonia, decubitus ulcers and urinary infection 3 years after the onset of the neurological disease.

4. At necropsy the major spinal vessels were abnormal in

. that there was a large convoluted vessel on the posterior aspect of the cord from T9 downwards.

5. Histological examination of the spinal cord showed extensive necrosis affecting the grey and white matter with many intramedullary vessels with thick hyalinised walls. The abnormal posterior vessel appeared to be an arterialised vein.

COMMENT ON CASES 21-25.

These five cases are examples of an angiomatous malformation affecting the spinal veins. The clinical history in all the cases was similar with the slow progression of a neurological syndrome beginning with sensory changes and paresis of the lower limbs and ascending to involve the trunk and arms. The neurological syndrome progressed for several years and death eventually occurred from its complications of pressure sores, urinary tract infection and respiratory infection. In some cases the angiomatous malformation had been diagnosed by myelography and confirmed by a laminectomy operation. At necropsy the spinal vessels were seen to be very abnormal in a distribution which was characteristic of the condition in that it was the caudal part of the spinal cord and its posterior aspect that showed the most vascular abnormality. On detailed examination of the vessels, all the cases showed a normal anterior spinal arterial system, a spinal venous system which was normal in position but abnormal in being very much enlarged, and a mass of abnormal venous channels which when examined critically appeared to be single convoluted vessels usually on the posterior aspect of the cord and with the histological structure of an arterialised vein.

All these findings pointed to the mechanism of this

angiomatous malformation being an abnormal communication between the spinal arterial and the spinal venous system so that the latter was distended and hypertrophied and the intramedullary vessels were altered by having thick hyalinised walls. The consequences of this abnormality on the spinal cord was that of necrosis affecting both grey and white matter with slow progression as indicated by the clinical course of the disease.

CHAPTER VII

DISCUSSION (ANATOMY)

The anatomical aspects of the spinal cord blood supply will be discussed under the same subheadings used in chapter V.

Origin of the spinal vessels.

In considering the major arteries from which theblood supply to the spinal cord is derived, the distinction must be made between the subclavian-vertebral arterial supply to the cephalic part of the cord and the aortic supply to the more caudal part of the cord. The evidence derived from anatomical observations indicated that the place of change from the subclavian-vertebral arterial supply to that of the aorta is situated at some variable point between the first and the third thoracic segments of the spinal cord. The findings on anatomical dissection suggested this because the superior intercostal artery, derived from the costo-cervical trunk, gave rise to tributary arteries which supplied the spinal cord in the region of the first thoracic segment. At some point caudal to the first thoracic segment supply was derived more directly from the aorta.

Some information on this point is given by the injection experiments of Bolton (1939) and in particular those experiment

in which she injected the vertebral arteries. Vertebral artery injection was performed in four cases and in these the dye filled the spinal cord arteries down to a variable point between the first and fourth thoracic segments. The posterior spinal arteries were also injected but the dye passed much less readily downwards and rarely reached, in the posterior spinal arteries, a level below the fifth and sixth cervical segments. In one of Bolton's injection experiments into the vertebral arteries, she tied the vertebral artery inside the skull and, in this case, only the anterior spinal artery was filled by the injection material and none of the dye entered the posterior spinal arteries. In my own injection experiments, some observations suggested that undue weight should not be placed on the distribution of the injected material. For example, with a slow injection into any major source of the anterior spinal artery supply it was possible, by prolonging the injection for several minutes, to inject almost the whole of the anterior spinal artery and often considerable portions of the posterior spinal arteries. As seen in some of the case reports of chapter VI, on the basis of pathological observations in human cases of disease, there is good evidence in support of an important division between the cephalic blood supply to the cord down to approximately the second thoracic segment and the supply to

the spinal cord caudal to this point. Cases 5, 6 and 7 were illustrative of this point. In Case 5, where obstruction of the 2nd, 3rd, 4th and 5th intercostal arteries was demonstrated, the spinal cord was completely infarcted below the T3 segmental level. In cases 6 and 7, in which vertebral artery obstruction was demonstrated, the effects of spinal-cord ischaemia were not observed below the T1 segmental level.

Examination of the major vessels in the cadaver showed minor variations in the arteries concerned. The vertebral artery on one side was sometimes much smaller than normal and it appeared that in these cases the bulk of the supply came from the other vertebral artery. In a similar manner the number and position of the intercostal and lumbar spinal arteries was variable. The four pairs of spinal lumbar arteries were variable in their position in the relation to the two renal arteries. It seems very unlikely that these variations should jeopardise the spinal cord blood supply but they may be important in determining which of these spinal arteries provides the source for important radicular tributary arteries.

Radicular tributary arteries (figs 6 - 16).

The radicular tributaries to the anterior and posterior spinal arteries were confirmed in their importance in the

spinal cord vasculature. The following table summarises the observations of the many authors who have commented on these tributaries to the anterior and posterior spinal arteries.

Anterior and posterior radicular tributaries to the anterior and posterior spinal arteries.

		Anterior tributaries			Posterior tributaries		
Author	Date	Min.	Max.	Mean.	Min.	Max.	Mean.
Haller	1762	2	60	31			
Adamkiewicz	1882	3	10	7		60	
Kadyi	1889	2	17	7.4	11	23	15
Suh-Alexander	1939	6	8	7	5	8	
Corbin	1961	4	14	6.8	18	22	20
Mannen	1963	3	10	5.8			
Romanes	1964	2	10	5.0			
Jellinger	1966	2	13	5.6	8	28	16
Present study	1967	3	9	5.6			20

The earliest recorded observations are those of Haller (1762) and these are at variance with all subsequent reports. Adamkiewicz (1882) found a minimum of three radicular tributaries and a maximum of ten and Kadyi (1889) found a

variation from two to seventeen. The largest number of observations are those of Mannen (1963) and Jellinger (1966). Mannen found a minimum of three radicular tributaries and a maximum of ten and Jellinger found a minimum of two and a maximum of thirteen radicular tributaries. These findings agree with the present investigation in which a minimum of three and a maximum of nine major tributaries to the anterior spinal artery were found. Some of the difficulty in interpreting the literature on this subject is due to the definition of a major tributary. In the present work the example of Suh and Alexander (1939) was followed, who correlated their observations with measurements of the diameters of their vessels. In my own studies the size of an anterior tributary, that was considered important, always exceeded 150 microns in diameter.

The largest anterior radicular tributary (fig 8, 10, 13) is also called the artery of Adamkiewicz, and the position of this vessel varies in the published accounts from the fifth thoracic segment down to the fifth lumbar segment. There are so many observations in the literature on this subject on the position of this major tributary that for brevity these observations have been tabulated.

Position of largest anterior radicular tributary

Author	Date	Range	Commonest position
Adamkiewicz	1882	T8 - L3	T9 - T11
Kadyi	1889	T9 - L4	T10, L1, L2
Suh-Alexander	1939	T8 - L4	L2
Corbin	1961	T8 - L2	T10
Mannen	1963	T6 - L3	T9
Romanes	1964	T6 - L3	T10
Jellinger	1966	T7 - L4	T9 - 12 (66%)
Present study	1967	T7 - L3	T10

From this table it may be seen that whilst there is a wide scatter of the position of this artery, certain positions have been very commonly quoted. My finding of this vessel most frequently on T10 root (left side in 75%) agrees with the reports of Corbin and Romanes and is within the experience of Adamkiewicz, Kadyi and Jellinger. Mannen found this artery on T9 and Suh and Alexander, in the most widely divergent report, found it most often on L2. Most authors comment on the artery being commoner on the left and Jellinger (1966) in reviewing 761 examined spinal cords in the literature found this to be so in 73% of the specimens examined.

The radicular tributaries to the posterior spinal arteries (fig 7, 12, 15) are much more difficult to enumerate because of their smaller and more variable size. Many of the numbers given in the literature differ markedly and some authors have made no observations on this subject. The figures given by Corbin (1961) were of a minimum of 18 and a maximum of 22 radicular tributaries to the posterior spinal arteries and those of Jellinger (1966) were of a minimum of 8 and a maximum of 28 radicular tributaries to the posterior spinal arteries.

In my own specimens, if vessels of over 100 microns in diameter were considered significant tributaries, there were about 20 posterior radicular tributaries and these were distributed about 5 to the cervical region, 10 to the thoracic region and the remaining number, about 5, to the lumbar and sacral regions. It seemed clear that none of the posterior spinal artery tributaries were so large that their interruption would be likely to cause damage to the spinal cord.

It was not considered justifiable to select the largest posterior tributary since there were usually several large examples of almost equal size in one spinal cord. These large posterior tributaries were found between T11 and L3 segmental levels.

Anterior Spinal Artery (figs 7, 10, 11, 13, 14)

This present study confirmed this artery as the most important structure in the whole vascular supply of the spinal cord. It was always continuously present on the anterior aspect of the spinal cord and ran longitudinally from the first cervical segment to the cauda equina. This unbroken longitudinal extent of the anterior spinal artery was nevertheless compatible with its consideration as an arterial chain formed by the union of shorter arterial lengths, the size of these shorter lengths being determined by the position of radicular tributaries.

