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Original Research Article

ORIGINAL RESEARCH ARTICLE

Trends in Paediatric surgerical volume and associated mortality in England: a nationwide study over an eight year period

Juri Althonayan[1], Alexander J. Fowler[1], Benjamin Allin[2], Amaki Sogbodjor[3], Timothy Bradnock[4], Nara Orban[5], Thomas D. Dobbs[6], Marian Knight[2], Rupert M. Pearse[1] and Tom E. F. Abbott[1,*]

[1]William Harvey Research Institute, Queen Mary University of London, London, UK, [2]National Perinatal Epidemiology Unit, University of Oxford, Oxford, UK, [3]Department of Paediatric Anaesthesia, Great Ormond Street Hospital for Children, London, UK, [4]Department of Paediatric Surgery, Royal Hospital for Children, Glasgow, UK, [5]Barts Health Ear, Nose and Throat Service, Royal London Hospital, London, UK and [6]The Welsh Centre for Burns & Plastic Surgery, Morriston Hospital, Swansea, UK

*Corresponding author. E-mail: t.abbott@qmul.ac.uk

Abstract

Background: Reports on delays to National Health Service (NHS) surgical care have been widespread during and after the pandemic, however the impact on paediatric surgery is poorly described.
Methods: This retrospective observational cohort study used NHS hospital data in England for children aged <18 yr undergoing surgery over an 8-yr period from 1 April 2015 to 31 December 2020, with supplementary data until March 2023. The primary outcome was in-hospital mortality within 90 days after surgery. The secondary outcome was hospital stay. We report trends in annual surgical procedure volume and mortality. Frequencies presented as *n* (%).
Results: We identified 36 605 870 surgical procedures, between 1 April 2015 and 31 December 2020, of which 1 846 965 (5.0%) were for children. A total of 759 083/1 846 965 (41.1%) patients were female and 313 981 (17.0%) were from minority ethnic groups. There were 41 018/1 846 965 (2.2%) procedures among neonates, 93 872 (5.1%) for children aged 28 days to 1 yr, 532 828 (28.8%) for years 1–5, 502 971 (27.2%) for years 5–12, 361 176 (19.6%) for years 12–15, and 315 100 (17.1%) for years 15–17. Median hospital stay was 1 (0–1) day. There were 6 573/1 846 965 (0.36%) in-hospital deaths within 90 days after surgery, and a trend for increasing mortality risk between 2015 and 2020 ($P<0.05$). The average annual number of procedures before the pandemic (2015–19) was 340 596, decreasing to 266 049 in 2023 (22% reduction in volume).
Conclusions: We report the trends in paediatric surgical volume and assocaited mortality for an entire healthcare system over eight years inlcuding during the COVID-19 pandemic. One in 14 surgical procedures were performed on children, with substantially lower mortality risk than adults.

Keywords: anaesthesia; COVID-19; elective recovery; paediatric surgery; public policy

Editor's key points

- In this retrospective observational cohort study using National Health Service data, the authors describe paediatric surgery and associated mortality in England over an 8-year period from 2015 to 2023.
- In hospital mortality for paedatric patients was 0.36% with one in 14 surgical procedures performed in children compared to adults.
- A notable decrease in pediatric surgical volume was reported in England post-pandemic which only partially recovered to pre-pandemic levels.

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Five million surgical procedures are performed in the UK each year and, before the pandemic, volume for surgery was increasing annually.[1] One in six adults undergoing surgery experience a perioperative complication, associated with mortality in 1–3% of cases.[2,3] There is an increasing research focus on older adults and multi-morbidity,[4] as the surgical population is growing rapidly older with increasing burden of multiple chronic conditions.[5,6] However, 20% of the UK population are children aged under the age of 18 yr,[7] and yet, the impact of surgery on children and the burden of perioperative complications is poorly characterised.

The development of strategies to improve the quality of paediatric surgical care requires robust epidemiological data. Compared with childhood infectious diseases and conditions such as cancer or diabetes, few countries routinely collect and publish data reporting the frequency of paediatric surgical procedures and associated morbidity.[8] Despite this, it is clear that childhood conditions requiring surgery can have lifelong clinical, functional, and psychological impact.[9] This has consequences for child development,[9] return to education and educational attainment, carer's occupation, and the associated financial and social implications for children and their caregivers.[10] The COVID-19 pandemic substantially reduced the delivery of surgical care,[11] leading to cancelled procedures, increasing delays and extending waiting lists.[12] NHS England reports that seven million adults are currently waiting for elective care, an increase from four million in 2019.[13] However, the extent and impact of delays on paediatric surgical procedures remains poorly characterised, not least because the annual number of children undergoing surgery before the pandemic had not been described. Without accurate national data, policymakers are limited in planning recovery strategies, allocating resources, and ensuring equitable access to timely surgical care for children.

