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Impact of the COVID-19 pandemic on the clinical management trends for acute appendicitis among the under-25s: a retrospective study

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ABSTRACT

Objective To describe the COVID-19 pandemic's impact on acute appendicitis management on children and young people (CYP).

Design Retrospective cohort study.

Setting All English National Health Service hospitals.

Patients Acute appendicitis admissions (all, simple, complex) by CYP (under-5s, 5–9s, 10–24s).

Exposure Study pandemic period: February 2020–March 2021. Comparator pre-pandemic period: February 2015–January 2020.

Main outcome measures Monthly appendicectomy and laparoscopic appendicectomy rate trends and absolute differences between pandemic month and the pre-pandemic average. Proportions of appendicitis admissions comprising complex appendicitis by hospital with or without specialist paediatric centres were compared.

Results 101 462 acute appendicitis admissions were analysed. Appendicectomy rates fell most in April 2020 for the 5–9s (–18.4% (95% CI –26.8% to –10.0%)) and 10–24s (–28.4% (–38.9% to –18.0%)), driven by reductions in appendicectomies for simple appendicitis. This was equivalent to –54 procedures (–68.4 to –39.6) and –512 (–555.9 to –467.3) for the 5–9s and 10–24s, respectively. Laparoscopic appendicectomies fell in April 2020 for the 5–9s (–15.5% (–23.2% to –7.8%)) and 10–24s (–44.8% (–57.9% to –31.6%)) across all types, which was equivalent to –43 (–56.1 to 30.3) and –643 (–692.5 to –593.1) procedures for the 5–9s and 10–24s, respectively. A larger proportion of complex appendicitis admissions were treated within trusts with specialist paediatric centres during the pandemic.

Conclusions For CYP across English hospitals, a sharp recovery followed a steep reduction in appendicectomy rates in April 2020, due to concerns with COVID-19 transmission. This builds on smaller-sized studies reporting the immediate short-term impacts.

INTRODUCTION

The COVID-19 pandemic disrupted hospital services worldwide,^{1 2} and early studies reported significant declines in surgeries, in part to ensure capacity for surges in COVID-19 admissions and to reduce possible exposure risk through aerosol-generating procedures (AGPs) within hospitals.^{3 4} While SARS-CoV-2 produces a mild, self-limiting viral illness in most children and young people (CYP),^{5–7} the indirect impacts of the pandemic on CYP's health appear to be significant.⁸

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ COVID-19 studies on how acute appendicitis was clinically managed have often focused on smaller numbers of hospitals, adult populations and fewer pandemic waves.
- ⇒ Most published studies in this area have focused on the first few pandemic weeks and compared this only with the previous year.

WHAT THIS STUDY ADDS

- ⇒ This is the first study to capture all acute appendicitis hospital admissions among the under-25s in England from February 2015 to March 2021.
- ⇒ There were large changes in appendicectomy and laparoscopic appendicectomy rates for simple appendicitis during the pandemic but relatively stable procedure rates for complex appendicitis.
- ⇒ Pre-pandemic trends towards centralisation of care and reduced variation in surgery rates for children with complex appendicitis in non-specialist centres continued during the pandemic.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ These findings reinforce the importance of early recognition and referral of appendicitis by paediatricians, general practitioners and all acute child health professionals.
- ⇒ The COVID-19 pandemic may have strengthened previous efforts to address variations in complex appendicitis by hospital, but future research could explore what impact the pandemic had on variations in the rate of negative appendicectomy or laparoscopic appendicectomy.
- ⇒ These findings can be used to better understand how COVID-19 impacted the management of appendicitis, providing a national picture of how hospitals dealt with acute appendicitis admissions in the first 14 months of the pandemic.

Appendicitis, one of the most common surgical emergencies affecting CYP, is a useful condition to better understand the pandemic's impacts on CYP. A national initiative⁹ has highlighted disparities in care for CYP with appendicitis and has

recommended improving access to laparoscopic surgery, in contrast to open surgery, in younger children and standardising postoperative care as key approaches to addressing these disparities in care. Paediatricians and the multidisciplinary health teams play a pivotal role in supporting improvements in patient care for CYP with appendicitis^{10 11} as they are experienced in dealing with unexplained symptoms in CYP¹⁰ and are frequently the first point of contact.¹²

Smaller-scale studies have reported changes in the care of CYP with appendicitis during the pandemic,^{13–15} but to fully appreciate this impact, measuring changes over a longer pandemic period and understanding pre-pandemic trends beyond the previous year are needed. Key pre-pandemic changes in care include the increased provision of laparoscopic surgery and non-operative management in simple appendicitis,^{16–19} which likely changed during the pandemic when early guidance cautioned against using laparoscopy as it is an AGP.^{20 21} In the UK, acute appendicitis is generally treated by general or paediatric surgeons within specialist paediatric centres,²² and there is ongoing debate about where paediatric surgeries are conducted and how this may impact disparity in outcomes.^{21 23}

Acute appendicitis is a high-volume time-sensitive paediatric surgical condition, where presentation delays may result in higher complex appendicitis rates. The pandemic's impact on acute surgical activity in the UK needs to be better understood in the context of pre-pandemic trends and beyond the first few pandemic weeks for CYP.

Primary aims

To describe the monthly impact COVID-19 had on appendectomy and laparoscopic appendectomy rates and if any changes persisted.

Secondary aim

To explore changes to the proportion of complex appendicitis admissions by hospital between study periods.

METHODS

Data sources and cohort definition

England's Hospital Episode Statistics (HES) admitted patient care data were analysed and individuals with at least one hospital spell were extracted. Further information on HES is available elsewhere.²⁴ At the time of analysis, data were available up to March 2021. Transfers between consultants and hospitals were linked into 'superspells' and referred to as admissions.

Admissions by patients under-25 were extracted. Acute appendicitis was defined using codes provided elsewhere²⁵ (online supplemental tables A–C). The WHO age categories were used: 0–4 (under-5s), 5–9 (5–9s) and 10–24 years (10–24s). Although local protocols may vary, these age groups broadly reflect National Health Service pathways whereby most children under-5 years with appendicitis would be transferred to a specialist centre, while most aged 10 years or over would be treated in a District General Hospital.

Acute appendicitis was analysed into three subgroups: (1) all (2) simple and (3) complex (online supplemental table A). K35 was stratified into simple and complex appendicitis. Clinical coders use histopathology to code appendicitis. Admissions with diagnosis codes for simple and complex appendicitis were classified as complex, as we assumed that these admissions reflected admissions that started as simple appendicitis and, within the course of the admission, developed into complex appendicitis.

Exposure and outcomes

The pre-pandemic period was 1 February 2015–31 January 2020. The pandemic period was 1 February 2020–31 March 2021, covering three national lockdowns approximately defined as March–June 2020, November 2020 and January–March 2021.²⁵ The pandemic period included February 2020, as the first cases of COVID-19 diagnosed in England occurred in late January 2020.²⁶

Primary outcomes

Monthly appendectomy and laparoscopic appendectomy rate trends, differences in rates and counts between each pandemic month and the average of the same month for 5 pre-pandemic years, and if changes persisted beyond the first pandemic wave. When we refer to absolute differences, we refer to the difference in admission counts. The numerator and denominator for the monthly appendectomy rate were the number of acute appendicitis admissions treated with appendectomy divided by the number of acute appendicitis admissions, respectively. For monthly laparoscopic appendectomy rates, the numerator and denominator were defined as the number of acute appendicitis admissions treated with laparoscopic appendectomy and the number of acute appendicitis admissions treated with appendectomy, respectively. Further details on how appendectomy and laparoscopic appendectomy were coded can be found in the online supplemental table B.