In all the specimens, the artery began by the union of the anterior spinal branches of each vertebral artery given off in the cranial cavity. The point of union of these two spinal branches, which usually occurred at or above the foramen magnum, was in 10% delayed as far as the lower cervical region (fig 10). This observation has frequently been made in the literature on the subject. Perese and Fracasso (1959) found that in 13 out of 28 spinal cords the anterior spinal artery was double in the cervical region and Corbin (1961) found in 42 cases that there was a late union of the anterior spinal artery in five cases. In the present series there was no case in which the anterior spinal artery was double throughout most of its length,

although this abnormality has been reported. Corbin described in three out of his 42 specimens how the anterior spinal artery was actually interrupted; in two specimens this occurred in the cervical region and in one specimen in the thoracic region. This was not observed in the present series except that in some of the specimens there was a plexiform arrangement of the anterior spinal artery in which some parts of the artery were duplicated and through such a region of complexity it was sometimes difficult to trace a channel that might be called the anterior spinal artery. The course of the anterior spinal artery was always approximately longitudinal in or near the anterior median fissure but there were slight deviations from the midline determined by the entry of the radicular tributaries (fig 13). This point has not been emphasised in other reports but it appears constantly in published illustrations of the anterior spinal artery. The deviation from the midline is usually very small but in certain operations such as that of antero-lateral cordotomy this variation is of importance.

The calibre of the anterior spinal artery varied considerably but was always widest in the lumbo-sacral region (fig 13) and smallest in the thoracic region (fig 14) with intermediate figures in the cervical region. This relative

variation in size is similar to that found by Suh and Alexander (1939) and Jellinger (1966) but the figures given by the authors for the diameter of the vessel have been larger than my own measurements. It is likely that my own figures, based on paraffin-embedded transverse sections, will be less due to shrinkage than those obtained on thick frozen sections. These variations in size emphasised that the artery was a longitudinal anastomotic chain whose calibre of lumen was appropriate to the amount of cord substance supplied in that region. Another important point observed was the way in which the calibre of the anterior spinal artery was narrow above the entry of an important radicular tributary (fig 13). Below the entry of the tributary the calibre widened and this arrangement suggested that the major part of the entering flow from these tributaries is directed caudally.

The Posterior Spinal Arteries (figs 7, 12, 15).

These two arteries were found to have a far less regular pattern than was seen in the anterior spinal artery. In the injection experiments it was found that the easiest way of filling the posterior spinal arteries was to fill the anterior spinal arteries by an injection into a large radicular tributary and to continue the injection until the

injection material ran around the cauda equina into the posterior spinal artery (fig 12). In a similar manner it was possible to fill the upper parts of the posterior spinal arteries by an injection into an anterior spinal tributary in the lower cervical or upper thoracic region (fig 15). These observations demonstrated the anastomoses between the anterior and posterior spinal arteries and agreed with the findings of Romanes (1964). This arrangement whereby the posterior spinal arteries have a significant contribution from the anterior spinal artery explains some of the pathological observations related to clinical cases. Infarction of the posterior spinal arterial territories with preservation of the anterior spinal arterial territory is a rare event. The posterior spinal territories are usually either preserved or they are involved together with the anterior spinal territory. In the latter case and when the lower part of the anterior spinal artery is obstructed the affect on the posterior part of the spinal cord may be seen to a higher level than the infarction of the anterior part of the cord. This particular finding was in agreement with the injection studies because in the caudal part of the spinal cord it was possible by an injection into an anterior tributary to fill the posterior spinal arteries and the injecting fluid rose to a higher level than the level in the

anterior spinal arteries (fig 12).

The measurements undertaken on the calibre of the posterior spinal arteries were difficult because of their irregular course. By selecting the largest arteries found on either side in relation to the posterior roots and measuring their diameters measurements of 100 microns in the cervical region, 50 microns in the thoracic region and 75 microns in the lumbo-sacral region were obtained. These measurements are smaller than those given by Corbin (1961) and Romanes (1964) and again the smaller measurements are probably explicable by shrinkage in paraffin-embedded sections. It is interesting that the posterior-spinal arteries are largest in the cervical region (near to their origin), next largest in the lumbo-sacral region (from the anastomotic supply via the anterior spinal artery) and smallest in the thoracic region.

It must be emphasised that whilst it was possible to make these approximate measurements, in no specimens were two posterior spinal arteries seen as continuous vessels. The usual finding was a plexus of small arteries (fig 15) which occasionally united to form a single vessel in the position of the entry of the posterior roots.

The other finding of importance was that the feeding tributaries to the posterior spinal arteries were numerous

but not large (fig 7) and there was no single artery of any considerable size. These observations have already been commented upon in the discussion on the radicular tributary arteries.

The Sulcal Arteries (figs 17, 18, 19).

These arteries were named by Adamkiewicz whose nomenclature is retained in this work. Later the same arteries were called central arteries by Kadyi. The sulcal arteries are the branches of the anterior spinal artery which proceed posteriorly in the anterior median sulcus and enter the cord in the region of the grey commissure (fig 18). They are of considerable importance as through them the largest part of the arterial supply enters the spinal cord and this division of the blood supply, from the manner of its entry and branching, is called the centrifugal vascular system (fig 19).

In the present study the number of sulcal arteries in a single spinal cord was found to be approximately 200, this figure being the mean of counts on two specimens. The figures found by previous authors are as follows:- Adamkiewicz (1881, 1882), 260; Kadyi (1889), 189; Suh and Alexander (1939), 200, Lazorthes (1961), 240.

Perhaps of equal interest to the total numbers of sulcal

arteries was the variation in numbers in different regions of the spinal cord. About 70 sulcal arteries were found in the eight segments of the cervical region whilst the thoracic region having twelve segments and each segment of greater length than the cervical segments, had only 60 sulcal arteries. The lumbar region with 60 sulcal arteries to five segments was the richest supplied and the sacral region was also, in comparison to its five small segments, well supplied with sulcal arteries, having 20-25 sulcal arteries.

Added to the numbers of sulcal arteries at different segmental levels was the information obtained by diameter measurements. The largest diameter sulcal arteries were found in the cervical region and in T1 segment. With the exception of T1 segment the sulcal arteries in the thoracic region were always small in diameter. The lumbar and sacral region had measurements just below those of the cervical region.

It follows from all these observations on the sulcal arteries that the greater blood supply to the cervical and lumbar enlargements of the spinal cord is effected by changes both in number and size of the sulcal arteries. In these regions the increased requirements are met by more sulcal arteries which have a greater calibre.

Following these observations on the number and size of the sulcal arteries, their course and distribution was studied (fig 19). A sulcal artery proceeds posteriorly in the anterior median fissure to its depths where it pierces the white matter and enters the grey commissure. From this point the artery becomes a sulco-commissural artery but usually this is only a change of direction into either one or the other grey column. Adamkiewicz (1881) described the sulcal artery as dividing into two equal sulco-commissural arteries one to each grey column but this observation is incorrect. Only occasionally in the lumbar region was this arrangement found. The more usual finding was that the sulcal arteries entered alternately into the left and right grey columns.

The area of distribution of the terminal branches of the sulcal arteries (fig 19) is of some importance because this determines the area of the spinal cord which will be affected by a blockage of this centrifugal arterial system. The sulcal arteries give off their first branches to supply the white matter of the anterior white column in the region of the anterior median fissure and this territory includes the direct cortico-spinal tracts. The sulco-commissural arteries, the continuation of the sulcal arteries, have a very large area of supply including the whole of the grey

commissure, the anterior horn, the lateral horn in the thoracic region, and Clarke's column in the appropriate segments. It will be appreciated from this list that the whole of the grey matter with the exception of the posterior horns is supplied by the branches of the sulcal arteries.

The fringe of this centrifugal arterial system extends into all three white columns. Only the most anterior part of the posterior columns receive the terminal branches of the sulco-commissural arteries but the anterior and especially the lateral white columns are supplied, in the parts adjacent to grey matter, to a considerable extent. It will be noticed that the indirect cortico-spinal tracts are supplied in part by the terminations of these arteries.

The Coronal Arteries (fig 16).

The fine subpial plexus of small arteries surrounding the spinal cord is an important part of the centripetal arterial system originally described by Adamkiewicz. In the present macroscopical observations and examination of histological sections, it was clear that there were contributions to the vascular network from several sources. The major source was the anterior spinal artery but contributions also came from major radicular tributaries and from minor tributaries which hardly reached the anterior

spinal artery but still fed into this network of small vessels. These coronal arteries formed a plexus mainly around the anterior surface of the spinal cord but also spreading towards its lateral aspect. A similar but less well defined plexus was seen posteriorly and this came directly from the radicular tributaries accompanying the posterior spinal nerve roots.

The coronal arterial plexus is of less importance than the arteries earlier described and briefly its function is to supply the peripheral rim of the spinal cord. These small vessels are vulnerable to certain types of lepto-meningeal infection and toxins which may cause a peripheral rim of spinal cord degeneration.

The Radial Arteries (figs 20, 21).