There is a need for reliable national data describing the volume of paediatric surgical procedures and associated patient outcomes to support effective service planning and inform health policy. The aim of this study was to analyse national health systems data to report the volume of paediatric surgical activity in England and associated in-hospital mortality within 90 days after surgery, over an 8-yr period that included the COVID-19 pandemic.

Methods

Study design

Nationwide epidemiological study describing all hospital admissions for a surgical procedure in the National Health Service (NHS) in England between 1 April 2015 and 31 March 2023.

Setting

All NHS hospitals in England and NHS funded care in private settings.

Data source

We have previously described our approach in detail.[12,14] We used routinely collected pseudonymised electronic health record Hospital Episode Statistics for Admitted Patient Care (HES APC) data to identify eligible patients. This data source provides detailed data describing every episode of hospital care in England from 1 April 2015 until 31 December 2020. Surgical procedures were identified using Office for Population Censuses Surveys version 4.9 (OPCS4) codes as described previously.[1] We defined surgical procedures as those performed in a specialist facility (i.e. operating theatre) by surgeons under the care of an anaesthetist. Admissions were defined from the date of the first surgical procedure, until the discharge date. Hospital discharge date was determined based on the discharge from continuous in-patient spells, constructed by mapping continuous in-patient episodes.[15] The project was approved by the Health Research Authority (20/HRA/3121) and the NHS Digital Independent Group Advising on the Release of Data (DARS-NIC-375669-J7M7F).

For the financial years 2020–3 we used publicly available aggregate data published by NHS England (digital.nhs.uk). We selected primary procedures and interventions using OPCS4 codes for patients aged <18 yr, from HES APC procedures and interventions data, to ensure comparability with patient level data.[1]

Participants

All patients who underwent a surgical procedure were <18 yr of age. We identified surgical procedures using the previously published list of procedure codes stratified by urgency of surgery. Age for children <1 yr old recorded as 700x codes (7001: <1 day, 7002: 1–6 days, 7003: 7–28 days, 7004: 29–90 days, 7005: 91–181 days, 7006: 182–272 days, and 7007: 273–364 days).

Exposure

The exposure of interest is a surgical procedure according to the previously published list of OPCS-4.9 procedure codes.[1]

Outcomes

The primary outcome was in-hospital death, censored at 90 days for patients remaining in hospital beyond this point. The secondary outcome was length of hospital stay, calculated as the number of days between the initial operation date and discharge date of their continuous in-patient spell, censored at 90 days. Outcome data were available in the record-level cohort (1 April 2015–31 December 2020). We stratified the cohort by demographic data (age, sex, ethnicity, and socioeconomic status). Count data for outcomes with small numbers were suppressed in line with standard procedures for Health Systems Data.[16]

Derivation of variables

Age was defined as that recorded on the start date of the hospital episode including the first surgical procedure. Classification of the type of surgical procedure was based on the first operative code. Where multiple operative codes were associated with surgery on a single day, the highest ranked code was considered the principal surgical procedure. Socioeconomic deprivation was defined according to lower super-output areas using the Index of Multiple Deprivation.[12]

Statistical methods

Count data are presented as frequencies with percentages, and continuous data are presented as mean with standard deviation or median with inter-quartile range. The volume of surgical procedures was calculated with a 95% confidence interval (CI). We compared the annual procedure volume for the years 2015–19 (pre-pandemic) with the years 2020–3 (post

