

Title Page

Title of article: Is Partial Wrist Denervation Beneficial in Chronic Wrist Pain? A Systematic Review

Authors: Murtaza Kadhum ¹, Nicholas Riley ¹, and Dominic Furniss ¹

¹ Botnar Research Centre, Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, Oxford University.

Corresponding author:

Mr Murtaza Kadhum

Address: Botnar Research Centre, Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, Oxford University.

Email: Murtaza.kadhum@medsci.ox.ac.uk

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Is Partial Wrist Denervation Beneficial in Chronic Wrist Pain? A Systematic Review

Abstract

Background: The prevalence of chronic wrist pain and subsequent functional decline is increasing. Diagnosis is challenging, with non-surgical treatment frequently failing. Recently, partial wrist denervation (PWD) has gained popularity as a procedure to alleviate chronic pain.

Methods: A systematic review was performed in April 2019. Inclusion criteria involved clinical studies with a minimum of ten wrists, focusing on PROMs, objective measures of function and complications. Papers investigating complete or mixed denervation procedures were excluded.

Results: Nine studies were included (292 wrists), all of which were observational in study design and limited in patient numbers, evaluation techniques and follow-up length. PWD appears to be associated with a reduction in pain, and functional improvement. Further surgery was required in 54 (24%) wrists at an average follow-up of 18 months. PWD was not found to complicate further surgery.

Conclusion: PWD is associated with improvement in short-term pain relief and functional status, yet carries a high re-operation rate without contraindicating further salvage surgery.

48 Further research is required to evaluate the benefits, duration of relief and long-term
49 complications of PWD.

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Background:

Musculoskeletal system complaints are common in the adult population, affecting approximately 159 females and 143 males per 1000¹. As the global population lives longer, the prevalence of musculoskeletal disorders, chronic pain and disability are increasing². Specifically, prevalence of wrist pain ranges from 3% to 26% depending on geographic location³.

Deciphering the aetiology of wrist pain is challenging, mainly due to the anatomical and biomechanical complexity of the distal radioulnar, radiocarpal and midcarpal joints and the relation of the carpus to the stabilising soft tissue structures⁴. The differential diagnosis may be classified according to location, namely radial-sided, central or ulnar-sided⁵. Careful evaluation through a thorough history, examination and radiological investigations provides a diagnosis in approximately 70% of cases⁶. Depending on the specific diagnosis, varying treatment options exist, ranging from conservative, medical and ultimately surgical management⁵. Treatment aims to improve wrist function, namely strength and range of motion, whilst minimising pain⁷.

Whilst specific surgical options exist for each diagnosis, wrist arthrodesis is reserved by hand surgeons as the end-stage salvage treatment, aiming to minimise pain and improve overall quality of life^{8,9}. However, wrist arthrodesis is technically challenging and requires optimal bone surface preparation, bone grafting and fixation to enhance outcomes^{7,10,11}. Complications including contracture, bony erosion, tendon rupture, infection, instability, component failure and complex regional pain syndrome have been reported in 51% to 68% of procedures^{10,11}. Ultimately, arthrodesis leads to a reduced range of wrist motion and grip

strength compared to the normal side, which may contribute to further disability despite pain relief ^{10,11}.

Recently, wrist denervation has gained popularity as an alternative surgical approach in treating the chronic painful wrist, especially in cases where conservative, medical and primary surgical management have failed ¹², or to delay more radical procedures, such as arthrodesis. This involves transection of the terminal sensory fibres of peripheral nerves that innervate the wrist ¹³.

This procedure was first described in 1959 by Albrecht Wilhelm, who performed a total wrist denervation in a patient with a 30-year-old scaphoid non-union and progressive osteoarthritis ¹⁴. This procedure utilised five skin incisions to transect 10 terminal nerves (Figure 1) ¹⁴. This aimed to interrupt pain transmission from the wrist joint to the central nervous system via A-delta and nociceptive C-fibers, without interfering with the wrist's motor function and avoiding post-operative immobilisation that commonly occurs in arthrodesis ¹⁴. Interestingly, complete wrist denervation has been shown to offer significant symptom relief in patients with chronic wrist pain, whilst preserving range of motion and grip strength in long-term observational studies ¹⁵⁻¹⁷. In cases of treatment failure, complete denervation did not preclude further surgical salvage procedures ¹⁵⁻¹⁷.