By this name are called the vessels of the centripetal vascular system of Adamkiewicz which originate from the coronal vessels and proceed in a radial direction towards the centre of the spinal cord. These vessels were originally described by Ross (1880) and were studied carefully by Adamkiewicz (1881) and Kadyi (1889).

These radial arteries are of most importance in the blood supply of the posterior white columns and the posterior grey horns (fig 20). These particular supplying arteries are long penetrating vessels running in well defined

connective tissue septa. They were given by Adamkiewicz descriptive names according to their position but these cumbersome names are unnecessary in a consideration of their functions.

The radial arteries to the anterior and lateral white columns are much less important being shorter and only supplying the outermost parts of the white columns (fig 21). As has been earlier described, the white matter adjacent to the grey columns has a substantial supply from the centrifugal vascular system.

Small Intramedullary Arteries and Capillaries.

Ross (1880), Adamkiewicz (1881) and Suh and Alexander (1939) were particularly interested in the small intramedullary arteries and capillaries. The main finding in this study was the very much richer vascular network in the grey matter by comparison with the white matter.

Spinal Veins (fig 9).

The best account of the spinal venous system is that of Kadyi (1889) to which this study has added no new information. The spinal veins are most prominent on the posterior aspect of the spinal cord and take the form of an irregular network with many large anastomoses. The largest vein is usually a single large median posterior vein (fig 22) whilst on the anterior aspect there is always

an anterior spinal vein accompanying the anterior spinal artery.

The main spinal veins are drained by veins accompanying the spinal nerve root. These draining veins, which may be termed the radicular draining veins, were found to be more numerous than the corresponding arterial tributaries and more often accompanying the posterior nerve roots. In most other respects they were arranged in an analogous manner to the radicular tributary arteries.

CHAPTER VIII

DISCUSSION (PATHOLOGY)

It will be convenient to arrange the discussion of the pathological findings detailed in this thesis according to the anatomical situation of the obstruction in the vascular supply to the spinal cord. In this way the subject will be considered under the following headings:-

Aorta, vertebral arteries, intercostal arteries, radicular tributary arteries, anterior spinal artery, small spinal vessels, spinal veins.

AORTA

The first case reports described in chapter VI deal with a condition in which the cord is affected by chronic ischaemia due to a severe degenerative condition of the aorta. The clinical details of these four cases were instructive and although all the patients had a complex clinical history, this included many common features. They were elderly, with ages ranging from 65 to 82 years. The clinical history included evidence of extensive arteriosclerotic degenerative disease. Three of the patients (cases 1, 3 & 4) had severe and protracted episodes of congestive heart failure due to arteriosclerotic heart disease and in case 1 there was a history of episodic acute cardiac failure which proved at

necropsy to be due to a myocardial infarction. In only one patient (case 1) was a significant degree of hypertension present. Features that were not thought to be relevant to the neurological problem were carcinoma of the breast (present in two cases), myxoedema (one case), peptic ulcer (one case), and old herpes zoster (one case).

The clinical features of the neurological syndrome of these cases whilst having a common pattern, differed in the extent and severity of the neurological changes. The main abnormality was paresis which in two of the cases (case 1 and 4) affected all four limbs but in cases 2 and 3 was only a paraparesis. The weakness was often asymmetrical and the involvement of proximal and distal muscles varied from case to case, but in all the cases the legs were more severely affected than any other part. The trunk muscles were often involved but the cranial nerves were normal. The type of weakness varied and was sometimes difficult to ascertain; usually it had the features of a combined lesion of the upper and lower motor neurone. Hyperreflexia was present in cases 1 and 3 but in case 2 there was areflexia in the lower limbs. Wasting was present in cases 1, 2, and 4 and chiefly affected the lower limbs. The cases with hyperreflexia often had loss of superficial reflexes and a Babinski sign.

These patients were under observation for prolonged periods during their severe and debilitating illnesses and the observations made here are condensed from large numbers of neurological examinations. Frequently these findings varied in a particular case, and the tendency, as the disease progressed, was for a spastic paresis to change gradually to a flaccid paresis with wasting and areflexia. Sensory changes of any degree were rare, but in case 2 there was diminution of all types of sensation irregularly below the fifth cervical dermatome.

The duration of the illness from the onset of the paresis to death varied from 10 months to 3½ years. Exacerbation of the paresis related to exercise and improvement following rest was not recorded in the clinical notes of the cases, but it must be emphasised that many of the patients had marked exercise intolerance due to cardiac decompensation and this may have concealed a picture of intermittent paresis related to exercise and rest.

The general necropsy findings confirmed the presence of extensive arteriosclerosis with particular emphasis on atheroma of the aorta. In three cases (cases 1, 3 and 4) there was mural thrombus in the abdominal aorta (figs 38, 39), and in case 4 there was a large atherosclerotic aneurysm just above the aortic bifurcation (fig 39). Severe coronary atherosclerosis with myocardial ischaemic degeneration

was present in cases 1, 2 and 3 and an old healed infarct was found in case 1.

The macroscopical examination of the nervous system did not permit immediate recognition of this disease. In each case moderate cerebral atrophy was present, and this was associated with atheroma of the major cerebral arteries. The spinal cords in all five cases were notably atrophied to the naked eye and sometimes on transverse slicing greyness of the posterior or of the lateral columns suggested Wallerian degeneration. In some instances the anterior nerve roots could be seen to be atrophied and in these cases wasting of the muscles was also noticed at necropsy.

The microscopical appearances in the spinal cord were distinctive and it was at this stage that the diagnosis in each of these cases was made. These microscopical changes could be grouped into those found in the white matter and those seen affecting the grey matter. These changes were found in all four cases and were considered important in the recognition of this pathological entity (figs 23-37).

<u>Microscopical Findings in the Spinal Cord White Matter.</u>

1) Small Focal Areas of Necrosis (fig 32).

2) Large Spongy Areas of Diffuse Degeneration (figs 24, 27, 29, 36, 37).

3) Wallerian Degeneration of Long Tracts (figs 23, 35).

Microscopical Findings in the Spinal Cord Grey Matter.

1) Small focal areas of necrosis (fig 33).

2) Depletion of neurones with gliosis (fig 34).

3) Ischaemic "changes" in surviving neurones (fig 34).

These microscopical features were so important in the recognition of these cases that some elaboration of them is indicated.

Focal areas of necrosis. These focal areas were present in grey and white matter, but in both appeared to be of a similar nature. In transverse sections of the cord, they were seen as round, well demarcated regions of almost total necrosis. The size range was up to 1 mm. in diameter, but the majority of these lesions were much smaller than this maximum size. The lesions showed differences in cellularity and these could be interpreted as due to differences in age and development. The early lesions were cellular with many lipid phagocytes but the older lesions were acellular and inactive. The older lesions were similar to the lacunes seen in the brain except that the size range of these lesions in the spinal cord was always smaller. The lacunes of the brain are well known lesions which are thought to be in some way caused by arteriosclerosis but the manner in which they are formed is not at present known.

Large spongy areas of diffuse degeneration of the white matter.

Spongy areas of diffuse degeneration were prominent in the lateral and anterior white columns of all the patients. The posterior columns were less commonly involved. These spongy areas, in the worst affected regions, involved up to half the cross sectional area of the spinal cord. The detailed histology was that of a loose glial network from which myelin and nerve axons had disappeared. These spongy areas were similar in their histological appearance and in their distribution to the spongiform state seen in subacute combined degeneration of the spinal cord. The main difference was that the spongy state in these present cases was usually much worse than that seen even in an advanced case of subacute combined degeneration of the cord. The other difference was that there was a complete disappearance of the axons in the affective regions and this complete destruction of axons is not always the case in subacute combined degeneration of the cord. A feature common to many degenerative states of the spinal cord is an abundance of corpora amylacea. This non-specific finding, indicating a severe chronic degeneration of the spinal cord, was present in each one of these four cases, often to a remarkable extent indicating the severity of the white matter degeneration.

Wallerian degeneration of the long tracts in the white columns.

There were no unusual features in the Wallerian degeneration which affected both upward and downward tracts. In the cervical region of the cord, the posterior columns and the spino-cerebellar tracts were chiefly affected, whilst in the caudal part of the spinal cord, the cortico-spinal tracts were outlined. These myelin and nerve fibre degenerations were those expected from a degeneration situated within the spinal cord. They were most easily seen in the cephalic or caudal regions but this was only because here this Wallerian degeneration was not obscured by the direct damage to the spinal cord.

Ischaemic changes in neurones.

Depletion of neurone cell bodies from the grey matter was a constant feature in these cases. This neuronal loss was in some respects similar to motor neurone disease but in the cases under study the neuronal loss was much less regular and more asymmetrical than that seen in motor neurone disease. In many cases the spaces caused by the loss of the neurones were outlined by clusters of surviving oligodendroglial nuclei. The changes seen in the surviving neurones were pyknosis of the nuclei and shrinkage of the cell bodies. These changes, although commonly seen in several neuropathological conditions, are usually considered

to indicate an ischaemic process.