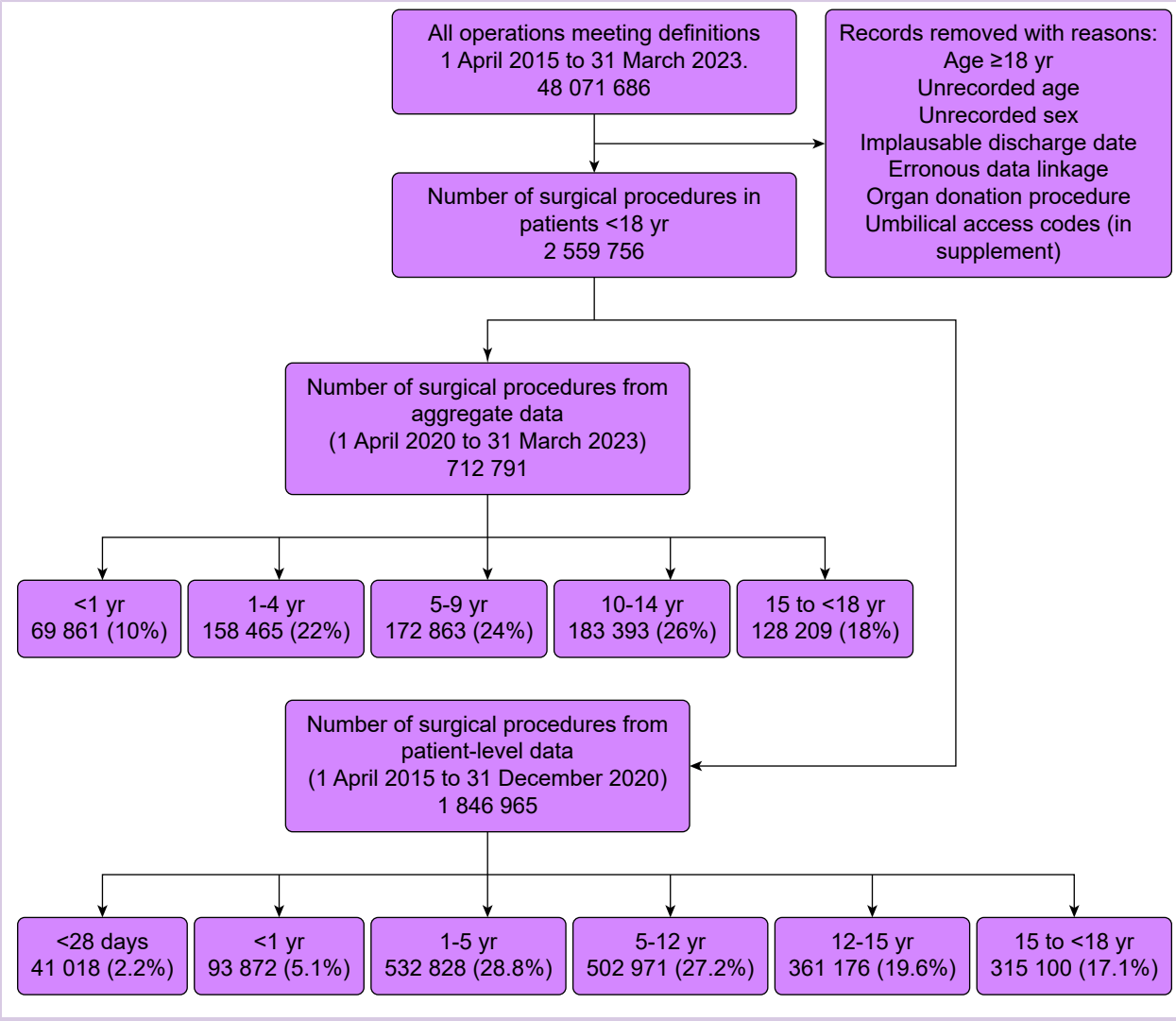

Fig 1. Inclusion of patients in the analysis, categorised by age for patient level data from 1 April 2015 until 31 December 2020 and aggregate data from 1 April 2020 until 31 March 2023.

pandemic). We calculated the deficit of surgical activity in April 2023 by comparing the expected and the actual number of cases that took place in 2020 until 31 April 2023. The expected numbers of procedures were derived from a time series model using pre-pandemic data. We created an additive Holt–Winters exponential smoothing time series model, which accounts for seasonal variation and temporal linear trends (i.e. overall change in number of procedures performed over time).[17] We extrapolated this trend to estimate the number of procedures expected from pre-pandemic trends and subtracted the observed number of procedures to calculate the deficit in surgical activity.

We undertook a *post hoc* analysis of mortality data using a Cochrane Armitage test for trend to determine if a statistically significant linear trend was observed in 90-day in-hospital mortality between 2015 and 2020. We subsequently undertook logistic regression analysis of aggregate mortality data using year as an ordered factor, with 2015 as the reference group.

Subgroup analysis

To provide additional context, we undertook a planned subgroup analysis for 10 pre-specified sentinel procedures, chosen by consensus among investigators [with corresponding OPSC-4.9 codes][1]:

- Appendicectomies [H01]
- Inguinal herniotomies [T19]
- Tonsillectomies [F34], adenoidectomies [E20.1], grommet insertions [D15.1] (TAGs)
- Cleft palate surgeries [F29]
- Micro-laryngoscopy [E37] and bronchoscopies (MLB) [E49]
- Trachea-oesophageal fistula repairs (TOF) [G07.1]