Secondary outcomes

Proportion of complex appendicitis admissions by hospital trust (a trust may comprise more than one hospital site) between pandemic periods.

Statistical analyses

Pre-pandemic trends were plotted. Graphically, the pre-pandemic monthly mean over the five pre-pandemic years links to the pandemic monthly count or rate. To avoid seasonal biases, the difference between the observed and expected monthly figures was reported based on the pre-pandemic mean.

Funnel plots compared crude complex appendicitis admissions by hospital between pandemic periods. Funnel plots were used to identify which hospitals had significantly higher or lower proportions of crude complex appendicitis relative to the other trusts in the plot. To ensure hospital sample sizes were comparable between pandemic periods and not unfairly penalise larger hospitals that may treat a higher proportion of complex appendicitis admissions, the 14 pandemic months were compared with the preceding 14 pre-pandemic months. As control limits for the funnel plot are not robust when admission counts are low, hospitals that had fewer than 50 appendicitis admissions in either the pre-pandemic or pandemic period were excluded. Trusts that provided specialist paediatric services were highlighted.²⁷

An interrupted time series (ITS) analysis was performed to establish if rate changes in the first pandemic wave persisted beyond it. ITS enables the comparison of the pre-pandemic trend with the trend after the first pandemic wave, which is important as considerable pre-pandemic trends occurred before the pandemic. By accounting for pre-pandemic trends, we are able to statistically test for any changes in these trends that occur after the first pandemic wave. ITS modelled patient-level data for better granularity; the interaction variables were coded as an ascending continuous month variable and a dichotomous pandemic variable, where '1' was the pandemic period.

Table 1 Patient characteristics

Feature	Value	Acute appendicitis	
		Pre-pandemic N=83 590 (%)	Pandemic N=17 872 (%)
Appendicitis classification	Simple appendicitis (K35.8)	70 756 (84.6)	9882 (55.3)
	Complex appendicitis (K35.2, K53.3)	9882 (11.8)	5716 (32.0)
	All (including unspecified, K37)	83 590 (100.0)	17 872 (100.0)
Age	Mean (SD)	15.4 (5.5)	15.5 (5.5)
	0–4	1624 (1.9)	368 (2.1)
	5–9	12 679 (15.2)	2853 (16.0)
	10–24	69 287 (82.9)	14 651 (82.0)
Gender	Male	48 156 (57.6)	10 575 (59.2)
	Female	35 434 (42.4)	7297 (40.8)
Deprivation quintile	1 (least deprived)	16 848 (20.2)	3825 (21.4)
	2	15 803 (18.9)	3426 (19.2)
	3	15 202 (18.2)	3304 (18.5)
	4	15 983 (19.1)	3343 (18.7)
	5 (most deprived)	18 823 (22.5)	3878 (21.7)
	6 (unknown)	931 (1.1)	96 (0.5)
Ethnic group	Black or Black British	1755 (2.1)	366 (2.1)
	Asian or Asian British	5780 (6.9)	1329 (7.4)
	White	61 393 (73.5)	12 857 (71.9)
	Other (including mixed)	4635 (5.5)	1071 (6.0)
	Unknown	10 027 (12.0)	2249 (12.6)
Admission source	Home	78 079 (93.4)	16 655 (93.2)
	Transfers from acute hospital	478 (0.6)	122 (0.7)
	Transfers from other hospital	4417 (5.3)	981 (5.5)
	Other/unknown	616 (0.7)	114 (0.6)
Emergency admissions in previous 12 months	0	73 488 (87.9)	15 552 (87.0)
	1	7866 (9.4)	1837 (10.3)
	2	1457 (1.7)	312 (1.8)
	3+	779 (0.9)	171 (1.0)

Differences in appendicectomy and laparoscopic appendicectomy rates between periods and the last quarter of the study were tested using Pearson's X^2 test. Where expected counts were less than five, Fisher's exact test was used.

All analyses used SAS software V.9.4, and the statistically significant threshold was 0.05.

Sensitivity analysis

The appendicitis definition for the sensitivity analysis is in online supplemental tables A–E. The main and sensitivity definitions were compared.

RESULTS

Table 1 describes the patient characteristics. 625 (0.6%) admissions were coded as both simple and complex within the same admission.

Appendicectomy

The proportion of appendicitis admissions treated surgically via an appendicectomy was slowly declining over the last five years before the pandemic (online supplemental figure 1). During the pandemic, rates for the 5–24s reduced significantly (figure 1). The largest reduction was among the 10–24s in April (–28.4% (–38.9 to –18.0)) and May 2020 (–19.7% (–28.5 to –11.0)), driven by fewer appendicectomies for simple appendicitis (online supplemental tables 1–4). The absolute reductions were –54 appendicectomies (–68 to –40) for the 5–9s and –512

appendicectomies (–556 to –467) for the 10–24s in April. A similar reduction was observed in May (5–9s: –39 (–52 to –27); 10–24s: –424 (–465 to –384)). A small number of under-5s were diagnosed with appendicitis (online supplemental tables 5 and 6), but a reduction in appendicectomy rates for simple appendicitis was shown.

ITS analysis demonstrated that the odds of surgical treatment (appendicectomy) after the first pandemic wave, compared with the pre-pandemic period, dropped significantly for all admissions (under-5s: 0.39 (0.19 to 0.80), $p=0.0102$; 5–9s: 0.33 (0.24 to 0.45), $p<0.0001$; 10–24s: 0.31 (0.27 to 0.36), $p<0.0001$) (table 2). Fewer surgeries for complex admissions drove this for the under-5s (OR 0.22 (0.08 to 0.59), $p=0.0028$) and for simple and complex admissions for the older age groups. For each month after the first wave, treatment with appendicectomy for all appendicitis was statistically significant, but with small effect sizes (all: under-5s: OR 0.99 (0.98 to 1.00), $p=0.025$; 5–9s and 10–24s: 0.99 (0.99 to 0.99), $p<0.0001$). The appendicectomy rate slope recovered after the first wave and remained unchanged for the under-5s (OR: 1.08 (0.95 to 1.23), $p=0.2249$) but was significantly steeper for the older CYP (5–9s: OR 1.10 (1.04 to 1.16), $p=0.001$; 10–24s: 1.05 (1.03 to 1.08), $p<0.0001$).

The overall appendicectomy rate of the last 3 pandemic months remained unchanged from the pre-pandemic rate for the under-5s (all: $p=0.4711$; simple: $p=0.7544$; complex: $p=0.2873$). There was a similar pattern for complex admissions