Finally the appearances in the spinal vessels requires comment. No abnormality was seen in the major arteries such as the anterior and posterior spinal arteries which were free from atheroma and not demonstrably obstructed. The main spinal veins were normal. A feature seen in some of the cases was mural thickening of the capillaries and of the small arteries in the spinal cord. This change was an increase of acellular connective tissue both in the wall of the vessel and as a condensation of loose connective tissue in the perivascular space. Part of the thickening of the vessel wall consisted of structureless hyaline material but there was no evidence of any fibrinoid degeneration. These changes in small arteries and capillaries are a feature of prolonged hypertension but among these cases the systemic blood pressure was significantly elevated only in case 1. The vessels affected by these changes were the arterioles in the connective tissue septa and the capillaries in both the grey and the white matter. These small vessel changes are common in the elderly spinal cord but so far they have not been adequately explained.

In the review of the literature in chapter three, the early references in the French Medical Journals of the late nineteenth century were given with particular mention of the

papers of Letulle (1880) of Martin (1881), and of Demange (1884). The clinical accounts of these early French Physicians are excellent but the pathological details were sometimes scanty. The case of Demange however was well documented both by a detailed account of his clinical observations and also by a careful account of the necropsy findings. This case showed severe generalised arteriosclerosis with conspicuous atheroma of the aorta. The spinal cord was affected by widespread areas of degeneration of the grey and white matter and associated with thickening of the small spinal arteries by perivascular fibrosis. Similar pathological findings were reported by Campbell (1894), Nonne (1899) and Sander (1900). These authors noted a similar type of degeneration in the spinal cord with gliosis and perivascular fibrosis. More recently similar findings have been reported by Mannen (1963) and by Jellinger and Neumayer (1962). None of these authors described in detail the pathogenesis of this chronic spinal cord disorder.

The overall pattern of these cases suggested that the degeneration of the spinal cord was attributable to an ischaemic process. The obvious cause of this was the severe arteriosclerosis present in every case with particular evidence of severe atheroma in the abdominal aorta from which the

blood supply to the caudal part of the spinal cord arises. In these necropsies the lumbar intercostal arteries and the lumbar spinal branches were dissected but this dissection failed to demonstrate any thrombosis or occlusion in the course of these vessels. Frequently the mouths of these arteries were buried in plaques of calcified and ulcerating atheroma (present in every case) and lower aortic thrombus (present in three cases). The most reasonable explanation appeared to be that the structural changes in the aorta were the cause of the spinal cord condition and that the perivascular fibrotic changes in the small spinal cord vessels are secondary to the diminution in total blood supply to the spinal cord. Systemic hypertension was not thought to be an important cause because this was present only in one case. Three patients suffered episodes of congestive heart failure and in one, there was some evidence of moderate cardiac decompensation which might have been a contributary factor.

It might be wondered why the condition described in cases 1 - 4 is so infrequently diagnosed in spite of the prevalance of arteriosclerosis. The reason for this may not be the rarity of the condition but the difficulty in separating the disorder from other effects of generalised arteriosclerosis. Arteriosclerotic heart disease and cerebral arteriosclerosis can cause a very complex combination of physical signs and

these may conceal an underlying syndrome of spinal cord ischaemia.

Cases 1 - 4 appear to be examples of chronic ischaemia causing an atrophic spinal cord syndrome. In contrast to these cases is case 5 in which an acute infarction of the spinal cord was caused by a traumatic haematoma in the aortic wall. No similar case has been found in the literature of this subject but the mechanism of the arterial obstruction is comparable to the situation that follows a spontaneous dissection of the wall of the aorta and the literature of these cases was reviewed in chapter III. Both in case 5 and in these reviewed cases of spontaneous dissection of the aorta, there is a haematoma in the wall of the aorta which causes obstruction to the paired intercostal or lumbar spinal arteries. The obstruction appears to be due to actual compression of these arteries at their point of origin.

One interesting feature of the reviewed cases is the variation in the size of the spinal-cord infarction caused by the arterial obstruction. In some cases (Kalischer, 1914; Lange-Kosack and Kühn, 1962, case 1), there was very little tissue destruction whilst in others there was a partial necrosis of the affected segments affecting either grey matter (Reitter, 1916; Thompson, 1956; Kepes 1965) or white matter (Scott and Sancetta, 1944). Many cases had complete necrosis affecting the whole cross-sectional area

of the spinal cord (Schwarz, Shorey and Anderson, 1950; Ballantine, 1952; Hill and Vaquez, 1962). These vagaries of infarction appear to be dependent on the exact position and extent of the arterial obstruction. In case 6 it was found that the second, third, fourth, and fifth intercostal arteries were obstructed on both sides. The region of infarction in the spinal cord is interesting both in its longitudinal extent and in the cross-sectional area involved. The segmental levels of the spinal cord, which were totally infarcted, were from the second thoracic level down to and involving the seventh thoracic cord segment. This extensive region of infarction is interesting and suggested that a major tributary to the spinal cord accompanying an anterior spinal root in the upper thoracic region was involved. The cervical region of the spinal cord is supplied by the vertebral artery system and this region, apart from a small area of infarction at C7 (figs 40, 41) and minor ischaemic changes at C8, was intact. The region of gross infarction, from T2 to T8 segmental levels, agrees with the supply of a major upper thoracic tributary whose territory extended to that of a lower thoracic tributary at about T7 or T8.

The cross-sectional area of the spinal cord was also interesting. Proceeding caudally down the cord the first evidence of infarction was a well demarcated round area

situated in the middle of the posterior columns at the seventh cervical level (figs 40, 41). This central area of necrosis is common to several infarcting conditions of the spinal cord and also to disorders which do not have a primary vascular basis. It probably represents a vulnerable area due to vascular insufficiency of this region. From an examination of several cases of this type, of his own and in the literature, Zulch (1954) considered this zone, being a border zone between the territory of supply of the anterior and posterior spinal arteries, was vulnerable to a variety of pathological processes. In case 6 the area of infarction expanded to involve at T2 the whole diameter of the spinal cord and this amount of destruction was present down to T7. This is the pattern expected of a lesion situated in the aorta which would deprive the spinal cord totally of its arterial supply by obliterating the radicular tributary arteries leading both to the anterior and the posterior spinal arteries.

VERTEBRAL ARTERIES.

The vertebral arteries, the branches of which supply the upper part of the arterial system of the spinal cord, ascend in the vertebral foramina of the transverse processes of the upper six cervical vertebrae. In this part of their course they are vulnerable to chronic processes such as

atheromatous plaques and the spurs of degenerative disease of the spine. The main hazard to acute bilateral obstruction of these arteries is trauma and this seems to be the only mechanism in which both vertebral arteries may be suddenly obstructed with serious consequences. This was the pathological mechanism in cases 6 and 7 and these two cases may be compared with a similar case reported by Schneider, Thompson and Bebin (1958). This article reports twelve cases of cervical spinal injury causing a central lesion of the cervical cord, but in only one case (case 6) were the findings demonstrated at necropsy. This was a man of 72 who fell from a wagon striking his head and sustaining a paralysis of all four limbs together with loss of sensation below the neck. At necropsy a central region of infarction affected C4 and C5 spinal cord segment. There is no account of an examination of the vertebral arteries or of the spine. Fractures of C2 and C3 spinous processes were demonstrated radiologically during life but there appears to have been no malalignment of the spinal canal. This case of Schneider, Thompson and Bebin appears very similar to cases 6 and 7 in this thesis.

These cases have clinical importance in that they provide an explanation of neurological damage caused by

injuries to the cervical spine when radiological examination during life has shown no fracture of bone or displacement of the spinal canal at the time of the radiological examination. Cases 6 and 7 had clinical features which were in their essentials similar. Following an accident both patients developed, in the course of several hours, a lesion of the lower cervical part of the spinal cord. In both cases X-rays of the cervical spine showed no fracture or displacement involving the spinal canal. In case 7 a laminectomy was performed and the spinal canal, when seen at operation, appeared normal. The clinical course of these two cases differed in that case 6 died on the fourth day of his accident whilst in case 7 four months elapsed before his death from intercurrent infection.

The pathological finding at necropsy which was common to both the cases was a tear of the C5-6 intervertebral disc (fig 42, 48, 49) with abnormal angulation of the spine and kinking of both vertebral arteries. It could be demonstrated by fluid injection in both cases that the vertebral arteries were blocked when slight extension was applied to the spine. From these experiments on the necropsy specimen of the spine it appeared that whilst the head was maintained erect the vertebral arteries were not malaligned but on extension (drawing the head backwards) there would

be a diminution of flow in the vertebral arteries. It is also likely that to this effect of partial stenosis would be added a diminution of flow due to spasm of the vertebral arteries. The appearances in the spinal cord of cases 6 and 7 were similar in showing evidence of infarction but differed in that in case 6 this was of recent formation (figs 46, 47) whereas in case 7 organising changes had taken place. In case 6 histological changes of ischaemia could be seen from C1 down to the upper half of C4. These changes were moderate congestion, capillary proliferation, and depletion and ischaemic changes in the neurones of the grey matter. From the lower part of C4 to the lower part of C6 spinal cord segments, gross infarction had occurred and this was in the shape of a cone. The upper limit of the cone was first seen as a round area of necrosis in the posterior columns immediately posterior to the grey commissure (fig 46). As one proceeded caudally this infarcted area enlarged and at C5 and C6 segmental levels this area involved most of the central part of the posterior columns and the whole of the grey matter (fig 47). This area of infarction is similar to that seen in the aortic trauma case (case 5) and has a similar explanation. The bilateral obstruction of the vertebral arteries had caused a total obstruction of the tributary vessels feeding

into the anterior and posterior spinal arteries of the cervical cord. The effect of the vertebral artery obstruction on the upper cervical cord and on the brain was investigated in this case and part of this examination included a careful examination of the circle of Willis. The circle of Willis (in case 6) was atypical in that both posterior communicating arteries were large and the blood flow to both the posterior cerebral arteries came mainly from the internal carotid arteries. This anatomical arrangement would explain why in case 6 there was no cerebral infarction and why the upper cervical region of the cord showed ischaemic changes which were less than complete infarction.