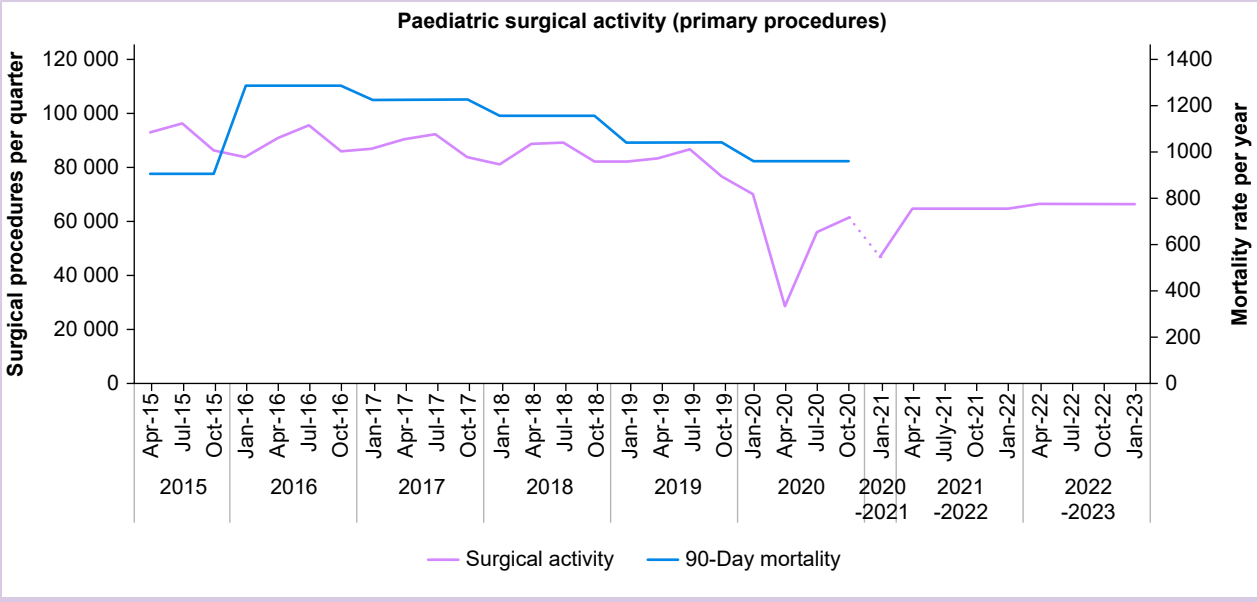

Fig 2. Patient level data of surgical activity from April 2015 until December 2020. Aggregate data of annual paediatric surgical volume from January 2021 until March 2023, presented in financial years. Dotted line represents gap between record-level and aggregate cohorts. The 90-day mortality rate is represented by year from 2015 until 2020. Annual aggregate data were divided by 4 to represent surgical volume by quarter. Mortality data are not available for aggregate data (2021 onwards).

- Hypospadias corrections [M73.1]
- Orchidopexies [N08]
- Pyeloplasty [M05.1]
- Open reduction internal fixation [W20]

These procedures were stratified into elective (tonsillectomies, adenoidectomies, grommet insertions, cleft palate surgeries, hypospadias corrections, herniotomies, and orchidopexies) and urgent or emergency procedures, which were considered to be either an emergency or were given high prioritisation by surgeons during the pandemic (tracheaoesophageal fistula [TOF] repairs, pyeloplasty and open reduction internal fixation, and appendicectomies).

Results

Participants

We identified 36 605 870 surgical procedures in England between 1 April 2015 and 31 December 2020 using the record-level cohort and 11 465 816 admissions between 1 April 2020 and 31 March 2023 using the aggregate cohort. After applying predefined exclusion criteria and excluding missing data, we identified 1 846 965 admissions (5.05%) of paediatric surgical patients in the record-level cohort and 712 791 (6.22%) in the aggregate cohort (Fig. 1).

Volume of surgery

On average, 312 104 (95% CI 272 000–353 000) paediatric surgical procedures were conducted each year between 2015 and 2020. Between 2020 and first quarter of 2023 there were 247 398 (95% CI 225 126–269 670) procedures per year. We observed an expected seasonal variation of a 2.5% reduction in the winter months (Fig. 2).

Stratification by age

Between 1 April 2015 and 31 December 2020; 41 018/1 846 965 (2.2%) procedures were performed for neonates (<28 days old); 93 872/1 846 965 (5.1%) for 28-day to <1-yr-olds; 532 828/1 846 965 (28.8%) for 5–12-yr-olds; 502 971/1 846 965 (27.2%) for 5–12-yr-olds; 361 176/1 846 965 (19.6%) for 12–15-yr-olds; and 315 100/1 846 965 (17.1%) for 15 to <18-yr-old children. From 1 April 2020 to 31 March 2023; 69 861/712 791 (10%) primary surgical procedures involved <1 yr-olds; 158 465/712 791 (22%) 1–4-yr-olds; 172 863/712 791 (24%) 5–9-yr-olds; 183 393/712 791 (26%) 10–14-yr-olds; and 128 209/712 791 (18%) 15 to <18-yr-olds (Fig. 1).