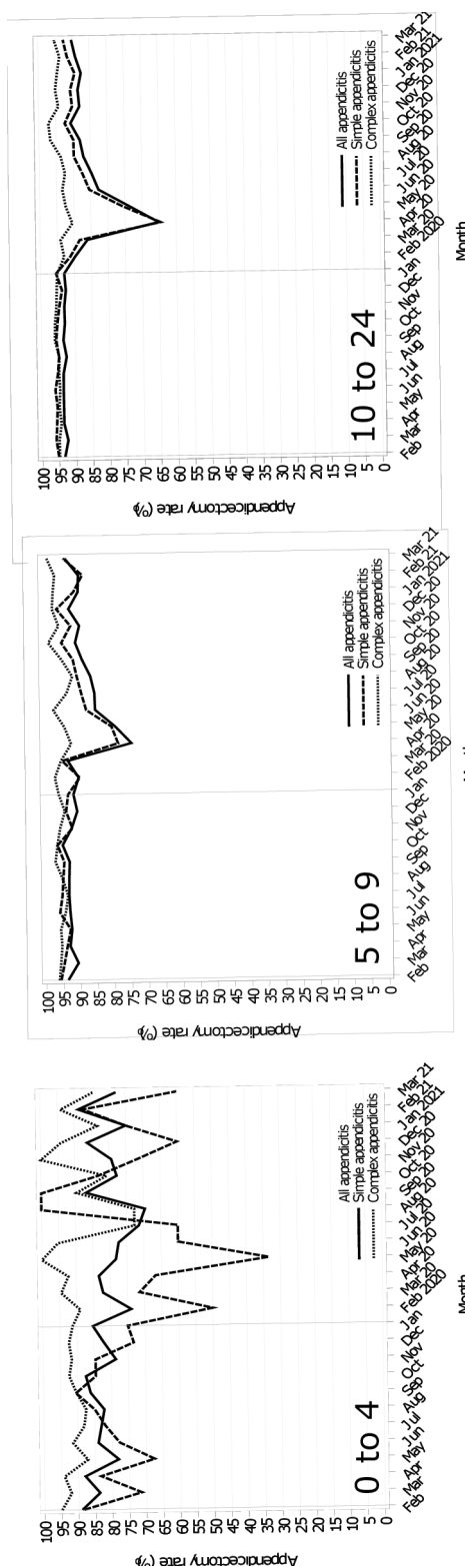


Figure 1 Monthly appendectomy rate trends during the pandemic and the mean monthly rates for the previous 5 years, stratified by appendicitis type and age group.

(5–9s: $p=0.1505$; 10–24s: $p=0.2238$). Overall appendectomy rates for simple appendicitis admissions significantly increased in the later pandemic months for the 5–9s (91.3% vs 94.5%, $p=0.0159$), and decreased for the 10–24s (95.3% vs 91.2%, $p<0.0001$).

Laparoscopic appendicectomy

There was a clear increasing pre-pandemic trend for laparoscopic appendicectomies, as opposed to an open appendicectomy, with approximately 85% performed laparoscopically in CYP before the pandemic (online supplemental figure 2). Laparoscopic appendicectomy rates fell sharply in April (under-5s all: -39.0% (-51.2 to -26.7); simple: -66.7% (-82.7 to -50.7); complex: -29.2% (-39.8 to -18.6); 5–9s all: -15.5% (-23.2 to -7.8); simple: -18.9% (-27.5 to -10.4); complex: -16.0% (-23.9 to -8.2)); 10–24s all: -44.8% (-57.9 to -31.6); simple: -49.5% (-63.3 to -35.7); complex: -37.9% (-49.9 to -25.8)) and May 2020, followed by a rapid recovery, across all subtypes and ages from July 2020 onwards (figure 2 and online supplemental tables 7–9). The largest absolute reductions were among the 10–24s for April 2020 (all: -643 procedures (-693 to -593); simple: -395 (-434 to -356); complex: 143 (-166 to -119)) (online supplemental tables 10–12).

After the sharp decline in laparoscopic appendicectomy rates early in the pandemic, rates rebounded significantly and peaked in March 2021 (all: $+38.9\%$ (26.7 to 51.1)) for the under-5s, October (all: $+23.9\%$ (14.3 to 33.4)) for the 5–9s and February 2021 (all: $+12.7\%$ (5.7 to 19.7)) for the 10–24s (online supplemental tables 7–9). The equivalent absolute difference was non-significant for the under-5s ($+0.8$ (-1.0 to 2.6)) and significant, but of relatively minor clinical effect, for the older age groups (5–9s: $+28.0$ (17.6 to 38.4); 10–24s: $+10.0$ (3.8 to 16.2)) (online supplemental tables 10–12).

The odds of laparoscopic appendicectomy significantly increased after the first wave for all admissions (under-5s: OR 2.53 (1.23 to 5.23), $p=0.0118$; 5–9s: 3.97 (3.18 to 4.95), $p<0.0001$; 10–24s: 2.83 (2.43 to 3.30), $p<0.0001$) (table 2). For the under-5s and 10–24s, the gradient of the laparoscopic appendicectomy rate did not significantly change, but for the 10–24s, the gradient was significantly but modestly steeper after the first wave for all appendicitis (OR 1.03 (1.01 to 1.06), $p=0.0192$).

Laparoscopic appendicectomies significantly increased in the last quarter, compared with the pre-pandemic period, across all age groups and subtypes, except for simple appendicitis among the under-5s (57.3% vs 69.2%, $p=0.5691$). Overall, laparoscopic appendicectomies for all (56.5% vs 83.9%, $p<0.0001$) and complex (55.7% vs 88.1%, $p<0.0001$) for the under-5s significantly increased in the last 3 pandemic months, compared with the pre-pandemic period. The 5–9s (all: 43.4% vs 61.9%, $p<0.0001$; simple: 39.7% vs 54.8%, $p<0.0001$ and complex: 49.0% vs 70.3%, $p<0.0001$) and 10–24s had similar trends (all: 82.3% vs 91.7%, $p<0.0001$; simple: 83.5% vs 91.7%, $p<0.0001$ and complex; 79.3% vs 91.4%, $p<0.0001$).

Funnel plots

The funnel plots reflect 115 hospitals. 21 of the 22 hospitals with specialist paediatric surgical services (specialist) were included. The funnel plots showed significant variation in both pre-pandemic and pandemic rates (figure 3). Further details on the funnel plot are provided elsewhere (online supplemental text C).

Sensitivity analysis

Sensitivity and main analysis definitions generated similar counts across age groups (online supplemental figures D–F).

Table 2 Summary of the interrupted time series analysis for appendicectomy and laparoscopic appendicectomy rate of the 5 pre-pandemic years compared with the rates after the first pandemic wave