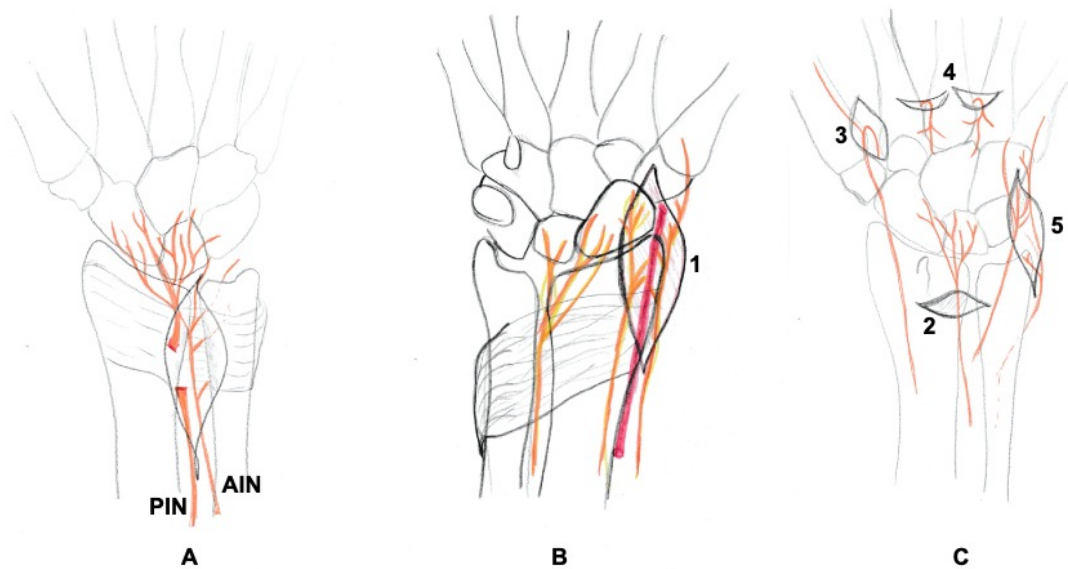


Figure 1 - An Illustration of PWD using the one-incision approach (A) and Wilhelm's Total Wrist Denervation (palmar aspect in B and dorsal aspect in C). In the one-incision approach (A), the PIN and AIN are found about the interosseous membrane. In Wilhelm's Total Wrist Denervation (B and C), incision 1 transects the AIN and superficial branch of the radial nerve. Incision 2 transects the PIN, incision 3 transects the recurrent branch of the dorsoradial nerve, incision 4 transects the recurrent branches and incision 5 transects the dorsal branch of the ulnar nerve.

Although positive results have been documented for pain relief and wrist function, complete wrist denervation is surgically challenging, requiring numerous incisions, whilst resulting in a longer operation length and larger financial burden ^{12,19}. Longer operations will inevitably compound operative and anaesthetic risks, whilst procedure-specific complications, such as a theoretical loss in proprioception, may occur ^{12,19}. Consequently, in 1998, Richard Berger introduced a technique for partial denervation of the wrist ¹⁹. This involved transection of the anterior interosseous nerve (AIN) and posterior interosseous nerve (PIN) using a single dorsal

incision adjacent to the ulnar head, which is possible due to the close anatomical relationship of these nerves about the interosseous membrane of the forearm (Figure 1)^{19,20}. These nerves innervate approximately two thirds of the wrist joint; the PIN predominately innervates the dorsal aspect of the wrist and the AIN innervates the ventral joint capsule and ligament insertions^{13,19}.

In an effort to improve our understanding of the risks and benefits of using partial wrist denervation (PWD) (defined as neurectomy of the AIN, PIN or both) as a means of managing chronic wrist pain, a systematic review was performed. This focussed on patient reported outcome measures (PROMs), objective measures of function (such as grip strength or range of movement) and complications.

Methods:

A systematic review was performed in April 2019, utilising the preferred reporting items for systematic reports and meta-analyses (PRISMA) statement as an overall guideline for this study. The review was registered in PROSPERO (CRD42019133873).

The search protocol included all relevant articles from a case series (acting as the minimal level of evidence accepted), to randomised controlled trials and systematic reviews. Case reports were excluded due to their low level of evidence and inability to provide adequate data for our specified outcome measures. The primary outcome measure involved assessment of all relevant PROMs after PWD surgery, including the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, Patient-Rated Wrist Evaluation (PRWE), Gartland and Werley score, Michigan Hand Outcomes score, Mayo Wrist Score and the Short Form 36.

Secondary outcome measures included objective measures of grip strength, range of movement or proprioception. Complications after PWD surgery, including infection, failure and requirement for salvage surgery were also included. No restriction was applied on patient age or follow-up length, due to the varying causes of chronic wrist pain. Only articles in English were considered. Patients who had complete wrist denervation or mixed wrist denervation (involving AIN, PIN and other nerve transections) were excluded. A minimal criterion for included studies was established (Table 1).