The findings in case 7 were similar in their essential features of obstruction of both vertebral arteries and infarction from C3 to T1. The differences were that, due to a survival period of four months, the histological changes in the cervical cord were those of absent neurones and gliosis replacing the areas damaged by ischaemia. The other abnormality was that, in contrast to case 6, the circle of Willis was normally formed and there was evidence in the brain of ischaemia at the extreme part of the boundary territory between the middle and posterior cerebral arteries on both sides.

In summary, it is clear from these cases, that obstruction to the vertebral arteries will infarct the spinal cord to a degree that depends on the location of the obstruction and the integrity of the circle of Willis. These cases described here are unusual in that it was possible to demonstrate a pure obstructive lesion of the vertebral arteries. It may well be that in the more common fracture dislocations of the cervical spine a considerable element of vertebral artery stenosis or occlusion is concealed by the other effects caused directly on the spine and spinal cord by the trauma.

INTERCOSTAL AND LUMBAR SPINAL ARTERIES.

A search of the literature did not discover any case reports in which an ischaemic effect on the spinal cord had been caused by a primary disease affecting the paired intercostal or lumbar spinal arteries. There are however some reported cases in which surgical procedures have caused spinal cord infarction by damage or obstruction to these spinal arteries. In the review of these case reports in chapter III thirteen recorded cases are mentioned but of these the majority are clinical accounts without any verification at necropsy of the situation and extent of the spinal cord damage. Only in the case of Mosberg, Voris, and Duffy

(1954) and the case of Nathan (1956) were pathological observations at necropsy recorded. For this reason case 8 described in this thesis is of particular interest as the clinical details, including a careful account of the operative and anaesthetic procedure, indicated the probable site of vascular obstruction. The extent of the infarction in the spinal cord was examined at necropsy.

The site of the obstruction in case 8 is known because the causative operation of thoraco-lumbar sympathectomy involved the resection of the right ninth rib. It is possible that other arteries could have been disturbed in the operation but the likeliest explanation is that the right ninth intercostal artery had to be ligated when the rib was resected and the thoracotomy performed. The causative relationship between this operation of thoracotomy and thoraco-lumbar sympathectomy and the development of motor and sensory paralysis was clearly evident since the neurological deficit was present on recovery from the general anaesthesia. The details of the clinical course of this case are extremely interesting. The onset of the neurological disability was sudden and the extent of the initial spinal cord disturbance was that of a profound paresis and sensory loss below the T9 segmental level. In addition there was paralysis of the bladder and rectum. It is interesting that

from this maximal neurological deficit gradual improvement occurred and eventually reached the state four months later of being able to walk a few yards with the aid of a stick and a right leg caliper. Spasticity of the legs remained and the perception of pain, temperature and vibration were not recovered. Some perception of touch and joint movement (posterior column fibres) returned. The other feature of clinical interest was that a lumbar puncture obtained a completely normal specimen of cerebrospinal fluid. The pathological findings at the necropsy ten years later confirmed that a major tributary to the anterior spinal artery in the lower thoracic region was missing. The anterior spinal artery was joined by large radicular arteries accompanying the left C3, right C8, left T1 and left L2 anterior nerve roots. The left L2 branch was large (fig 55) but above this there was no major tributary until that accompanying the left T1 anterior nerve root. The extent of the spinal cord infarction was demonstrated by a large number of transverse sections including one from each segmental level. The region of infarction (figs 53, 54) began at T6 and ended at T12 with minimal changes in T5 and L1. Above and below these levels there was Wallerian degeneration in the posterior columns and lateral columns respectively.

The cross-sectional area of the spinal cord affected by

the infarction (fig 54) was symmetrical and very similar in all the segments involved. The anterior two-thirds of the spinal cord was affected with a demarcation line at about the posterior grey commissure (fig 57). Anterior to this line all the grey and white matter of the spinal cord was destroyed whilst posterior to this line considerable preservation of neural tissue was seen. In effect this meant that the posterior columns and some of the posterior part of the lateral white column were preserved together with most of the posterior grey horns. The time that had elapsed since the neurological damage (10 years) meant that the histological stage of the degeneration was that of a contracted glial scar (fig 59). Because the anterior horn neurones were completely destroyed the anterior nerve roots in the affected segments were completely atrophied and devoid of both fibres and myelin. In contrast the posterior roots, connected to posterior root ganglia which were not affected by the disease process, were normal. Another interesting feature of this case was that the distribution of damage to the spinal cord is remarkably similar to that of a case of anterior spinal artery thrombosis. It would appear that the obstruction of a major radicular tributary leading into the anterior spinal artery produces a clinical syndrome and pathological sequel identical to an obstruction of the anterior spinal artery. The anterior and posterior

spinal arteries were examined carefully in all the sections of every segmental level but no evidence of any disease or obstruction was found.

RADICULAR TRIBUTARIES.

The next place of vascular obstruction to be considered is the intervertebral foramen. Through the intervertebral foramina and accompanying the spinal nerve roots pass the radicular tributary vessels that feed into and drain the anterior and posterior spinal arteries and veins. Case 9 and cases 10-14 are examples of obstruction of this part of the spinal cord blood supply. In case 9 the obstruction was acute whereas in cases 10-14 the obstruction was of a more gradual nature.

In case 9, a case of herpes zoster with infarction of the spinal cord, we have an example of the common association of herpes zoster with neurological disease. Some of these cases are secondary herpes zoster affecting spinal roots which are themselves already disturbed by some neurological disease. Other cases are instances of a spread of the inflammatory reaction, normally in the posterior root ganglion, along the posterior root and into the spinal cord. But in case 9 we have an association between herpes zoster and ischaemic changes in the spinal cord, an association not previously reported in the literature of this subject.

In this case, an elderly woman developed a typical herpes zoster erruption around her right shoulder and this was followed a few days later by a spinal cord syndrome centred in the lower cervical cord. At necropsy an acute infarct was seen affecting C7, C8 and T1 spinal cord segments (figs 60, 61). The infarction was at the stage of pronounced vascular proliferation, distention of intramedullary vessels and depletion of neurones with ischaemic changes in the neurone cell bodies remaining. None of the intramedullary vessels showed any sign of obstruction nor was any obstructive lesion seen in the anterior and posterior spinal arteries.

It is interesting that in herpes zoster there is a tendency to thrombosis and the nature of the local lesion in the posterior root ganglion is an infarct with arterial thrombosis. Evidence of this tendency to thrombosis was seen in this case in which there was a recent cardiac infarct and recent infarction in the territory of the most caudal part of the anterior cerebral artery on the right side.

Cases 10 to 14 are cases of malignant paraplegia in which the predominate cause of the neurological damage was a state of infarction of the spinal cord. These five cases have been selected from a much larger study of malignant paraplegia which as a group is divisible, in respect to the neurological damage, into several types. The most common

type is that of vertebral tumour infiltration with collapse and angulation of the spine which causes compression of the spinal cord. Further cases are explained by tumour in the spinal canal either extradurally (the commonest situation) or intradurally. Very rarely a metastases inside the spinal cord is the cause of the malignant paraplegia. With this knowledge of the common findings in a series of cases of malignant disease affecting the spinal cord we must now consider these selected five cases which had a distinctive clinical and pathological syndrome.

The clinical course of this complication was the gradual development of a spinal cord syndrome in a patient with malignant disease involving the spinal column. The type of tumour varied in the cases with a reticulosarcoma in cases 10 and 12, a fibrosarcoma in case 13 and carcinoma of the bronchus and breast respectively in cases 11 and 14. It is interesting that in three of the cases (10, 12, 13) rather rare tumours were involved. It may be that these tumours more readily infiltrate in the manner that produces this particular syndrome. The clinical course was that of the gradual development of motor paralysis and sensory impairment of the lower limbs and trunk which was not apparently due to any bony collapse or even any obstruction in the spinal canal. Sometimes the myelogram was completely

normal and in other occasions a laminectomy operation had demonstrated that the spinal cord was in no way compressed. The cerebrospinal fluid often showed no manometric block. The neurological syndrome then proceeded to a profound disturbance of many consecutive spinal cord segments and finally the paralysis became complete with flaccidity and areflexia. The sensory disturbance was also profound with a complete sensory paralysis often below a sensory dermatome level.