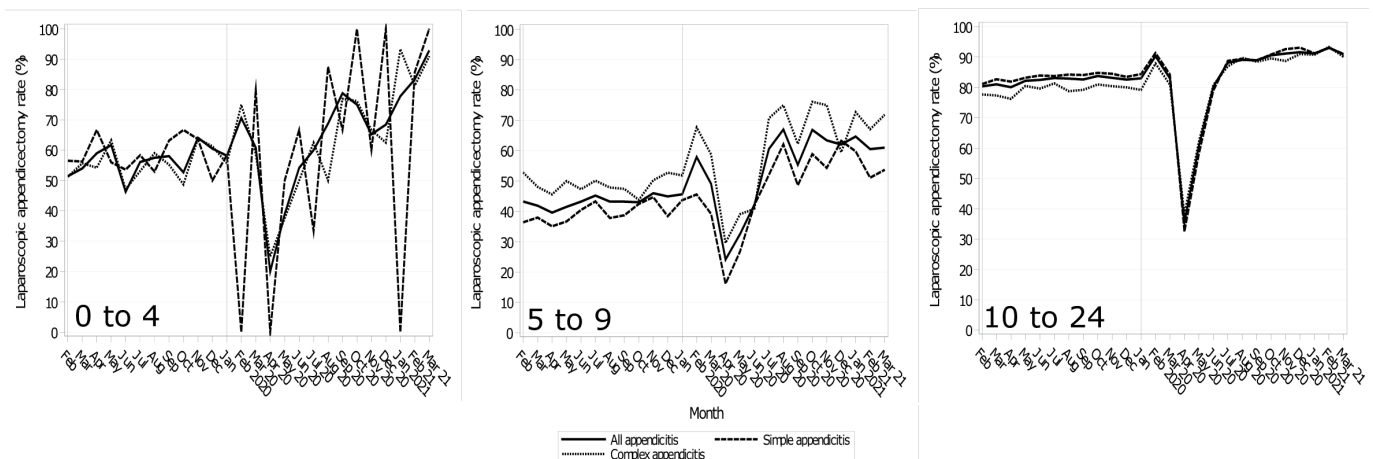
Appendicectomy						
	All		Simple		Complex	
	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Under-5s						
Month counter (A)	0.99 (0.98 to 1.00)	0.025*	0.99 (0.97 to 1.00)	0.0674	0.99 (0.98 to 1.01)	0.312
COVID-19 flag (B)	0.39 (0.19 to 0.80)	0.0102*	1.00 (0.19 to 5.18)	0.9979	0.22 (0.08 to 0.59)	0.0028*
A×B	1.08 (0.95 to 1.23)	0.2249	0.92 (0.70 to 1.19)	0.5119	1.18 (0.98 to 1.43)	0.0783
5–9s						
Month counter (A)	0.99 (0.99 to 0.99)	<0.0001*	1.00 (0.99 to 1.00)	0.2594	0.99 (0.98 to 1.00)	0.0229*
COVID-19 flag (B)	0.33 (0.24 to 0.45)	<0.0001*	0.50 (0.29 to 0.85)	0.0106*	0.37 (0.18 to 0.75)	0.006*
A×B	1.10 (1.04 to 1.16)	0.001*	1.04 (0.95 to 1.14)	0.3956	1.20 (1.04 to 1.39)	0.0121*
10–24s						
Month counter (A)	0.99 (0.99 to 0.99)	<0.0001*	0.99 (0.98 to 0.99)	<0.0001*	0.99 (0.99 to 1.00)	0.0013*
COVID-19 flag (B)	0.31 (0.27 to 0.36)	<0.0001*	0.25 (0.20 to 0.31)	<0.0001*	0.68 (0.46 to 0.99)	0.0437*
A×B	1.05 (1.03 to 1.08)	<0.0001*	1.06 (1.02 to 1.10)	0.001*	1.02 (0.96 to 1.09)	0.5334
Laparoscopic appendicectomy						
Under-5s	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Month counter (A)	1.02 (1.02 to 1.03)	<0.0001*	1.03 (1.02 to 1.04)	<0.0001*	1.02 (1.02 to 1.03)	<0.0001*
COVID-19 flag (B)	2.53 (1.23 to 5.23)	0.0118*	3.96 (0.83 to 18.89)	0.0847	2.16 (0.92 to 5.02)	0.0753
A×B	1.11 (0.97 to 1.28)	0.1272	1.03 (0.77 to 1.36)	0.8573	1.15 (0.98 to 1.36)	0.0822
5–9s						
Month counter (A)	1.02 (1.02 to 1.02)	<0.0001*	1.02 (1.02 to 1.02)	<0.0001*	1.02 (1.02 to 1.02)	<0.0001*
COVID-19 flag (B)	3.97 (3.18 to 4.95)	<0.0001*	3.40 (2.50 to 4.62)	<0.0001*	4.76 (3.35 to 6.78)	<0.0001*
A×B	0.98 (0.94 to 1.02)	0.2519	0.98 (0.93 to 1.03)	0.4811	0.97 (0.91 to 1.03)	0.3034
10–24s						
Month counter (A)	1.02 (1.02 to 1.02)	<0.0001*	1.02 (1.02 to 1.03)	<0.0001*	1.02 (1.02 to 1.02)	<0.0001*
COVID-19 flag (B)	2.83 (2.43 to 3.30)	<0.0001*	2.89 (2.35 to 3.54)	<0.0001*	3.23 (2.47 to 4.22)	<0.0001*
A×B	1.03 (1.01 to 1.06)	0.0192*	1.03 (0.99 to 1.07)	0.1037	1.03 (0.98 to 1.08)	0.1833

*, p<0.05.

DISCUSSION

There were fundamental changes in the care of CYP with appendicitis in the first 14 months of the COVID-19 pandemic. The proportion of CYP diagnosed with complex appendicitis increased, driven more by a reduction in simple rather than an increase in complex admissions, aligning with international studies spanning shorter periods.²⁸ It is unclear why hospital

admissions by CYP with simple appendicitis decreased. Possible reasons include earlier commencement of antibiotics before a confirmed diagnosis, changes to seasonal and helminth causes of appendicitis or spontaneous resolution of symptoms.²⁹ During the pandemic, there was a small but significant increase in the proportion of complex appendicitis treated within hospitals with specialist paediatric surgical centres. Before the pandemic,

**Figure 2** Monthly laparoscopic appendicectomy rate trends during the pandemic and the mean monthly rates for the previous 5 years, stratified by appendicitis type and age group.

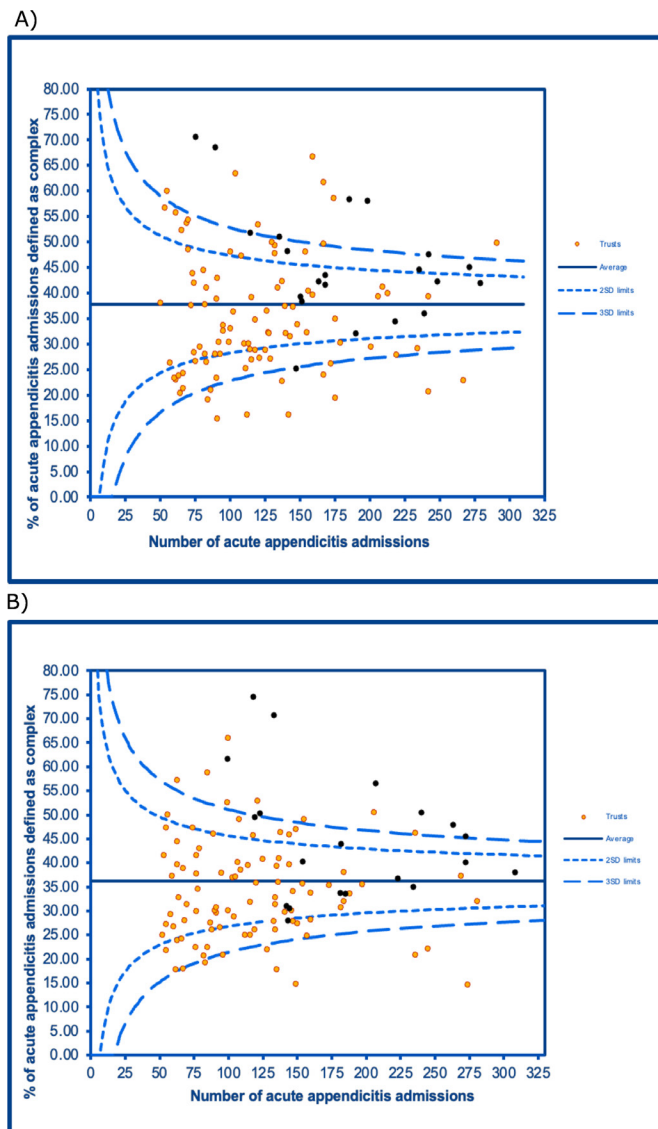


Figure 3 Funnel plot of (A) pre-pandemic and (B) pandemic crude complex appendicitis rates by trust in England, where hospital trusts with specialist paediatric surgical centres are marked black.

there were variations in the quality of care for appendicitis, which were identified by the Getting It Right First Time report, including variations in outcomes depending on where complex appendicitis is managed.⁹ Previous efforts to standardise care for CYP with acute appendicitis have included the introduction of paediatric networks at regional and national levels to improve the coordination of surgical services, with some early signs of improvement.⁹

Like many other European countries,³⁰ despite guidance advising against surgical procedures involving AGP, treatment of complex appendicitis remained relatively steady. More than 95% of complex appendicitis admissions for the 5–24s were treated with an appendicectomy. For the under-5s, who are more likely to present with complex appendicitis and not treated with an appendicectomy because of an appendix mass, the absolute difference in appendicectomies did not significantly change between periods for most pandemic months. This persistence in operative management throughout the pandemic demonstrates appendicectomies' pivotal role in treating complex appendicitis.