Patient outcomes

The median length of hospital stay for all children was 1 day (inter-quartile range 0–1 days). Some 6573/1 846 965 (0.36%) (95% CI 0.35–0.36%) children who underwent a surgical procedure died (Table 1). We observed a trend of increasing mortality risk between 2015 and 2020 ($P<0.05$). Logistic regression analysis of mortality risk by year identified an increased in mortality risk in 2020 compared with 2015 (odds ratio 1.37 [95% CI 1.25–1.50], $P<0.05$), with no increase in risk for the years 2016–19.

Trends during COVID-19 on surgical volume

Compared with pre-pandemic levels (1 April 2015-31 December 2019) the annual volume of paediatric surgical procedures reduced from 340 596 (95% CI 297 942–383 250) to 212 011 (95% CI 116 634–307 388) in 2020, representing a reduction of 38%. Between 2020 and 2023, the annual volume of procedures increased to 266 049, representing a 25% increase in annual volume. The annual volume of paediatric

Table 1 Mortality rates and median length of stay for all procedures (2015–20). Mortality data not available for aggregate data (2021 onwards). CI, confidence interval; IQR, inter-quartile range; LOS, length of stay. *P value <0.05.

Year	Number of patients	90-Day mortality *n* (%)	Mortality odds ratio (95% CI)	Median LOS
2015	264 822	905 (0.3)	0	0 (IQR: 0–1)
2016	342 451	1284 (0.4)	1.1 (1.01–1.2)*	0 (IQR: 0–1)
2017	339 426	1226 (0.4)	1.06 (0.97–1.15)	0 (IQR: 0–1)
2018	327 538	1156 (0.4)	1.03 (0.95–1.13)	0 (IQR: 0–1)
2019	314 655	1041 (0.3)	0.97 (0.89–1.06)	0 (IQR: 0–1)
2020	205 226	961 (0.5)	1.37 (1.25–1.5)*	0 (IQR: 0–1)

surgical procedures was 22% lower in 2023 compared with pre-pandemic levels (2015–19).

Subgroup analysis of surgical volume during COVID-19

Between 1 April 2015 and 31 December 2020, tonsillectomies, adenoidectomies, grommet insertions, cleft palate surgeries, hypospadias corrections, herniotomies, and orchidopexies (elective surgery), made up 330 182/1 872 622 (17.6%) of the total volume of surgical procedures. These were reduced by 64.5%, from an average of 75 810 (95% CI 55 692–65 603) per year in the years 2015–19 to 26 944 (95% CI 19 493–34 395) in 2020. Urgent and emergency procedures (represented by TOF repairs, pyeloplasty and open reduction internal fixation, and appendicectomies) constituted 87 086/1 872 622 (4.7%), and were reduced by 28.7% (Table 2). Elective surgical procedures were reduced by 43.1% from an average of 235 968 (95% CI 205 791–266 145) per year in the years 2015–19 to 134 369 (95% CI 69 896–198 856) in 2020. Non-elective surgical procedures reduced by 14.7% from an average of 91 012 (95% CI 80 584–101 441) per year in the years 2015–19 to 77 629 (95% CI 52 668–156 080) in 2020 (Table 3).

Index of multiple deprivation

Paediatric patients were categorised into index of multiple deprivation deciles. The most deprived decile underwent the greatest number of procedures 72 646/307 817 (23.6%). The least deprived decile consisted of the smallest number of procedures, 43 737/307 817 (14.2%). The trends observed in the annual number of procedures per decile were preserved throughout the period 2015 to 2020, including the COVID-19 pandemic (Table 3).

Discussion

The principal finding of this nationwide epidemiological study is that on average 340 596 surgical procedures are performed in children each year in the NHS in England. This represents 2.8% of the 12 093 288 children in England (2816 per 100 000 population aged <18 yr), and 7.5% of the total national surgical volume across all age groups including adults (4.8 million).[12] Surgical procedure volume reduced to 212 011 per year during the pandemic, and afterwards only partially recovered to 266 049 procedures per year. The average risk of in-hospital mortality within 90 days after surgery for children was 0.36%, which is much lower than for adults at around 2.3% using similar nationwide NHS data.[1] We observed a 37% increase in mortality risk in 2020 compared with 2015, which is consistent with increased morbidity and mortality in the adult surgical population during this period.[18,19]

There are only limited data describing clinical outcomes after surgery in children, which are mainly limited to disease-specific reporting of volume, mortality, and outcome, rather than systematic population-level reporting across the spectrum of paediatric surgical procedures.[20,21] The seventh national audit project of Royal College of Anaesthetists examined the incidence of perioperative cardiac arrest and reported a mortality rate of 6.5/100 000 within 24 h after surgery in

Table 2 Frequency and median length of stay for sentinel procedures. IQR, inter-quartile range; LOS, length of stay. Micro-laryngoscopy and bronchoscopies data unavailable.