The search protocol for this systematic review was executed in MEDLINE, EMBASE, Google Scholar and the Cochrane Central Register of Controlled Trials in April 2019. Results were not restricted by year of publication. The search strategy involved utilising specific vocabulary terms, keywords and synonyms, inputted according to the specifications of each database. The terms and keywords were also joined together in differing combinations, whereby each surgical procedure was combined with the remaining keywords in a cyclical search strategy (Supplementary data). The search terms included: *Wrist Denervation, Partial Wrist Denervation, Wrist Neurectomy, Patient Reported Outcome Measures, PROMs, DASH, PRWE, Gartland and Werley, Michigan Hand Outcome Score, Mayo Wrist Score, Short Form 36, Grip Strength, Range of movement, Proprioception and Complications*. All identified titles with abstracts were analysed using screening questions (Table 1) and if eligible, the full paper was scrutinised. The reference lists of included studies were reviewed to identify additional studies and remove duplicate datasets. Two authors independently performed the search strategy and extracted the relevant data. Disagreements were resolved by discussion with a third author. Data analysis was performed using R software (2019) and meta-analysis performed only if the results were similar in interventions and outcomes across two or more

studies. For each included study, assessment of bias was performed using the Cochrane Risk of Bias tool for RCTs or the Quality Assessment Tool For Quantitative Studies for non-randomised studies²¹. This included assessment of selection bias, study design, confounders, blinding, data collection and analysis methods, with each paper scored as “strong”, “moderate” or “weak”.

Table 1: Inclusion and exclusion criteria questions.

Question	Minimum Criteria
What language is used?	English only
Does it address the topic?	PWD Surgery (limited to neurectomy of AIN, PIN or both)
Does it address the study question?	PWD in Chronic Wrist Pain
Is it a clinical study?	Yes
How many wrists included?	n > 10
What is the level of evidence?	Case Series or above
Does it address relevant outcome measures?	Any of: <ul style="list-style-type: none"> PROMs - <i>DASH, PRWE, Gartland and Werley, Michigan Hand Outcome Score, Mayo Wrist Score and/or Short Form 36</i> Objective measures of function - such as <i>grip strength, range of movement or proprioception</i> Complications

Results:

The search generated 1433 hits (Supplementary data), with 464 duplicate records (Figure 2). As a result, the titles and abstracts of 969 records were assessed using the screening criteria set out in Table 1. Of these, 930 were excluded due to failing to meet the minimal screening criteria (Figure 2). Full text analysis of 39 records was performed, leading to 30 exclusions due to complete or mixed nerve denervation procedures, non-surgical procedures (such as anaesthetic nerve blocks) or non-clinical cadaveric studies (Figure 2). As a result, nine articles

were included in this systematic review (Figure 2). No randomised control trials or Cochrane reviews were identified. All included records were observational in study design. The level of evidence of included studies, as per the Oxford Centre for Evidence-Based Medicine ²², ranged from II to III. Six studies were of moderate quality, with three studies classed as weak after a risk of bias assessment (Supplementary data). A meta-analysis of the included records was not possible due to the overall heterogeneity of the outcome results.

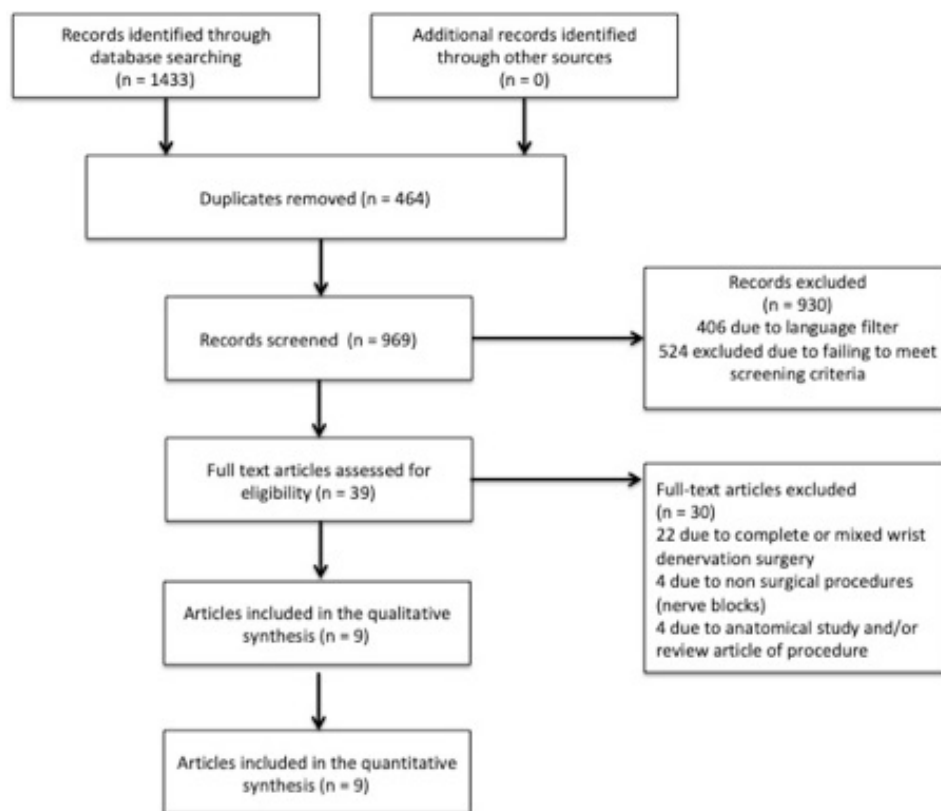


Figure 2 - Diagram showing search and selection methods.