There was a pre-pandemic reduction in the proportion of appendicitis admissions treated by appendicectomy, which adds to the growing international literature in adults^{31 32} and CYP³³ on the trend towards non-operative management of simple appendicitis. In keeping with some of the literature,^{16 34} a significant decrease in appendicectomy for simple appendicitis was seen across all ages in the first pandemic wave, with up to 35% non-operatively managed. It is unknown if an even higher proportion of CYP with presumed simple appendicitis started and failed a trial of non-operative management, resulting in a delay to appendicectomy, or whether the majority of those managed with antibiotics were successfully treated. Interestingly, this trend did not continue after the first pandemic wave, and the odds of undergoing appendicectomy for simple appendicitis were equivalent to or higher than that before the pandemic. This highlights an important area for future research into operative and non-operative pathways for appendicitis management with careful investigation of the success rate and the risk of recurrent appendicitis and operative complications.

The pre-pandemic laparoscopic appendicectomy rate steadily increased such that over 85% of appendicectomies in CYP were performed laparoscopically. During the first wave, the guidance cautioned the use of laparoscopy due to concerns it may contribute to SARS-CoV-2 spread. This reflects our findings where, during the first pandemic wave, <40% of appendicectomies were performed laparoscopically, matching a smaller study on adults.³⁵ Reassuringly, this was rapidly reversed, and the pre-pandemic trend of increasing laparoscopic appendectomy rates for CYP has continued.

The provision of care for CYP with complex appendicitis changed during the first pandemic year. While paediatric surgical centres are normally more likely to care for a higher proportion of children with complex appendicitis, these findings suggest that even more CYP were transferred to specialist centres during the pandemic. This could reflect the diversion of paediatric healthcare staff and areas to adult care during the pandemic, particularly within non-specialist centres, or changes to operating theatre availability for CYP with complex appendicitis could suggest that the CYP with complex appendicitis during the pandemic were more unwell. A more detailed investigation of why there is hospital-level variation is beyond the scope of this paper, but these findings highlight the need for more in-depth studies, which can be supported through initiatives like national audit programmes. Future studies could investigate the effects of the pandemic on length of stay, negative appendicectomy rate and laparoscopic appendicectomy rate by hospitals with or without specialist paediatric services. Additionally, future research could investigate if paediatric surgical centres continued to care for a higher proportion of children with complex appendicitis beyond the first 14 months of the pandemic.

Strengths and limitations

This study is the first to report a national overview of the month-by-month and overall trends and referral patterns spanning 14 months. First, this builds upon previous work focusing on the early pandemic weeks, adult populations or smaller groups of hospitals, whose findings cannot be generalised nationally. Incorporating 5 pre-pandemic years is a particular strength as it challenged assumptions of no pre-pandemic trends, highlighting the importance of accurately contextualising findings. Second, the large sample size provided robust numbers, facilitating stratifications by age and subtypes, and reporting of granular changes in relative and absolute terms. Third, applying ITS analysis, an

advanced statistical methodology generates robust and more accurate results.³⁶ Fourth, primary diagnosis and procedure codes in HES are >95%³⁷ accurate, further supporting the validity of our findings. Fifth, the cohort study design is methodologically robust over case reports and cross-sectional studies. Sixth, the month-by-month findings empower national decision-makers with details on how hospitals coped with changes during the pandemic, which can inform responses to possible future outbreaks or pandemics.

Limitations were first, being unable to draw causal inferences due to unmeasured confounding. Second, HES does not offer linked prescribing, laboratory or physiological data, such as diagnostic imaging or antibiotic prescribing data. Third, it was not possible to know which admissions were confirmed by diagnostic imaging or how diagnostic imaging evolved during the pandemic. CT scans are rarely used to diagnose appendicitis in children, but what impact possible changes to diagnostic imaging over the pandemic on diagnosis remains unclear. Fourth, one single-centre study reported underestimation of complex appendicitis coding³⁶; however, caution is needed before generalising results from a single-site study from 2012, nationally. Additionally, this study compared complex appendicitis between pandemic periods and found no indication that coding had changed suggesting they remained relatively consistent.

Policy and clinical practice implications

The pandemic may have strengthened previous efforts for reducing variation in the management of complex appendicitis, given that three fewer non-specialist centres had positive outliers for complex appendicitis during the pandemic than before it. We found a reduction in the proportion of simple appendicitis admissions treated surgically during the pandemic, contributing to the wider debate on the role of surgery in the treatment of simple appendicitis. These findings can build upon the existing literature to inform future recommendations and thresholds for stopping laparoscopic surgeries in possible future pandemics for surgically managed acute appendicitis.

CONCLUSIONS

Appendectomy and laparoscopic appendectomy rates recovered sharply after a steep drop in April 2020. These results provide national context to smaller studies reporting the immediate short-term impacts of COVID-19 appendicitis management.

Contributors Study conception and design—PF, AB, RH, SK, DH and RMV. Data acquisition—PA and AB. Analysis and data interpretation—PF, AB, DH and RH. Drafting of the manuscript—PF. Critical revision—PF, RH, SK, RMV, DH, AB and PA. Guarantor—AB.

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Disclaimer The views expressed in this publication are those of the author(s) and not necessarily those of the NIHR or the Department of Health and Social Care.

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Appendicectomy rates

Figure S1: Pre-pandemic three-monthly appendicectomy rate trend

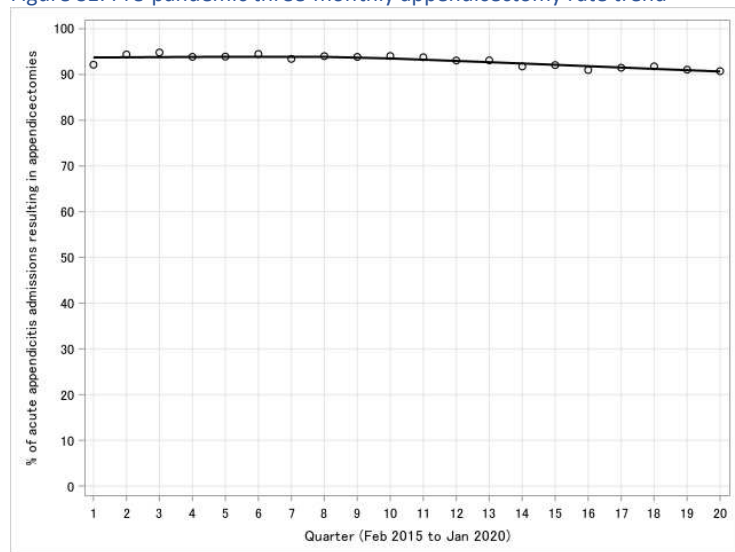


Table S1: The percentage difference between the monthly appendicectomy rate during the pandemic and the five-year pre-pandemic monthly mean by the 5-9s