Sentinel procedures	Procedure frequency *n* (%)		Median LOS	
	2015–19	2020	2015–19	2020
Appendicectomies [H01]	53 081 (14.1)	9796 (24.4)	2 (IQR: 1–3)	1 (IQR: 1–3)
Inguinal herniotomies [T19]	27 753 (7.4)	3675 (9.2)	0 (IQR: 0–0)	0 (IQR: 0–0)
Tonsillectomies [F34], adenoidectomies [E20.1], grommet insertions [D15.1] (TAGs)	251 527 (66.7)	19 977 (49.8)	0 (IQR: 0–1), 0 (IQR: 0–0), 0 (IQR: 0–0)	0 (IQR: 0–1), 1 (IQR: 0–1), 0 (IQR: 0–0)
Cleft palate surgeries [F29]	6234 (1.7)	868 (2.2)	1 (IQR: 1–2)	1 (IQR: 1–2)
Trachea-oesophageal fistula repairs (TOF) [G07.1]	776 (0.2)	132 (0.3)	21 (IQR: 11.5–35.5)	21 (IQR: 15–29)
Hypospadias corrections [M73.1]	10 345 (2.7)	1033 (2.6)	0 (IQR: 0–1)	0 (IQR: 0–1)
Orchidopexies [N08]	7379 (1.9)	1391 (3.5)	0 (IQR: 0–1)	0 (IQR: 0–1)
Pyeloplasty [M05.1]	1725 (0.5)	317 (0.8)	2 (IQR: 2–3)	2 (IQR: 1–3)
Open reduction internal fixation [W20]	18 331 (4.9)	2928 (7.3)	1 (IQR: 0–1)	1 (IQR: 0–1)

Table 3 Patient characteristics of record-level cohort for all paediatric surgical procedures. IMD, index of multiple deprivation. Demographic data not available for aggregate data (2021 onwards).

Year	2015	2016	2017	2018	2019	2020	2020–21	2021–22	2022–23
Total number procedures	272 104	351 442	348 733	337 377	325 246	211 998	187 363	25 9379	266 049
Sex, *n* (%)									
Male	158 861 (58.4)	205 936 (58.6)	205 017 (58.8)	205 017 (58.8)	198 762 (58.9)	121 122 (60)	—	—	—
Female	113 243 (41.6)	145 506 (41.4)	143 716 (41.2)	138 615 (41.4)	133 127 (40.9)	84 876 (40)	—	—	—
Admission category, *n* (%)									
Non-elective	76 099 (28)	95 781 (27.3)	96 147 (27.6)	94 098 (27.9)	92 937 (28.6)	77 629 (36.6)	—	—	—
Elective	196 005 (72)	255 661 (72.7)	252 586 (72.4)	243 279 (72.1)	232 309 (71.4)	134 369 (63.4)	—	—	—
IMD decile, *n* (%)									
1	37 235 (13.7)	48 556 (13.8)	47 828 (13.7)	46 736(13.9)	44 981 (13.8)	28 924 (13.6)	—	—	—
2	32 376 11.9)	41 393 (11.8)	41 252 (11.8)	39 223(11.6)	37 956 (11.7)	24 561 (11.6)	—	—	—
3	29 219 (10.7)	37 771 (10.7)	37 727 (10.8)	36 261(10.7)	35 516 (10.9)	22 684 (10.7)	—	—	—
4	26 826 (9.9)	34 196 (9.7)	33 876 (9.7)	33 065(9.8)	31 582 (9.7)	20 200 (9.5)	—	—	—
5	25 292 (9.3)	32 310 (9.2)	32 298 (9.3)	31 304(9.3)	29 743 (9.1)	19 218 (9.1)	—	—	—
6	24 391 (9)	31 333 (8.9)	31 123 (8.9)	30 163(8.9)	29 169 (9)	19 254 (9.1)	—	—	—
7	23 282 (8.6)	29 876 (8.5)	29 867 (8.6)	28 952(8.6)	28 143 (8.7)	18 575 (8.8)	—	—	—
8	23 152 (8.5)	30 073 (8.6)	29 573 (8.5)	28 761(8.5)	27 258 (8.4)	18127 (8.6)	—	—	—
9	22 856 (8.4)	29 693 (8.4)	29 419 (8.4)	28 447(8.4)	27 385 (8.4)	18 010 (8.5)	—	—	—
10	22 628 (8.3)	29 538 (8.4)	28 794 (8.3)	27 642(8.2)	26 635 (8.2)	17 842 (8.4)	—	—	—
Ethnicity, *n* (%)									
White	188 170 (69.2)	239 622 (68.2)	236 460 (67.8)	227 621(67.5)	21 5036 (66.1)	138 345 (65.3)	—	—	—
Asian	21 531 (7.9)	27 822 (7.9)	28 209 (8.1)	29 080 (8.6)	27 847 (8.6)	17 559 (8.3)	—	—	—
Black	12 045 (4.4)	15 556 (4.4)	15 818 (4.5)	15 843 (4.7)	15 575 (4.8)	9822 (4.6)	—	—	—
Other	10 662 (3.9)	13 855 (3.9)	14 093 (4)	14 226 (4.2)	14 449 (4.4)	9989 (4.7)	—	—	—
Not recorded, *n* (%)	39 696 (14.6)	54 587 (15.5)	54 153 (15.5)	50 607 (15)	52 339 (16.1)	36 283 (17.1)	—	—	—