Across the nine included articles, a total of 277 patients were involved, accounting for 292 wrists that underwent PWD (Table 2). From the eight articles that reported age of participants, the mean age was 43.2 (ranging from 30 to 67.1 years). The majority of included studies (eight records) were conducted in the United States of America (USA), with one article originating from Spain. Six articles employed a prospective study design and the remaining three described a retrospective design. The overall follow-up period ranged from 12 to 81 months, with an average follow-up of 32 months. Various indications for partial denervation were described, including osteoarthritis, inflammatory arthritis (mainly rheumatoid arthritis), hyperextension injuries or sprains, scaphoid or lunate non-union or post-fracture (notably Colles' fractures). The most common indication noted was osteoarthritis, accounting for 83 (28%) wrists. In five included studies, the authors transected both the AIN and PIN, accounting for 204 (70%) wrists. Four studies transected only the PIN, accounting for 77 (26%) wrists. The AIN was solely transected in one included study, accounting for only 11 (4%) of the total wrists investigated.

PROMs were employed in all nine included articles (Table 3). Pain relief post-denervation surgery was reported through multiple methods. Of note, four of these articles utilised a categorical pain grading system, ranging from excellent pain relief to no improvement^{19,23–25}. Out of the 96 patients these studies investigated, 54 patients reported an 'excellent' improvement in pain levels post-denervation surgery, whilst 18 reported 'good', 12 reported 'fair' and the remaining 12 patients reported 'no improvement'^{19,23–25}. Weinstein et al. reported pain using a different categorical grading system, ranging from 'more severe' to 'rare' after wrist denervation²⁶. Out of the 20 patients enrolled by the authors, 16 reported the pain was 'less severe' than pre-operatively, with 12 patients reporting the frequency of

pain as 'rare' compared to pre-operatively ²⁶. Hofmeister et al. reported pain using a 100-point grading system, with 0 indicating no pain and 100 indicating the most severe pain ²⁷. The authors report an improvement in average pain levels by 50 points, which reached statistical significance when compared to pre-operative levels ($p < 0.0001$) ²⁷. Riches et al. reported pain through the PRWE score, comparing denervation surgery to arthrodesis ²⁸. The authors report an average reduction in total pain from 44.2 pre-operatively to 22.0 post-operatively ($p < 0.001$), compared to 41.4 to 14.1 in the arthrodesis group ($p < 0.001$) ²⁸. Individual pain scores improved by 44% after denervation and 54% after arthrodesis, with no statistical difference between the two forms of treatment ($p = 0.18$) ²⁸. Sgromolo et al. reported pain by using a visual analog scale, ranging from 0 representing 'no pain' and 10 indicating 'worst pain' ²⁹. The authors report an overall improvement in pain levels from 4.0 to 2.2 post-denervation ($p < 0.05$) ²⁹. Lastly, O'Shaughnessy et al. reported pain (in combination with range of motion, grip strength and functional status) through the Mayo Wrist Score, with 90-100 indicating 'excellent' results, 80-90 'good' results, 60-80 'satisfactory' results and below 60 as 'poor' results ³⁰. The authors conclude that the average Mayo Wrist Score improved from 48 pre-operatively to 77 post-operatively ($p < 0.05$) ³⁰.

Patient satisfaction levels were reported in three included studies (Table 3) ²⁵⁻²⁷. Two studies reported patient satisfaction through a categorical scoring system, ranging from 'excellent' to 'no improvement' ^{25,27}. Of the 80 patients enrolled in these studies, 25 (31%) reported an 'excellent' improvement, 23 (29%) reported a 'good' improvement, 15 (19%) reported a 'fair' improvement and 15 (19%) reported 'no improvement' in overall satisfaction post-denervation surgery. Weinstein et al. employed a similar categorical scoring system to assess

patient satisfaction, concluding that 14 patients, from a total 20 patients investigated, were 'very' satisfied post-denervation surgery ²⁶.

The DASH score, ranging from 0 (no disability) to 100 (most severe disability), was reported by two papers ^{26,27}. Weinstein et al. observed an overall DASH score of 31 post-operatively, without investigating the baseline DASH score pre-operatively ²⁶. Hofmeister et al. reported an overall improvement of the DASH score from 42 pre-operatively to 27 post-operatively ($p < 0.001$) ²⁷.

The PRWE score utilised by Riches et al. also provided a score for overall functional outcome (Table 3) ²⁸, with a score of 100 indicating severe disability and 0 indicating no disability ²⁸. The authors report an improvement of function from 84.8 pre-operatively to 42.3 after denervation ($p < 0.001$), compared to 81.5 to 44.6 pre- to post-operatively in the arthrodesis group ($p < 0.001$) (Table 3). Riches et al. also report the individual function scores, concluding that overall function improved by 42% after denervation and 36% after arthrodesis, with no statistical significance between the two treatment options ²⁸.