	All			Simple			Complex		
	O	E	%Diff (95% CI)	O	E	%Diff (95% CI)	O	E	%Diff (95% CI)
Feb, 2020	90.1	93.7	-3.6 (-7.3 to 0.1)	89.8	95.8	-6.0 (-10.8 to -1.2)	97.0	96.3	0.7 (-0.9 to 2.4)
Mar	93.2	90.7	2.5 (-0.6 to 5.6)	94.9	94.8	0.1 (-0.5 to 0.7)	95.2	95.8	-0.6 (-2.1 to 0.9)
Apr	74.6	93.0	-18.4 (-26.8 to -10.0)	78.5	93.9	-15.4 (-23.1 to -7.7)	92.2	95.4	-3.2 (-6.7 to 0.3)
May	79.3	92.5	-13.2 (-20.3 to -6.1)	80.4	92.9	-12.5 (-19.4 to -5.6)	94.1	95.7	-1.6 (-4.1 to 0.9)
Jun	85.1	92.9	-7.8 (-13.3 to -2.4)	87.7	95.9	-8.2 (-13.9 to -2.6)	97.3	94.3	3 (-0.4 to 6.3)
Jul	85.2	93.2	-8.0 (-13.5 to -2.4)	89.1	95.2	-6.1 (-10.9 to -1.3)	93.4	93.5	-0.1 (-0.9 to 0.6)
Aug	86.4	93.2	-6.8 (-11.9 to -1.7)	90.4	94.9	-4.6 (-8.7 to -0.4)	91.7	95.1	-3.4 (-7.0 to 0.2)
Sep	88.8	93.0	-4.2 (-8.2 to -0.2)	91.5	94.6	-3.1 (-6.6 to 0.3)	94.7	97.1	-2.4 (-5.4 to 0.7)
Oct	90.7	95.0	-4.3 (-8.3 to -0.2)	94.7	96.5	-1.7 (-4.3 to 0.8)	98.5	96.5	2 (-0.8 to 4.8)
Nov	89.5	92.3	-2.8 (-6.1 to 0.5)	92.0	92.1	-0.1 (-0.5 to 0.4)	95.5	95.7	-0.1 (-0.9 to 0.6)
Dec	92.6	90.6	2.0 (-0.8 to 4.7)	96.1	93.9	2.2 (-0.7 to 5.1)	97.4	94.2	3.1 (-0.3 to 6.6)
Jan, 2021	89.8	91.7	-1.9 (-4.6 to 0.8)	91.1	93.2	-2.1 (-5.0 to 0.7)	97.1	96.0	1.1 (-1.0 to 3.2)

Feb	89.6	93.7	-4.1 (-8.1 to -0.1)	88.5	95.8	-7.3 (-12.6 to -2.0)	96.6	96.3	0.3 (-0.8 to 1.4)
Mar	93.5	90.7	2.8 (-0.5 to 6.0)	93.9	94.8	-0.9 (-2.7 to 1.0)	98.7	95.8	2.9 (-0.4 to 6.3)

Table S2: The percentage difference between the monthly appendicectomy rate during the pandemic and the five-year pre-pandemic monthly mean by the 10-24s

	All			Simple			Complex		
	O	E	%Diff (95% CI)	O	E	%Diff (95% CI)	O	E	%Diff (95% CI)
Feb, 2020	89.8	93.4	-3.6 (-7.3 to 0.1)	91.2	95.2	-4.0 (-7.9 to -0.1)	93.0	94.9	-1.9 (-4.6 to 0.8)
Mar	86.1	92.4	-6.3 (-11.2 to -1.4)	88.4	95.9	-7.5 (-12.9 to -2.2)	94.0	95.0	-1.0 (-3.0 to 1.0)
Apr	65.1	93.6	-28.4 (-38.9 to -18.0)	64.6	95.7	-31.1 (-42.1 to -20.2)	90.5	94.4	-3.9 (-7.7 to 0)
May	73.9	93.6	-19.7 (-28.5 to -11.0)	75.8	95.5	-19.6 (-28.3 to -10.9)	92.4	94.9	-2.6 (-5.7 to 0.6)
Jun	82.7	93.6	-10.9 (-17.4 to -4.5)	85.4	96.1	-10.7 (-17.1 to -4.3)	93.3	94.7	-1.4 (-3.6 to 0.9)
Jul	84.7	93.6	-8.9 (-14.7 to -3.1)	87.4	95.3	-7.9 (-13.4 to -2.4)	92.5	94.9	-2.4 (-5.5 to 0.6)
Aug	87.0	92.7	-5.6 (-10.3 to -1.0)	89.8	94.9	-5.1 (-9.5 to -0.7)	93.7	94.8	-1.1 (-3.2 to 1.0)
Sep	88.0	93.5	-5.5 (-10.1 to -0.9)	89.9	95.7	-5.8 (-10.5 to -1.1)	96.7	96.1	0.6 (-0.9 to 2.1)
Oct	90.7	93.1	-2.4 (-5.4 to 0.7)	92.4	95.3	-2.9 (-6.2 to 0.4)	97.2	96.0	1.2 (-0.9 to 3.4)
Nov	88.1	93.2	-5.1 (-9.6 to -0.7)	90.2	94.7	-4.5 (-8.6 to -0.3)	94.2	95.5	-1.3 (-3.5 to 0.9)
Dec	88.5	92.7	-4.2 (-8.2 to -0.2)	90.7	93.8	-3.1 (-6.5 to 0.4)	95.1	95.4	-0.3 (-1.2 to 0.7)
Jan, 2021	87.5	93.1	-5.6 (-10.2 to -0.9)	89.3	95.5	-6.1 (-11.0 to -1.3)	94.5	95.1	-0.6 (-2.2 to 0.9)
Feb	89.1	93.4	-4.3 (-8.4 to -0.2)	91.5	95.2	-3.7 (-7.4 to 0.1)	93.8	94.9	-1.1 (-3.3 to 0.9)
Mar	90.2	92.4	-2.2 (-5.1 to 0.7)	92.6	95.9	-3.3 (-6.8 to 0.3)	95.3	95.0	0.3 (-0.7 to 1.2)

Table S3: The absolute difference between the monthly appendicectomy counts during the pandemic and the five-year pre-pandemic monthly mean counts by the 5-9s

	All			Simple			Complex		
	O	E	Diff (95% CI)	O	E	Diff (95% CI)	O	E	Diff (95% CI)
Feb, 2020	164.0	191.0	-27.0 (-37.2 to -16.8)	79.0	91.2	-12.2 (-19 to -5.4)	65.0	77.4	-12.4 (-19.3 to -5.5)
Mar	165.0	203.0	-38.0 (-50.1 to -25.9)	74.0	98.0	-24 (-33.6 to -14.4)	80.0	78.4	1.6 (-0.9 to 4.0)
Apr	141.0	195.0	-54.0 (-68.4 to -39.6)	62.0	91.8	-29.8 (-40.5 to -19.1)	71.0	79.8	-8.8 (-14.7 to -3.0)
May	157.0	196.2	-39.2 (-51.5 to -26.9)	86.0	93.8	-7.8 (-13.3 to -2.3)	64.0	78.3	-14.3 (-21.8 to -6.9)
Jun	194.0	207.8	-13.8 (-21.1 to -6.5)	114.0	103.8	10.2 (3.9 to 16.5)	71.0	82.7	-11.7 (-18.4 to -5.0)
Jul	208.0	200.4	7.6 (2.2 to 13.0)	98.0	103.0	-5.0 (-9.4 to -0.6)	99.0	82.0	17.0 (8.9 to 25.1)
Aug	203.0	182.8	20.2 (11.4 to 29.0)	103.0	89.4	13.6 (6.4 to 20.8)	88.0	80.5	7.5 (2.1 to 12.9)
Sep	206.0	198.6	7.4 (2.1 to 12.7)	107.0	90.4	16.6 (8.6 to 24.6)	90.0	89.2	0.8 (-1.0 to 2.6)