children.[22] By contrast, we report an in-hospital mortality rate of 360/100 000 within 90 days after surgery, which is several orders of magnitude greater. This can be explained by the longer duration of postoperative follow-up, where only a small portion of postoperative morbidity occurs within the first 24 h after surgery, and the reporting methodology of national audit that was limited to positive cases and supplementary snapshot recording of a small portion of denominator activity opposed to systematic reporting of all surgical procedures.[1] Similarly, the APRICOT study reported anaesthetic-related morbidity and mortality in 30 874 children, but not all-cause surgical outcomes.[23] The multicentre perioperative outcome group (MPOG) conducted a study of 606 488 children undergoing surgery across 56 hospitals in the USA and Netherlands and reported a mortality rate of 0.18% with 30 days after surgery.[24] While this study did not measure activity across a whole healthcare system, the results are consistent with the findings of our nationwide study, including the expected increase in mortality between 30 and 90 days after surgery, which replicates the expected approximate doubling of mortality risk over this period.[1] Similarly, an observational study of paediatric surgery among 211 964 children in 81 hospitals across Sweden between 2019 and 2022 reported a mortality rate of 0.15% within 30 days after surgery. In contrast to our study, this included the pandemic period, but did not stratify the results by time or make comparisons with a reference time period.[25] The ASOS-Paeds study, describing the outcomes of 8625 children undergoing surgery in 249 hospitals across Africa, reported a mortality rate of 2.3% within 30 days after surgery.[26] The reported mortality risk is more than six times greater than our national data and does not include the time period between 30 and 90 days after surgery, which likely reflect differences in perioperative care, public health, and service provision in the low- and middle-income country context compared with the other data from high-income countries. There are also likely to be variations in underlying medical conditions and the indication for surgery, which could impact survival.

There are limited data reporting the impact of the COVID-19 pandemic on paediatric surgery, mainly restricted to single-centre and retrospective studies. Our data show that in England during 2020, at the peak of the COVID-19 pandemic, there were 212 011 surgical procedures in children, equating to a 38% reduction compared with 340 596, the annual average for the years 2015–19. This represents the cancellation or postponement of >120 000 surgical procedures in 2020 alone and is weighted much more heavily toward elective surgery compared with emergency surgery. These data are consistent with the surgical literature more broadly, which is more heavily influenced by the impact on adult surgical services. We have previously reported a 34% reduction in the volume of surgical activity in the NHS in England across all age groups over a similar timeframe.[12] Research groups estimate the volume of surgical activity in England is around 80% of pre-pandemic activity.[27] The resulting backlog of postponed and cancelled surgery is well reported, but the resulting impact on the quality and quantity of life for patients with surgical disease is largely unmeasured.[28,29] This is the focus of the NHS Elective Recovery plan,[13] which sets an ambitious target of increasing national surgical activity to 130% of pre-pandemic levels. Our data also signal health disparity across socioeconomic groups among children undergoing surgery, evidenced by a greater volume of procedures among children from more deprived socioeconomic strata. The greater need for surgical input in more deprived children is supported by a higher incidence of paediatric trauma in more deprived areas.[30] Families from higher socioeconomic strata may manage surgical conditions privately to avoid cancellations or delays, which may explain the lower volume of surgical procedures in higher socioeconomic strata.

While there are high-risk surgical procedures and patient groups, the overall mortality risk after paediatric surgery is low. However, we did observe an increase in mortality risk during 2020. Disruption of paediatric surgical procedures combined with the increasing mortality risk, highlights the vulnerability of the paediatric surgical population in healthcare system disruptions. Policy makers and healthcare providers would need to take account of health services utilisation, the specific characteristics of the pandemic disease in question, and individual needs of surgical patients, for example including the potential redeployment of staff to other clinical areas or services, when planning clinical services in future pandemics particularly when children are affected by the pandemic disease in question.