Objective outcome measures of function were reported in seven articles (Table 3). Return to work was the most commonly reported outcome ^{19,23,24,26,29}. Return to work was assessed at follow up using four categories, namely 'resumed regular job', 'amended duties', 'vocational rehabilitation' or 'no work'. From the available data and out of a total of 94 patients, 60 (64%) patients resumed regular work, with the remaining 34 (36%) patients resorting to amended duties or vocational rehabilitation ^{19,23,24,26,29}.

Range of motion about the wrist joint was objectively assessed in four included studies (Table 3)^{23,27,29,30}. Dellon et al. report that range of movement increased in 26 of 30 patients, but the direction and degree of wrist motion were not published²³. Hofmeister et al. reported that wrist motion was affected in flexion (from 52 to 69 degrees post-operatively), extension (from 63 to 58 degrees), radial deviation (from 19 to 20 degrees) and ulnar deviation (from 36 to 32 degrees)²⁷. Sgromolo et al. reported that flexion reduced from 59 to 57 degrees post-operatively, whilst extension increased from 57 to 61 degrees ($p = 0.6$)²⁹. Lastly, O'Shaughnessy et al. reported an average flexion-extension arc of 95 degrees (compared to 120 degrees in the contralateral unaffected side), but provided no comparison to pre-operative degree of motion³⁰.

Grip strength was reported in two papers and assessed via a dynamometer (Table 3)^{27,30}. Hofmeister et al. reports an improvement in grip strength from 34 to 40 kilograms ($p = 0.076$)²⁵. O'Shaughnessy et al. reports an improvement in average grip strength from 25 kilograms in the affected limb, compared to 34 kilograms in the contralateral unaffected side, but provided no comparison to pre-operative grip strength³⁰.

Surgical complications post-denervation were reported in all nine included articles (Table 3). Eight articles reported no complications as a result of PWD. One article reported the presence of epineural fibrosis and neuroma formation in an unspecified number of patients²³. Surgical failure, defined as the need for further operations was reported in five of the included studies. Out of a total of 224 wrists, 54 (24%) required further surgery. 30 (56%) of these 54 wrists received a limited arthrodesis, 8 (15%) received a total arthrodesis and the remaining 16 (30%) wrists receiving ligament reconstruction, radial styloidectomy or other unreported

282 operations at an average follow up of 18 months. As such, PWD may provide suitable pain
283 relief for a minimum of 18 months. Interestingly, PWD was not found to preclude further
284 salvage operations.

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288 **Table 2:** Baseline characteristics of included studies.

Study (Year)	Study Type	Location	Nerve Transected	Number Of wrists (patients)	Mean Age of Patients (Years)	Indication for Surgery (number)	Mean Length of Follow-up (Months)
Dellon et al. (1984)	Prospective Cohort	USA	AIN	11 (12 patients, one excluded)	36.2	Colles fractures (1); Scaphoid non-union (1); Ganglion (1); Carpal Collapse (1); Hyperextension injuries (7)	12.1
Dellon et al. (1985)	Prospective Cohort	USA	PIN	30 (29 patients)	38.5	Hyperextension injuries (11); Colles fractures (8); Scaphoid non-union (4); Arthritis (3); Ganglion (4)	29.6
Ferreres et al. (1995)	Prospective Cohort	Spain	PIN	30 (30 patients)	34.4	Radial fractures (7); Colles fractures (5); Lunate necrosis (5); Scaphoid non-union (3); Galeazzi fracture-dislocation (2); Hyperextension injury (2); Scapholunate instability (1); Undiagnosed (5).	56.4
Berger et al. (1998)	Prospective Cohort	USA	AIN and PIN	24 (24 patients)	Not specified	Osteoarthritis (19); Rheumatoid Arthritis (3); Ulnar translocation (1); Scapholunate instability (1)	12
Weinstein et al. (2002)	Retrospective Cohort	USA	AIN and PIN	20 (19 patients)	52	Scapholunate advanced collapse (12); Arthritis (3); Scaphoid non-union (1); Scapholunate instability/dissociation (3); Undiagnosed (1)	31.2
Hofmeister et al. (2006)	Prospective Cohort	USA	AIN and PIN	50 (48 patients)	30	Scapholunate (SL) instability (8); lunotriquetral (LT) instability (4); Combined SL and LT instability (38); Triangular fibrocartilage complex perforation (4);	28
Riches et al. (2014)	Prospective Cohort	USA	PIN	14 (13 patients)	67.1	Rheumatoid Arthritis (14)	22
Sgromolo et al. (2018)	Retrospective Cohort	USA	Isolated PIN (3 cases) or AIN and PIN (10 cases)	13 (13 patients)	33	Undiagnosed (13)	12.5
O'Shaughnessy et al. (2018)	Retrospective Cohort	USA	AIN and PIN	100 (89 patients)	54	Osteoarthritis (58); inflammatory arthritis (19); posttraumatic arthritis (7); Ligamentous injury (6); Scaphoid or lunate necrosis (3); Undiagnosed (7)	81

289 **Table 3:** Results and bias assessment of included studies.