Oct	166.0	193.0	-27.0 (-37.2 to -16.8)	90.0	92.8	-2.8 (-6.1 to 0.5)	67.0	78.5	-11.5 (-18.1 to -4.9)
Nov	153.0	196.6	-43.6 (-56.5 to -30.7)	81.0	98.0	-17.0 (-25.1 to -8.9)	64.0	73.7	-9.7 (-15.8 to -3.6)
Dec	187.0	181.6	5.4 (0.8 to 10.0)	98.0	82.8	15.2 (7.6 to 22.8)	74.0	79.0	-5.0 (-9.4 to -0.6)
Jan, 2021	167.0	203.0	-36.0 (-47.8 to -24.2)	92.0	96.6	-4.6 (-8.8 to -0.4)	66.0	83.0	-17.0 (-25.1 to -8.9)
Feb	190.0	191.0	-1.0 (-3.0 to 1.0)	92.0	91.2	0.8 (-1.0 to 2.6)	85.0	77.4	7.6 (2.2 to 13.0)
Mar	200.0	203.0	-3.0 (-6.4 to 0.4)	108.0	98.0	10.0 (3.8 to 16.2)	78.0	78.4	-0.4 (-1.7 to 0.9)

Table S4: The absolute difference between the monthly appendectomy counts during the pandemic and the five-year pre-pandemic monthly mean counts by the 10-24s

	All			Simple			Complex		
	O	E	Diff (95% CI)	O	E	Diff (95% CI)	O	E	Diff (95% CI)
Feb, 2020	864.0	1011.8	-147.8 (-171.6 to -124)	521.0	587.6	-66.6 (-82.6 to -50.6)	240.0	268.3	-28.3 (-38.7 to -17.9)
Mar	757.0	1098.4	-341.4 (-377.6 to -305.2)	418.0	637.8	-219.8 (-248.9 to -190.7)	251.0	289.7	-38.7 (-50.9 to -26.5)
Apr	521.0	1032.6	-511.6 (-555.9 to -467.3)	275.0	591.2	-316.2 (-351.1 to -281.3)	219.0	284.5	-65.5 (-81.4 to -49.6)
May	715.0	1139.4	-424.4 (-464.8 to -384)	405.0	675.2	-270.2 (-302.4 to -238)	254.0	299.5	-45.5 (-58.7 to -32.3)
Jun	932.0	1143.0	-211 (-239.5 to -182.5)	560.0	649.2	-89.2 (-107.7 to -70.7)	307.0	334.8	-27.8 (-38.2 to -17.5)
Jul	936.0	1068.8	-132.8 (-155.4 to -110.2)	569.0	611.4	-42.4 (-55.2 to -29.6)	283.0	314.8	-31.8 (-42.9 to -20.8)
Aug	952.0	1001.4	-49.4 (-63.2 to -35.6)	556.0	574.6	-18.6 (-27.1 to -10.1)	312.0	292.8	19.2 (10.6 to 27.7)
Sep	1031.0	1103.4	-72.4 (-89.1 to -55.7)	604.0	640.4	-36.4 (-48.2 to -24.6)	347.0	312.7	34.3 (22.8 to 45.8)
Oct	1094.0	1063.4	30.6 (19.8 to 41.4)	655.0	616.0	39.0 (26.8 to 51.2)	345.0	312.3	32.7 (21.5 to 43.9)
Nov	995.0	1105.0	-110 (-130.6 to -89.4)	596.0	640.8	-44.8 (-57.9 to -31.7)	310.0	301.0	9.0 (3.1 to 14.9)
Dec	930.0	985.8	-55.8 (-70.4 to -41.2)	536.0	552.8	-16.8 (-24.8 to -8.8)	311.0	297.8	13.2 (6.1 to 20.3)
Jan, 2021	938.0	1163.6	-225.6 (-255 to -196.2)	536.0	666.6	-130.6 (-153.0 to -108.2)	326.0	326.3	-0.3 (-1.5 to 0.8)
Feb	884.0	1011.8	-127.8 (-150 to -105.6)	529.0	587.6	-58.6 (-73.6 to -43.6)	285.0	268.3	16.7 (8.7 to 24.7)
Mar	987.0	1098.4	-111.4 (-132.1 to -90.7)	592.0	637.8	-45.8 (-59.1 to -32.5)	303.0	289.7	13.3 (6.1 to 20.4)

Table S5: The percentage difference between the monthly appendectomy rate during the pandemic and the five-year pre-pandemic monthly mean by the 0-4s

	All			Simple			Complex		
	O	E	% Diff (95% CI)	O	E	% Diff (95% CI)	O	E	% Diff (95% CI)
Feb, 2020	73.9	89.0	-15.1 (-22.7 to -7.5)	50.0	88.5	-38.5 (-50.6 to -26.3)	88.9	94.9	-6.0 (-10.8 to -1.2)
Mar	82.1	83.7	-1.6 (-4.0 to 0.9)	71.4	71.4	0.0 (0.0 to 0.0)	94.4	92.1	2.4 (-0.6 to 5.4)

Apr	83.3	88.0	-4.6 (-8.9 to -0.4)	66.7	83.3	-16.7 (-24.7 to -8.7)	92.3	94.1	-1.8 (-4.3 to 0.8)
May	78.3	78.1	0.2 (-0.6 to 0.9)	33.3	67.6	-34.2 (-45.7 to -22.8)	100.0	87.2	12.8 (5.8 to 19.9)
Jun	77.4	84.0	-6.6 (-11.6 to -1.6)	60.0	77.8	-17.8 (-26 to -9.5)	95.2	91.5	3.8 (0.0 to 7.6)
Jul	71.4	83.1	-11.7 (-18.4 to -5.0)	60.0	81.8	-21.8 (-31 to -12.7)	72.7	88.2	-15.5 (-23.2 to -7.7)
Aug	69.6	82.2	-12.6 (-19.6 to -5.7)	100.0	85.0	15.0 (7.4 to 22.6)	72.7	87.5	-14.8 (-22.3 to -7.2)
Sep	86.8	86.2	0.7 (-0.9 to 2.3)	100.0	90.5	9.5 (3.5 to 15.6)	89.7	90.3	-0.6 (-2.2 to 0.9)
Oct	77.8	87.5	-9.7 (-15.8 to -3.6)	83.3	84.6	-1.3 (-3.5 to 0.9)	80.8	92.4	-11.6 (-18.3 to -4.9)
Nov	79.3	78.6	0.7 (-0.9 to 2.3)	71.4	84.6	-13.2 (-20.3 to -6.1)	100.0	91.6	8.4 (2.7 to 14.1)
Dec	86.4	82.1	4.3 (0.2 to 8.4)	60.0	73.3	-13.3 (-20.5 to -6.2)	94.1	92.4	1.7 (-0.8 to 4.3)
Jan, 2021	75.0	85.3	-10.3 (-16.6 to -4.0)	75.0	75.0	0.0 (0.0 to 0.0)	83.3	91.3	-8.0 (-13.4 to -2.4)
Feb	88.9	89.0	-0.1 (-0.7 to 0.5)	87.5	88.5	-1.0 (-2.9 to 1.0)	94.1	94.9	-0.8 (-2.5 to 1.0)
Mar	77.8	83.7	-5.9 (-10.7 to -1.2)	60.0	71.4	-11.4 (-18.1 to -4.8)	84.6	92.1	-7.4 (-12.8 to -2.1)

Table S6: The absolute difference between the monthly appendicectomy counts during the pandemic and the five-year pre-pandemic monthly mean counts by the 0-4s