We report national trends of surgical volume and postoperative mortality; however, further healthcare system-wide research is needed to understand the causes of perioperative morbidity and mortality in children, a neglected research area compared with adult populations, to provide clinical context and inform service planning and prioritisation in future healthcare system disruptions. Future research should address focused paediatric outcomes such as school absence, although this would be challenging to deliver using administrative data without linking multiple data sets. A prospective observational cohort study would be unlikely to provide healthcare system perspective.

Strengths

We report paediatric outcomes on a national level, including data from 1.8 million paediatric surgical patients. We use routinely collected administrative data from all NHS hospitals in England, so our study is less subject to inclusion bias. We report in-hospital mortality rates within 90 days after surgery, which addresses the acknowledged narrow scope of traditional outcome assessment at 30 days after surgery. Our data are generalisable to high-income countries where, on a speciality level, similar reductions in surgical volume were observed nationwide.[31] Our data remain relevant, given the continued impact of pandemic-related cancellations on the recovery of elective surgical services. This is exemplified by the inclusion of winter quartiles, which confirms observed seasonal reductions in operating.

Limitations

The use of routinely collected data introduces a risk of incorporating incomplete or missing information. Although the impact is often minor, we excluded incomplete or missing data from our analysis to minimise this risk. Following industry-standard procedures, we applied small number suppression for low-volume surgical procedures or characteristics to prevent inadvertent identification of patient subgroups. Consequently, we were unable to report mortality rates for sentinel procedures because of low frequencies, instead reporting length of stay. Our use of national health systems data allowed us to report the volume of surgical procedures and associated mortality across an entire health

system. However, the data source is limited in some detail, including comorbidities, anaesthesia care, and specific paediatric outcomes such as absence from school. To broaden the scope of the record-level analysis, we supplemented the cohort with additional publicly available aggregate data. This allowed us to report the trend in procedure volume in the immediate post-pandemic period. However, the inclusion of two cohorts may be a source of bias. While the record-level cohort includes rich data on admissions and outcomes, the aggregate data lacked detail on clinical outcomes and we were unable to stratify the data by patient characteristic (e.g. age category), which limited granularity of the analysis. Variations in time coverage between the two cohorts may also cause temporal misalignment. We pre-specified the age categories and chose to report neonates aged <28 days separately from infants aged <1 yr because neonates form a distinct surgical population with unique physiological and pathological profiles. This analysis was limited to England's publicly funded national healthcare system so our findings may not be generalisable to other countries, private healthcare systems or low- and middle-income countries.

Conclusions

We report the trends in paediatric surgical volume and associated mortality for an entire healthcare system over eight years inlcuding during the COVID-19 pandemic. One in 14 surgical procedures were performed on children, with substantially lower mortality risk than adults.

Authors' contributions

Study design: TA, AF, TD, RP
Data collection: JA, AF
Data analysis: JA, AF, TA
Data interpretation: JA, AF, TA, RP
Wrote the first draft of the manuscript: JA, TA
Revised the manuscript for important intellectual content and approved the final version: All authors
Had full access to the data and act as guarantors: JA, AJF, TA

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Patient and public involvement

A patient representative was consulted in the design of this study.

Transparency declaration

JA affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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Declarations of interest

All authors have completed the Unified Competing Interest form and declare the following. AJF holds a National Institute for Health Research Doctoral Research fellowship (DRF-2018-11-ST2-062). BA holds an NIHR Health and Social Care Delivery Research grant. TDD sits on the editorial board for the Royal College of Surgeons of England Bulletin. MK is an NIHR senior investigator (Award Reference Number NIHR303806). The views expressed are those of the author(s) and not necessarily those of the NIHR or the Department of Health and Social Care. RP has received honoraria, research grants, or both from Edwards Lifesciences within the last five years; received funding from Intersurgical UK Ltd; holds editorial roles with the *British Journal of Anaesthesia*; and is an NIHR senior investigator. TA is supported by an NIHR DSE (NIHR305701); has received research funding from NIHR, Barts Charity, the Academy of Medical Sciences, The Royal College of Anaesthetists, and *British Journal of Anaesthesia*; has received honoraria from Merck Sharp Dohme, Edwards Life Sciences, and Elsevier; and is social media editor of the *British Journal of Anaesthesia*. All other authors report no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, and no other relationships or activities that could appear to have influenced the submitted work.

Data sharing

The data used in this study were derived from one data source. It is not possible to share the raw patient level data provided by NHS Digital describing NHS patients in England.

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