Study (Year)	Patient Reported Outcomes Measures (PROMs)	Objective Outcomes of Function	Complications	Bias Global Rating and Limitations
Dellon et al. (1984)	<i>Pain relief:</i> Excellent (9/11 cases), good (2/11).	<i>Return to work:</i> resumed regular job (4/11), amended duties (3/11), vocational rehabilitation (4/11)	Not specified	Weak One patient excluded without specified reason – In this case, pain relief was reported as poor. Short follow up and lack of control group.
Dellon et al. (1985)	<i>Pain relief:</i> Excellent (23/30 cases), good (5/30), fair (2/30), no improvement (1/30)	<i>Return to work:</i> 70% of cases (21/30 patients) resumed regular job <i>Range of movement:</i> objective range of movement increased in 87% of cases (26/30 patients)	<i>Epineurial fibrosis</i> – unspecified number of cases <i>Neuroma</i> – unspecified number of cases <i>Failure / re-operation</i> - Arthrodesis required in 2/30 attributed to scaphoid rotation and proximal carpal row collapse.	Weak
Ferreres et al. (1995)	<i>Pain relief:</i> Good (11/30 cases), fair (10/30) and no improvement (9/30). <i>Satisfaction:</i> Good (8/30), fair (11/30) and no improvement (11/30)	Not investigated	Not specified	Moderate
Berger et al. (1998)	<i>Pain relief:</i> Excellent (22/24 cases), no improvement (2/24)	<i>Return to work:</i> resumed regular job (22/24)	<i>Failure / re-operation</i> – Partial arthrodesis required in 2/24 cases for salvage. No other complications reported.	Weak Lack of control group and short follow up.
Weinstein et al. (2002)	<i>Pain relief:</i> Less severe than pre-operatively (16/20 cases),	<i>Return to work:</i> Only 15 of 20 cases were initially employed. Resumed regular job (11/15).	<i>Failure / re-operation</i> – Radial styloidectomy (1/20, for scapholunate instability),	Moderate

	<p>rare compared to pre-operatively (12/20)</p> <p><i>Grip Strength:</i> Improvement in grip strength (9/20), equal to pre-operatively (5/20), weaker to pre-operatively (6/20)</p> <p><i>Satisfaction:</i> Very satisfied (14/20)</p> <p><i>DASH Score:</i> 31 (range 6-58; median 32; standard deviation (13.1)</p>		<p>partial wrist arthrodesis (1/20, rheumatoid arthritis) and total wrist arthrodesis (1/20)</p> <p>* Failure associated with workers' compensation claims and pre-operative flexion-extension of less than 80 degrees). No association with chronicity of symptoms, age or previous surgery.</p> <p>No other complications reported.</p>	<p>Authors excluded patients with previous surgical procedures, significantly limiting study sample. Pre-intervention or serial DASH scores unavailable. Lack of a control group. Short follow up.</p>
Hofmeister et al. (2006)	<p><i>Pain relief:</i> on a 100-point scale, pain relief was 50 (p < 0.0001 compared to pre-operative results)</p> <p><i>Satisfaction:</i> excellent (25/50 cases), good (15/50), fair (4/50) and poor (4/50)</p> <p><i>DASH Score:</i> 42 (range 7-100) to 27 post-operatively (range 0-90) (p = 0.0003)</p>	<p><i>Range of motion (degrees):</i> Flexion (52 to 69), extension (63 to 58), radial deviation (19 to 20) and ulnar deviation (36 to 32)</p> <p><i>Grip Strength (Kilogram, Kg):</i> 34 to 40 (p = 0.076)</p>	<p><i>Failure / re-operation:</i> Ligament reconstruction (4/50), partial arthrodesis (12/50)</p> <p>No other complications reported.</p>	<p>Moderate</p> <p>Lack of control group, short follow up period</p>
Riches et al. (2014)	<p><i>PRWE total pain score:</i> 44.2 pre-operatively to 22.0 post-operatively (p<0.001), compared to 41.4 to 14.1 in arthrodesis group (p<0.001)</p> <p><i>Individual pain score:</i> total pain improved by 44% after denervation and 54% after arthrodesis (p=0.18)</p>	Not investigated	<p>No complications in PWD group.</p> <p>One complication (wound infection) in arthrodesis group.</p>	<p>Moderate</p> <p>Although two intervention groups, there is a lack of randomisation. Denervation group had significantly reduced follow up length.</p>