The necropsy findings in these six cases were similar in that extensive infiltration of the whole of the spine and particularly the paravertebral tissues had occurred. The spinal canal itself however was conspicuously free from tumour and there was usually either no collapse with angulation or only slight changes which did not cause any pressure on the spinal cord. Case 14 was an exception in which moderate angulation had caused pressure on the anterior spinal vessels. Histological examination of these cases showed little or no tumour within the dura and tumour in the extradural space had not caused compression of the spinal cord. The state of the spinal cord was that of infarction affecting many consecutive segments (figs 62-82). This infarction was often of the whole cross-sectional area of the spinal cord and involved both grey and white matter which were often completely

destroyed and replaced by lipid phagocytes. This pathological state explained the profound flaccid paralysis and complete sensory disturbance found in these cases. An examination of the vascular supply of the spinal cord in these cases showed that there was no obstruction proximally in the aorta or in the intercostal and lumbar vessels. There was no obstruction in the intramedullary vessels or in the anterior or posterior spinal arteries with the exception of the finding in case 14.

Decalcified sections taken to show the intervertebral foramina showed tumour completely surrounding the spinal nerve roots and enveloping all the tributary vessels which accompanied these spinal roots (fig 79). The explanation of the infarction in these cases appeared to be a total obliteration of all the tributary vessels to the anterior and posterior spinal arteries. It is possible that spinal veins were also occluded but the appearance was usually that of an arterial infarct with necrosis without the extreme haemorrhagic state associated with venous infarction.

ANTERIOR SPINAL ARTERY OBSTRUCTION.

The infarction of the spinal cord by obstruction of the anterior spinal artery is the type of spinal cord infarction which is most frequently recognised in clinical practice and has had the most attention in the literature of the

subject. This literature, which begins with the report of Bastian (1886), is now very large. Many of the reports however are of clinical observations without confirmation of the pathology at necropsy. When we review the cases with necropsy, these appear to be surprisingly few; in fact about nine published cases with necropsy are usually quoted.

An early report was that in 1905 by Stanilowski (quoted by Zeitlin and Lichtenstein, 1936) and there have been further single case reports with necropsies by Spiller (1909), Schott (1915), Grinker and Guy (1927), Zeitlin and Lichtenstein (1936) and Hughes and Brownell (1964). Margulis (1930) described three cases with necropsy.

It is interesting to consider the primary disease initiating the thrombosis in these nine cases. Syphilis was thought to be the aetiological factor in the cases of Stanilowski, Spiller, and the three cases of Margulis. In the cases of Zeitlin and Lichtenstein there was severe atheroma of the anterior spinal artery and its branches, a most unusual finding in the literature. In the remaining three cases some form of trauma was suggested by the authors. In the case of Grinker and Guy the thrombosis of the anterior spinal artery was thought to have followed subluxation of the cervical vertebrae because the neurological syndrome had developed a few hours after yawning and vigorous upward

stretching of the arms. Similar minor trauma was postulated as a cause in the cases of Schott (1915) and of Hughes and Brownell (1964) and this last case has been described here (case 16).

In the three cases of anterior spinal artery thrombosis described in this thesis (cases 15, 16 and 17) no definite primary disease could be incriminated. All the subjects were elderly (65, 70, 75 years) but gave no history of chronic ill health. There was mild hypertension in case 16 and case 17 and in case 17 moderate cardiac hypertrophy, not detectable clinically, was observed at necropsy. Apart from these findings there was no evidence of generalised arterial disease. The only aetiological factor demonstrated was that in case 16 the site of the thrombosis in the anterior spinal artery was adjacent to spondylotic protrusions extending into the spinal canal.

The clinical syndrome of these three cases was in its essentials similar. All three cases developed suddenly a neurological syndrome beginning with pain and paraesthesiae and rapidly developing weakness accompanied by anaesthesia. In case 17 this neurological syndrome affected the trunk and legs, but in cases 15 and 16 all four limbs and trunk were involved. The paresis progressed to an areflexic flaccid paralysis appropriate to the involved segments of the spinal

cord. The paralysis was accompanied by profound sensory loss often with an upper sensory level. Death occurred 4 weeks (case 15), 24 hours (case 16), and 6 weeks (case 17) after the onset of the neurological syndrome.

At necropsy, in all three cases, the aorta and major arteries were normal and in no case was there more than a small amount of atheroma unremarkable for the age of the patient.

Extent of the infarction (figs 83-107).

A large region of infarction was present in all three cases and its extent longitudinally and in cross-sectional areas was interesting.

The longitudinal extent in the cases was as follows: case 15 from C3 to T1, case 16 from C4 to T1, case 17 from T11 to L1 (perhaps as far as L5).

Cases 15 and 16 belong to the commonest group in which the cephalic part of the anterior spinal artery is obstructed. In case 17, as in the case of Zeitlin and Lichtenstein, the caudal part of the artery was obstructed. It is interesting that a similar region of spinal cord was infarcted in both case 15 and case 16 and also that the caudal extent of the infarct was at T1 segmental level. The division at T1 or T2 of the arterial supply between the cephalic part from the subclavian-vertebral system and the caudal part from

the aorta has been commented upon in chapters V and VII. One effect of this is that the region T1 to T2 forms a natural limit of infarction and in cases 15 and 16 the spinal cord caudal to this point was supplied by a radicular tributary to the upper thoracic region and this blood flow was unaffected by the thrombus in the anterior spinal artery above.

The cross-sectional area of the spinal cord infarction was also interesting in the three cases. The infarct always involved the anterior horns and the grey commissure but not the most posterior part of the posterior horns. In addition there was infarction of that part of the anterior and lateral white columns adjacent to the grey matter. At different segmental levels the area involved changed markedly in the perimeter of the infarction, affecting sometimes more the anterior or the lateral white columns and sometimes one side more than another (figs 83-89). These vagaries were well seen in cases 15 and 17. It was sometimes apparent that the side most affected at a particular level was related to the anatomical arrangement of the sulcal arteries at the level concerned. It will be recalled that in chapters V and VII it was stressed how the sulcal arteries entered and supplied one side of the cord only, and as a sulco-commissural artery, their terminal branches went to one side. This appeared to be the

explanation of the asymmetrical infarction seen in these cases, in particular in case 15 and case 17.

In all three cases the cause of the infarction was found in the anterior spinal artery which contained antemortem thrombus (figs 91, 99, 100, 105), but in all three cases thrombus was found at more than one segmental level and frequently in small arterial branches particularly the sulcal arteries (figs 92, 101) and the sulco-commissural arteries (fig 106). It was clear that the obstruction was not a single thrombus occluding one part of the anterior spinal artery but several obstructions to this artery and its main branches.

The nature of the thrombus was in cases 15 and 17 an organised thrombus firmly attached to the vessel wall. In case 16 the thrombus appeared more recent and was in its histological detail appropriate to the short survival of 24 hours since the onset of the clinical syndrome. In case 16 it was particularly interesting to relate the position of the thrombus in the anterior spinal artery to an effect of coexisting cervical spondylosis. Thrombosis was found in the parts of the anterior spinal artery which were adjacent to the cervical spondyletic protrusions. It is possible that pressure on the arterial wall initiated the thrombosis but how this may be caused is uncertain. It is known that minor damage to an arterial wall will release

toxic factors into the lumen and these will cause thrombosis. In this way this case is similar to the case of Grinker and Guy in which the thrombosis followed yawning and stretching of the arms.

SMALL SPINAL ARTERIES.

There are a number of pathological processes which involve arteries of small calibre and when these disease processes affect the vessels of the spinal cord the pathological lesions produced give rise to profound neurological disturbances. In this thesis three cases have been selected to illustrate the involvement of the spinal cord in syphilis (case 18), tuberculosis (case 19) and sarcoidosis (case 20). These three case reports have been chosen because in them the involvement of the spinal cord was severe and more evident than the effect on the rest of the nervous system and the other systems of the body.

Neurosyphilis.

Case 18 is a case of neurosyphilis in which involvement of the spinal cord by meningovascular syphilis predominated. To this type of syphilis the name Erb's spinal syphilis or syphilitic amyotrophy is usually given.

Case 18 was a man of 64 with a long standing history of syphilis treated in its primary stage. He had a neurological

syndrome of long duration which had caused weakness and wasting in the muscles of his arms and legs with a particular involvement of the left hand. His eventual death was due to bronchopneumonia superimposed on a carcinoma of the left main bronchus.

At necropsy the spinal cord showed marked leptomeningeal fibrosis filling the anterior median sulcus and binding the leptomeninges to the spinal cord (figs 108, 109, 110). The leptomeningeal vessels everywhere showed concentric mural thickening by fibrous tissue (fig 112). The intramedullary vessels were surrounded by a condensation of fibrous tissue and their numbers were increased suggesting some widespread process causing vascular proliferation (fig 113). The spinal veins showed some dilatation. The grey matter showed loss of anterior horn neurones in many sections, and in some (C3, C4 and T7) they were almost entirely absent (fig 114). Wallerian degeneration was present in the posterior columns at the top of the cord and in the cortico-spinal tracts in the caudal segments. The picture was added to in the cervical region by cervical spondylosis causing distortion of the spinal cord at C3, C4 and C6.