	<p><i>PRWE functional outcome score:</i> 84.8 pre-operatively to 42.3 post-operatively ($p<0.001$), compared to 81.5 to 44.6 post-operatively in arthrodesis group ($p<0.001$)</p> <p><i>Individual function score:</i> overall function improved by 42% after denervation and 36% after arthrodesis ($p=0.34$)</p>			
Sgromolo et al. (2018)	<p><i>Pain relief:</i> Assessed with a visual analog scale (VAS, 0 to 10, 0 representing no pain and 10 worst pain) (improved from 4.0 to 2.2 ($p < 0.05$))</p>	<p><i>Return to work:</i> resumed regular work (2/13 cases), amended duties (6/13) and medical discharge (5/13)</p> <p><i>Range of movement (Degrees):</i> Flexion (from 59 to 57 post-operatively) ($p = 0.9$), Extension (from 57 to 61 post-operatively) ($p = 0.6$)</p>	No complications reported	<p>Moderate</p> <p>Limitations include small sample size, lack of control group and may represent selection bias (due to sample population of military personal)</p>
O'Shaughnessy et al. (2018)	<p><i>Mayo Wrist Score:</i> Average score of 77 (Range, 35-100) post-operatively, from 48 (Range, 10-70) pre-operatively</p>	<p><i>Range of movement:</i> Flexion-extension arc of 95 degrees (compared to 120 degrees in contralateral unaffected side).</p> <p><i>Grip Strength:</i> 25 Kg compared to 34 Kg in contralateral unaffected side.</p>	<p><i>Failure / re-operation:</i> 31 patients (31%) underwent revision; 20/31 received arthrodesis (15 partial and 5 total).</p> <p>No other complications reported.</p>	<p>Moderate</p> <p>Limitations include lack of a control group and loss of follow-up over the 20-year follow up period</p>

Discussion

In this systematic review, nine articles pertaining to use of PWD in chronic wrist pain were scrutinised. Of note, the results demonstrate that PWD is associated with a beneficial effect of alleviating pain, improving patient satisfaction and functional status. The results may also indicate improved rates of return to routine work. No significant association was reported for objective measures of function, such as grip strength or range of motion. Although complications were reported, the incidence of these was not investigated. Failure, defined in the included articles as a requirement for further surgery, was observed in 54 of 224 wrists (24%) and having undergone the PWD did not hinder the further surgery.

For the chronic painful wrist, a surgical procedure that would alleviate pain, improve carpal motion and grip strength without lengthy immobilization may be considered as the gold standard ¹². PWD aims to achieve this, through transection of the AIN and PIN (singly or in combination) to alleviate chronic pain without disrupting wrist motor function ¹². In the literature, PWD appears advantageous due to its technical simplicity and fast post-operative recovery, without contraindicating further surgical intervention in cases of treatment failure ¹². At its optimum, it provides symptomatic relief without altering any underlying mechanical disruption of the wrist joint ¹². It remains unclear whether proprioception is detrimentally altered after wrist denervation with various conflicting published reports ^{31,32}. Although clear guidance on the indications of this procedure remains limited, a careful evaluation of patients with chronic wrist pain is required to identify any mechanical disruption that may be treated more definitively. Diagnostic local anaesthetic nerve blocks may also be used to identify candidates that are likely to benefit from denervation prior to surgery ³³. Interestingly, a high proportion of failed cases in our nine included articles, were reported to be secondary to

dynamic instability. Such failure may be prevented through rigorous history taking, wrist examination and provocation tests, imaging and alternative initial surgical management such as ligament reconstruction ^{27,30}.

The Berger technique utilises a single incision to transect the AIN and PIN, which are reported to innervate two thirds of the wrist joint. However, the radial and ulnar sides of the wrist joint are also densely innervated by other sensory branches; namely the dorsal branch of the ulnar nerve and sensory branches of the radial and musculocutaneous nerve ¹³. Recent anatomical studies have suggested a need for a two-incision mixed denervation technique, which permits transection of the AIN, PIN and the aforementioned sensory branches to provide a more definitive wrist denervation ¹³. In this systematic review, five articles transected the AIN and PIN (accounting for the majority of the included wrists), four articles transected the PIN and one article transected the AIN (Table 2). As such, this variability of surgical technique and consequently the specific location and fibre of the peripheral nerve transected may represent a significant limitation when interpreting the overall effect of PWD. For isolated AIN denervation, although the one included article reported excellent pain relief and return to work for patients, the study was limited by a short follow-up, small sample size and lack of a control group. Three articles investigated PIN denervation specifically. Here only one paper utilised a validated PROM. Although these articles described excellent pain relief post denervation, the studies were limited by sample size. For combined AIN and PIN denervation, five articles were included housing larger sample sizes and stronger study designs, providing stronger evidence for this approach compared to the isolated AIN or PIN neurectomies.

In the wider literature, other forms of wrist denervation are described, ranging from mixed to complete wrist denervation ^{15,17,34}. For the latter, long-term observational studies utilising pre- and post-denervation DASH scoring have reported subjective pain improvement in two-thirds of patients over a 10-year follow up period, without affecting range of motion and further surgical intervention ¹⁷. These denervation techniques, however, remain more technically challenging, requiring longer operative periods and incurring a larger financial burden ¹².