This pathological picture is that of a profound chronic ischaemic disturbance on the spinal cord affecting both grey and white matter. The loss of upper and lower motor neurones is as profound as in amyotrophic lateral sclerosis but lacks

the symmetry of this condition. The additional features not seen in amyotrophic lateral sclerosis are the severe leptomeningeal fibrosis with vessel changes suggestive of a long standing vascular degenerative condition affecting particularly the small arteries of the spinal cord. It is interesting to compare these findings with those of tuberculosis and of sarcoidosis. The affect of ischaemia appears to be very much more chronic in syphilis with a selective effect on the neurone cell bodies. There is no evidence of frank infarction as is seen in tuberculosis and not even the smaller foci of degeneration seen in sarcoidosis.

Case 19 is a case of generalised tuberculosis and tuberculous meningitis with particular involvement of the spinal cord. The course of her illness was swift and death occurred in her first admission to hospital for an illness which proved to be a combination of pulmonary miliary tuberculosis, tuberculous endometritis, and tuberculous meningitis. One month after the commencement of her illness the spinal cord involvement was such that she had a complete flaccid paraplegia with areflexia in the lower limbs.

At necropsy tuberculous meningitis was present around the brain with a typical exudate at the base causing

obstruction of the lateral, third, and fourth ventricles. The tuberculous exudate was made up of lymphocytes and macrophages with only a few giant cells and very many acid-fast bacilli. The vessels at the base of the brain were buried in tuberculous exudate and showed considerable endarteritis which had caused many ischaemic foci in the substance of the brain. Although extensive, the lesions in the brain were less striking than those in the spinal cord. The spinal cord was surrounded by tuberculous exudate which distended the subarachnoid space into a cylinder around the cord with the arachnoid mater stretched to its greatest extent. The state in the spinal cord was that of infarction which extended from T4 segmental level caudally to the conus medullaris. Throughout this region the cord was seen and felt to be soft and histologically there was a profound infarction affecting the grey and the white matter (figs 115,116,117). The vessels in the subarachnoid space around the cord showed extensive endarteritis obliterans (figs 119, 120, 121). Almost all the vessels seen were involved in this process and it appeared that the spinal cord was cut off from almost every part of its blood supply. In the clinical management of these cases this type of pathological change is extremely grave for the endarteritis causes severe irreversible damage to

the spinal cord (fig 118) whilst the thick exudate prevents the dissemination of active chemotherapeutic drugs.

In case 19 the amount of damage to the spinal cord caused by tuberculous endarteritis is exceptional but in other respects the findings are similar to several reports (Rigdon, 1947; Smith, Vollum and Cairns, 1948: Brooks, Fletcher and Wilson, 1954) describing the ischaemic damage caused to the brain and spinal cord from the obstruction of arteries bathed in tuberculous exudate.

Case 20 is a case of sarcoidosis with widespread lesions affecting the spinal cord. In many respects it resembled the case of Aszkanazy (1952) which also has this particular area of involvement. In case 20 there was an illness lasting 3 years and which consisted of backache and pain in the limbs and then weakness first in the legs and then in the arms. The disorder progressed to involvement of the bladder and bowel functions. The paresis became severe with widespread muscle atrophy. The diagnosis of sarcoidosis was established during life by a muscle biopsy. Electromyography showed changes of active denervation. Death after three years of this syndrome occurred from peritonitis in connection with operations on the bladder and intestines.

At necropsy, outside the nervous system, the only

evidence of sarcoidosis were small tubercles of sarcoid seen in histological sections from both lungs. Sarcoid nodules were seen around the cerebrum (fig 122) but were particularly evident in the spinal cord. All the segmental levels examined showed long tract degeneration in the posterior columns above and in the pyramidal tracts in the caudal part of the cord. In all the spinal cord sections large sarcoid nodules were present (figs 123-127) and these tended to enter the cord alongside blood vessels both along the radial blood vessels in the white matter (fig 126,129) and along the sulcal arteries (fig 125) into the grey commissure. In addition to this intramedullary involvement the anterior and posterior spinal nerve roots were often embedded in sarcoid granulation tissue. The effect of the sarcoidosis on the spinal cord was that of an infiltrating granuloma with large lesions distending the perivascular spaces. There was also some evidence of ischaemia both in the grey and white matter. Small foci of degeneration were present but it was noticeable that areas of frank infarction were absent. In this respect the sarcoid process produced far less vascular obstruction than was seen in the tuberculosis exudate in contact with vessels in similar situations.

VEINS.

Cases 21-25 are examples of a disorder of the spinal

veneus system which is of long duration and slow progression to profound destruction of the spinal cord. This condition, of which these five cases are examples, is known in the medical literature by several different names which, it is now realised, refer to a similar pathological entity. In the review of the literature in chapter III we have seen how the original report of Foix and Alajouanine (1926) under the heading "La myelite necrotique subaigüe" described two cases which are now included in this group. Bodechtel and Erbslöh (1957) considered the condition under the heading "Die Foix-Alajouaninesche Kranheit" and considered this title synonymous with the original name "Myelite necrotigue subaigüe" and their own preferred name "Angiodysgenetic Myelomalacia". From a consideration of the published accounts of these cases which have been reviewed in chapter III it seems clear that the majority of these published cases are similar to case 21-35 whose features will now be discussed.

The clinical course of the condition was that of a distinctive pattern of progressive neurological disturbance, whose time span was measured often in years. The syndrome began with symptoms of sensory disturbance preceeding or accompanied by paresis affecting the lower limbs. There was gradual progression of the symptoms and signs with

enhancement of the disturbance in the lower limbs and the slow ascent of involved parts to include the trunk. When the disease was fully manifest there was paralysis and complete loss of sensation in the lower limbs. In all the cases there was slight or moderate elevation of the spinal fluid protein (80, 90, 45, 65 and 125 mgms/100 ml.) but little or no excess of cells in the fluid (3, 3, 0, 0, 0). The diagnosis was usually made by myelography which when expertly performed would show diagnostic shadowing due to the myodil outlining the irregular vascular channels situated in the leptomeninges around the spinal cord (cases 21, 23, 25). The cases were sometimes explored by a laminectomy operation and this confirmed the diagnosis in the finding of a large vascular anomaly usually on the posterior aspect of the spinal cord and in its most caudal part (cases 21, 25). Recently the diagnosis of these cases has been elegantly demonstrated by subclavian and retrograde lumbar arteriography, and this technique is described in a series of papers by Djindjian and other collaborators. Using the technique of subtraction to remove the shadows of the overlying bone structure the vascular system of the spinal cord can be demonstrated in these cases. Not only can these techniques demonstrate the vascular malformation but they have provided evidence for its aetiology. It is possible

to visualise the feeding tributary into the malformation and to follow the course of the radio-opaque medium into the spinal venous system.

The necropsy findings were remarkable for the similarity found in the five cases. No generalised cardio-vascular disease was found and in no case was there any angiomatous malformation outside the spinal cord. In all five cases the necropsy showed a complicated abnormality of the spinal cord vascular system. This affected the caudal part of the spinal cord more than the cephalic part and the posterior aspect (fig 129) of the cord more than its anterior aspect (fig 128). The vascular anomaly was situated in the vessels of the meninges with only secondary (although often striking) changes in the intramedullary vessels. A close examination of the abnormal spinal vascular system in these cases has shown that within this confused complexity of vessels a general plan may be outlined. In all the cases the following features were found.

1. A normal or slightly dilated anterior spinal artery (fig 133).
2. A normal system of posterior spinal arteries.
3. A spinal venous system which on close examination was seen to be normal in position but abnormal in hypertrophy and distension of the normal spinal veins (figs 133, 135).
4. An abnormal large thick-walled tortuous vessel pursuing

an irregular course longitudinally along the posterior aspect of the spinal cord. This appeared to be part of the abnormal vascular communication between the spinal cord arterial and venous system and was usually an enlarged median posterior spinal vein (figs 132, 141, 147, 152, 156).

5. Abnormal capillaries and other small but thick walled channels within the substance of the cird (figs 136, 137, 138).

These features are so important in the understanding of the pathological mechanism of these cases that they will be considered in more detail.

Anterior and posterior spinal arteries.

These arteries showed the least change of all the spinal vessels, being slightly enlarged (fig 133).

Spinal venous system.

The spinal veins were grossly abnormal in all five cases. On close examination the abnormality seemed to be the hypertrophy of a spinal venous system that otherwise was normal in its anatomical situation. This change was best seen in the anterior spinal veins which could always be found adjacent to the anterior spinal artery (figs 133). The use of the elastic stain was always helpful to identify the

anterior spinal vein with certainty because the wall was of comparable thickness to the companion artery (figs 134, 135). The connective tissue stains showed that there was gross hypertrophy of the vein wall with an increase of connective tissue but little or no increase in electric tissue or smooth muscle.

Abnormal large posterior vessel.