Alternatively, chronic or intractable wrist pain may also be treated by arthrodesis or arthroplasty, especially in end-stage osteoarthritis or rheumatoid disease ²⁸. Interestingly, wrist arthroplasty utilising the newer fourth-generation implants, has been shown to have comparable outcomes (function, pain and grip strength), but with higher complication rates compared to arthrodesis ³⁵. However, arthrodesis inevitably causes a loss of residual wrist motion, and may lead to functional decline in some cases ³⁶. One paper included within this systematic review directly compared PWD to arthrodesis utilising a prospective observational study design and comparable inclusion criteria ²⁸. Although limited by the lack of randomisation between the two treatment arms, the authors found comparable results in overall pain relief and overall function, but with significantly fewer complications in those undergoing PWD ²⁸. This, combined with previous reports that PWD does not preclude further surgical intervention, may influence hand surgeons to reserve further surgical options (limited or total arthrodesis, four corner fusion or proximal row carpectomy) for cases of failed denervation.

The data assessed and included in this systematic review suffers from limitations. Due to the lack of randomised control trials, quantifying the overall benefits and risks of PWD, compared to the alternative surgical options remains difficult. All the studies included within this systematic review were observational in study design and lacked homogeneity in patient selection, pre- and post-operative evaluation and duration of follow-up. As such, further statistical analyses involving funnel plots or meta-analyses were not possible. The bias assessment (Table 3) revealed a risk of selection, attrition and reporting bias in differing variations across the nine included articles, mainly resulting from deficiencies of study design. Defining denervation failure by re-operation rates also contributes directly to detection bias, as decision to re-operate may be influenced by both patient and surgeon preferences and beliefs. At review level, incomplete retrieval of appropriate records may have occurred (posing a selection bias), although an attempt to minimise this risk by repetition of the search strategy was employed. The study was also limited to work published in English (resulting in exclusion of 406 records), therefore it was not possible to identify results from the worldwide literature.

Conclusion

Chronic wrist pain is common and increasing in prevalence, especially within our ageing population and ultimately leads to functional decline or disability. Viable treatment options are available to alleviate pain, such as total wrist denervation or arthrodesis. These options are supported in literature with well-designed observational and randomised trials. Recently, PWD has been coined as a technically simple and morbidity-minimising alternative, permitting reduced operative and post-operative recovery times. With the limited data

available, PWD is associated with improvements in short-term pain relief, patient satisfaction and functional level. This, combined with the ability to conduct salvage operations unhindered in cases of failure, presents PWD as a possible alternative to skeletally altering surgical interventions. However, hand surgeons should remain vigilant of the high re-operation rates. Further research is clearly required to evaluate benefits, duration of relief, optimal surgical techniques and long-term complications including the theoretical possibility of accelerating the underlying disease. This may be approached through differing avenues. Firstly, evidence is required to evaluate both the short and long-term benefits (pain relief and functional status) and risks (neuroma formation, infection, proprioception decline, disease acceleration and failure rates). Ideally, this should be evaluated by a placebo-controlled trial including a sham surgical procedure ³⁷. Then, randomised control trials evaluating PWD, compared to current mainstay practice may help establish equivalence or non-inferiority. Finally, research is required to evaluate the specific surgical techniques employed, including one-incision versus two-incision approaches and degree of denervation (AIN/PIN versus mixed denervation). In all cases standardised and validated outcome measures should be used, enabling future meta-analyses.

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507 **Appendix S1 (Search Strategy):**

Search Strategy	All Database Total Hits	Exclusions
"Wrist Denervation"	464	Language (95) Excluded – Did not Meet screening criteria (348) Remaining new records - 21
"Partial Wrist Denervation"	48	Language (13) Excluded – Screening criteria (27) Remaining new records – 8
"Wrist Neurectomy"	476	Language (97) Excluded – screening criteria (369) Remaining new records - 10
"Wrist Denervation" AND "Patient reported outcome measures; PROMs; DASH; PRWE; Gartland and Werley; Michigan Hand Score; Mayo Wrist Score; Short form 36; Grip Strength; Range of movement; Proprioception; complications"	199	Language (59) Excluded – screening criteria (or duplicate) (140) Remaining new records - 0
"Partial Wrist Denervation" AND "Patient reported outcome measures; PROMs; DASH; PRWE; Gartland and Werley; Michigan Hand Score; Mayo Wrist Score; Short form 36; Grip Strength; Range of movement; Proprioception; complications"	41	Language (18) Excluded – screening criteria (or duplicate) (23) Remaining new records - 0
"Wrist neurectomy" AND "Patient reported outcome measures; PROMs; DASH; PRWE; Gartland and Werley; Michigan Hand Score; Mayo Wrist Score; Short form 36; Grip Strength; Range of movement; Proprioception; complications"	205	Language (124) Excluded – screening criteria (or duplicate) (84) Remaining new records - 0

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511 **Appendix S2** (Review author's bias assessment of included articles – Red indicates weak,
 512 orange indicates moderate and green indicates strong studies):

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	Selection Bias	Study Design	Confounders	Blinding	Data Collection Methods	Analyses Methods	Global Rating
Dellon et al. 1984							
Dellon et al. 1985							
Ferreres et al. 1995							
Berger et al. 1998							
Weinstein et al. 2002							
Hofmeister et al. 2006							
Riches et al. 2014							
Sgromolo et al. 2018							
O'Shaughnessy et al. 2018							

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