A constant feature in each case was the presence on the posterior aspect of the caudal part of the spinal cord of a large thick walled tortuous vessel. In some cases this vessel was in the position of the posterior median central vein but in other cases it appeared to be extra to this normally positioned vein. The structure of this abnormal vessel was similar to that described in the anterior spinal vein. There was gross mural thickening with connective tissue but little increase in smooth muscle or elastic tissue. The connective tissue and elastic stains strongly suggested that this vessel was an 'arterialised' vein i.e. a vein with structural changes consequent on a raised intraluminar pressure. This large posterior vessel was frequently so tortuous that a single section out the vessel more than once and in this the spurious appearance of a collection of abnormal vessels was given (fig 139, 142).

Abnormal intramedullary vessels.

The sections showed many abnormal intramedullary vessels in the caudal necrotic regions of the spinal cord. The vessels were mainly abnormal in having gross mural thickening sometimes with the deposition of calcium and haemosiderin (figs 136, 137, 138). The size and position of these altered vessels suggested that formerly they had been capillaries and small veins.

These findings at necropsy added to the radiological studies during life on similar patients by Djindjian and his colleagues permit an explanation of the pathological mechanism in these cases. All these abnormalities of the spinal vasculature may be explained by postulating an arterio-venous fistula causing a rapid passage into the spinal veins of the spinal arterial blood. The spinal cord itself would, through this mechanism, be starved of its normal blood supply and *via* the spinal venous system the capillaries would be subjected to an abnormally high retrograde blood flow. This postulated mechanism would explain most if not all of the findings at necropsy. The 'arterialised' spinal veins would be explicable by the raised venous pressure which would also cause the mural changes in the intramedullary capillaries and veins. The necrosis in the spinal cord is explained by the lack of blood passing through the normal capillary bed in the spinal cord. It is gratifying that the studies at

necropsy, lacking as they are in the actual demonstration of the haemodynamics of the arterio-venous fistula, complement the studies in the living by arteriography.

There remains to be considered the actual site of the abnormal communication between artery and vein. This was studied in the many sections from these five cases but despite a careful search no single major communication could be identified. It appeared probable that the abnormal intramedullary vessels were themselves the place where the arterial system joined the venous system. The large posterior vascular channel would then be the main draining vein and not itself the anastomosis.

ABSTRACT.

The vascular supply to the human spinal cord has been studied in a series of observations made in the cadaver during routine necropsies performed at the Radcliffe Infirmary, Oxford. In addition to conventional anatomical dissection of the larger vessels concerned, injections with either indian ink or radio-opaque material were made into the spinal vessels. The examination of the larger spinal vessels was aided by X-rays or by rendering the spinal cord transparent with oil of wintergreen.

The origin of the spinal vessels was studied and a division suggested between a subclavian-vertebral supply to the cephalic part of the spinal cord and a direct aortic supply to the more caudal part of the spinal cord. From the evidence of both anatomical and pathological observations, the point of transition between the subclavian-vertebral supply to the direct aortic supply was considered to be in the region of the T1 spinal-cord segment.

The anterior radicular tributary arteries to the anterior spinal artery were studied in a series of 40 injected spinal cords. The number of tributaries ranged from 3 to 9 with a mean of 5.6. More tributaries joined the anterior spinal artery from the left (127) than the right (97) side. The largest anterior tributary (the artery of Adamkiewicz) was

always found accompanying one of the nerve roots from T7 to L3. It was three times commoner on the left than on the right side and in 12 out of the 40 specimens was accompanying the left T10 spinal nerve root.

The anterior spinal artery was confirmed as the most important single vessel and was always found to run longitudinally for the whole length of the spinal cord. The posterior spinal arteries were much smaller and were more irregular vessels than the anterior spinal artery. A good anastomosis between the anterior and posterior spinal arteries was always demonstrable around the conus medullaris and was often seen in the cervical region. This was seen in the arterial injections which, when made into the anterior arterial system, flowed easily into the posterior spinal arteries.

The sulcal arteries arose from the anterior spinal artery and passed backwards in the anterior median sulcus. They entered the grey commissure and by turning either left or right supplied the grey matter and central white matter of one side. These vessels and their branches formed the centrifugal arterial system. The centripetal arterial system, of lesser importance, was formed by radial arteries proceeding inwardly as branches from the coronal arterial plexus surrounding the spinal cord.

The spinal veins, with some differences, were arranged on the same general plan as the spinal arteries. The differences were that the spinal veins were more numerous and that the anastomoses between large veins were more common. The veins were most prominent on the posterior aspect of the spinal cord and the largest single vessel was usually a single median posterior vein.

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The pathological observations were made on cases selected for the information they provided on disorders of the human spinal vascular supply. These cases showed that obstruction or disturbance of the spinal cord vessels could occur at different points of the pathway of arterial supply and venous drainage.

Aorta. Aortic atherosclerosis and aortic thrombosis were shown to cause a syndrome of chronic ischaemia of the spinal cord. Aortic trauma with mural haematoma caused acute infarction of the spinal cord, a similar sequel to that more commonly seen following spontaneous medial dissection of the aortic wall.

Vertebral arteries. Two cases illustrated spinal cord infarction and ischaemia caused by obstruction to both

vertebral arteries. This unusual syndrome arose from trauma to the cervical spine causing a tear through one intervertebral disc. The resultant angulation at the point of the intervertebral disc tear kinked and obstructed both vertebral arteries.

Intercostal arteries. Surgical damage to an intercostal artery giving rise to an important radicular tributary to the anterior spinal artery was shown to cause extensive infarction of the spinal cord in the territory of the anterior spinal artery. These paired intercostal and lumbar spinal arteries supply the spinal cord below the T1 spinal-cord segment. The majority of these spinal arteries may be obstructed with impunity but when, as in this case, the occluded artery is an intercostal artery giving rise to a major radicular tributary, serious infarction of the spinal cord will be caused.

Radicular tributaries. Obstruction to these vessels in the intervertebral foramina was shown to be caused acutely by herpes zoster and more gradually in cases of malignant tumour infiltration. The sequel to this obstruction of the radicular tributaries was a state of haemorrhagic infarction affecting most of the cross-sectional area of the spinal cord and extending through several spinal-cord segments.

Anterior spinal artery. Three cases of infarction of the spinal cord due to obstruction of the anterior spinal artery by thrombus were described. In two of these cases the cervical part of the anterior spinal artery was obstructed whilst in the third case the spinal cord below T11 segmental level was affected. In one case there was a relationship between the site of the thrombosis in the anterior spinal artery and the position of cervical spondylotic protrusions which were adjacent to the thrombosed artery. No cause for the arterial lesion was found in the other two cases.

The longitudinal extent of the infarction in the two cervical cases was similar and its caudal extent was at the T1 segmental level. Below this level the spinal cord was supplied by a radicular tributary to the upper thoracic region and the blood flow was unaffected by the thrombus in the anterior spinal artery above.

In its cross-sectional area the infarction always involved the anterior horns and the grey commissure but not the most posterior part of the posterior horns. The white matter of those parts of the anterior and lateral white columns adjacent to the grey matter was also infarcted. The region of infarction was often asymmetrical and might differ markedly at slightly different levels. The asymmetry was considered to be an effect of the various sulcal arteries

which entered to supply either the left or the right side of the spinal cord.

Small spinal vessels. Three cases were selected to describe the effects of disease affecting the small spinal vessels. In one of these cases meningo-vascular syphilis had caused chronic atrophy of the spinal cord affecting both grey and white matter. The spinal vessels showed connective tissue thickening due to former syphilitic arteritis.

Another case studied was a case of tuberculous meningitis causing, by arteritis, a severe haemorrhagic infarction of the spinal cord. In this case the subarachnoid space was distended with tuberculous exudate which had caused an endarteritis affecting all the spinal arteries surrounding the spinal cord.

The third case considered in this group was a case of sarcoidosis affecting the spinal cord. Sarcoid granulomata were present around small spinal vessels in the leptomeninges and entering the spinal cord along perivascular spaces. In contrast to the effects of syphilis and tuberculosis, the vessels in contact with the sarcoid granulomata were not obstructed and there was no gross infarction evident in the spinal cord.

Veins. Five cases of a chronic necrotising spinal cord disorder associated with grossly abnormal spinal vessels were

described. The necropsies showed a complicated abnormality of the spinal vessels with large abnormal veins in the caudal and posterior regions of the spinal cord. The anterior and posterior spinal arteries were normal apart from slight enlargement but the spinal veins were enormously enlarged and their walls were thickened suggesting an increased venous pressure. The intramedullary vessels were abnormal in having markedly thickened walls and the position of the vessels so affected suggested that formerly they had been capillaries or small veins.

The explanation of the vascular abnormality was thought to be the presence of an arterio-venous fistula causing the passage of arterial blood directly into the spinal veins without the intervention of the normal capillary bed. The small intramedullary veins and the capillaries would then be affected by a retrograde blood flow at a high pressure. These findings at necropsy were complementary to the radiological studies made during life on similar patients by Djindjian and his colleagues, who have similarly concluded that these cases are explained by the presence of a spinal arterio-venous fistula.

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