	All			Simple			Complex		
	O	E	Diff (95% CI)	O	E	Diff (95% CI)	O	E	Diff (95% CI)
Feb, 2020	17.0	21.0	-4.0 (-7.9 to -0.1)	Supp*	4.6	Supp* (-7.3 to 0.1)	16.0	16.0	0.0 (0.0 to 0.0)
Mar	23.0	22.6	0.4 (-0.8 to 1.6)	5.0	4.0	1.0 (-1.0 to 3.0)	17.0	16.6	0.4 (-0.9 to 1.7)
Apr	15.0	23.4	-8.4 (-14.1 to -2.7)	Supp*	6.0	Supp* (-7.9 to -0.1)	12.0	15.8	-3.8 (-7.7 to 0.0)
May	18.0	21.4	-3.4 (-7.0 to 0.2)	Supp*	5.0	Supp* (-6.4 to 0.4)	16.0	15.8	0.2 (-0.6 to 1.0)
Jun	24.0	24.2	-0.2 (-1.1 to 0.7)	Supp*	5.6	Supp* (-5.8 to 0.6)	20.0	17.8	2.2 (-0.7 to 5.1)
Jul	20.0	24.6	-4.6 (-8.8 to -0.4)	Supp*	7.2	Supp* (-8.2 to -0.2)	16.0	16.2	-0.2 (-1.0 to 0.6)
Aug	16.0	24.0	-8.0 (-13.5 to -2.5)	8.0	6.8	1.2 (-0.9 to 3.3)	8.0	15.2	-7.2 (-12.4 to -1.9)
Sep	33.0	22.4	10.6 (4.2 to 17.0)	Supp*	7.6	Supp* (-8.8 to -0.4)	26.0	15.5	10.5 (4.1 to 16.9)
Oct	28.0	22.4	5.6 (1.0 to 10.2)	5.0	6.6	-1.6 (-4.1 to 0.9)	21.0	16.2	4.8 (0.5 to 9.1)
Nov	23.0	20.6	2.4 (-0.6 to 5.4)	5.0	4.4	0.6 (-0.9 to 2.1)	18.0	16.3	1.7 (-0.9 to 4.2)
Dec	19.0	23.8	-4.8 (-9.1 to -0.5)	Supp*	4.4	Supp* (-3.7 to 0.9)	16.0	18.2	-2.2 (-5.1 to 0.7)
Jan, 2021	18.0	22.0	-4.0 (-7.9 to -0.1)	Supp*	4.8	Supp* (-4.4 to 0.8)	15.7	15.0	-0.7 (-2.3 to 0.9)
Feb	24.0	21.0	3.0 (-0.4 to 6.4)	7.0	4.6	2.4 (-0.6 to 5.4)	16.0	16.0	0.0 (0.0 to 0.0)
Mar	14.0	22.6	-8.6 (-14.3 to -2.9)	Supp*	4.0	Supp* (-3.0 to 1.0)	11.0	16.6	-5.6 (-10.2 to -0.9)

Laparoscopic appendectomy rates

Figure S2: Pre-pandemic quarterly trends for laparoscopic appendectomy rate

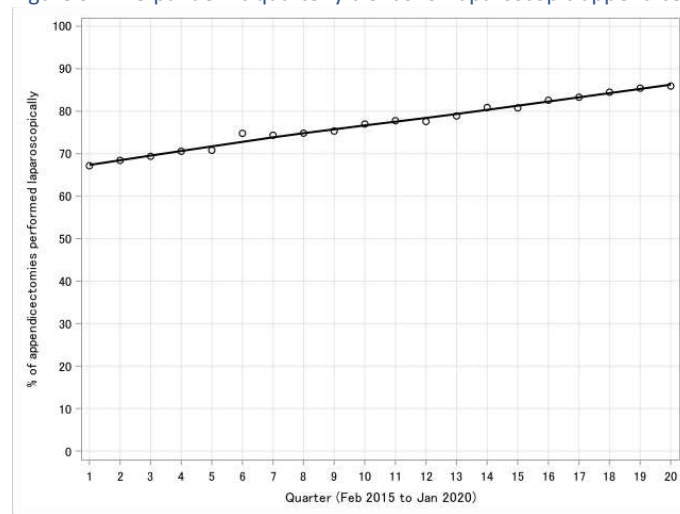


Table S7: The percentage difference between the monthly laparoscopic appendectomy rate, by the 0-4s, during the pandemic and the monthly mean laparoscopic appendectomy rate for the previous five years

	All			Simple			Complex		
	O	E	% Diff (95% CI)	O	E	% Diff (95% CI)	O	E	% Diff (95% CI)
Feb, 2020	70.6	51.4	19.2 (10.6 to 27.7)	0.0	56.5	-56.5 (-71.3 to -41.8)	75.0	51.3	23.8 (14.2 to 33.3)
Mar	60.9	54.0	6.9 (1.7 to 12.0)	80.0	56.3	23.8 (14.2 to 33.3)	58.8	55.7	3.1 (-0.3 to 6.6)
Apr	20.0	59.0	-39.0 (-51.2 to -26.7)	0.0	66.7	-66.7 (-82.7 to -50.7)	25.0	54.2	-29.2 (-39.8 to -18.6)
May	38.9	61.7	-22.8 (-32.2 to -13.4)	50.0	56.0	-6.0 (-10.8 to -1.2)	37.5	63.3	-25.8 (-35.7 to -15.8)
Jun	54.2	46.3	7.9 (2.4 to 13.4)	66.7	53.6	13.1 (6.0 to 20.2)	50.0	47.1	2.9 (-0.4 to 6.2)
Jul	60.0	56.1	3.9 (0.0 to 7.8)	33.3	58.3	-25.0 (-34.8 to -15.2)	62.5	53.1	9.4 (3.4 to 15.4)
Aug	68.8	57.5	11.3 (4.7 to 17.8)	87.5	52.9	34.6 (23.0 to 46.1)	50.0	59.0	-9.0 (-14.9 to -3.1)
Sep	78.8	58.0	20.8 (11.8 to 29.7)	66.7	63.2	3.5 (-0.2 to 7.2)	76.9	55.2	21.7 (12.6 to 30.8)
Oct	75.0	52.7	22.3 (13.1 to 31.6)	100.0	66.7	33.3 (22.0 to 44.6)	76.2	48.7	27.5 (17.2 to 37.8)
Nov	65.2	64.1	1.1 (-1.0 to 3.2)	60.0	63.6	-3.6 (-7.4 to 0.1)	66.7	63.8	2.9 (-0.4 to 6.3)
Dec	68.4	60.5	7.9 (2.4 to 13.4)	100.0	50.0	50.0 (36.1 to 63.9)	62.5	61.3	1.2 (-0.9 to 3.4)
Jan, 2021	77.8	58.2	19.6 (10.9 to 28.3)	0.0	58.3	-58.3 (-73.3 to -43.4)	93.3	55.7	37.6 (25.6 to 49.7)
Feb	83.3	51.4	31.9 (20.8 to 43)	85.7	56.5	29.2 (18.6 to 39.8)	81.3	51.3	30.0 (19.3 to 40.7)
Mar	92.9	54.0	38.9 (26.7 to 51.1)	100.0	56.3	43.8 (30.8 to 56.7)	90.9	55.7	35.2 (23.6 to 46.9)

Table S8: The percentage difference between the monthly laparoscopic appendectomy rate, by the 5-9s, during the pandemic and the monthly mean laparoscopic appendectomy rate for the previous five years

	All			Simple			Complex		
	O	E	% Diff (95% CI)	O	E	% Diff (95% CI)	O	E	% Diff (95% CI)

Feb, 2020	57.9	43.2	14.7 (7.2 to 22.2)	45.6	36.4	9.2 (3.2 to 15.1)	67.7	52.8	14.9 (7.3 to 22.4)
Mar	49.1	41.9	7.2 (2.0 to 12.5)	39.2	38.0	1.2 (-0.9 to 3.4)	58.8	48.1	10.7 (4.3 to 17.1)
Apr	24.1	39.6	-15.5 (-23.2 to -7.8)	16.1	35.1	-18.9 (-27.5 to -10.4)	29.6	45.6	-16.0 (-23.9 to -8.2)
May	32.5	41.5	-9.0 (-14.9 to -3.1)	26.7	36.7	-9.9 (-16.1 to -3.8)	39.1	50.0	-10.9 (-17.4 to -4.5)
Jun	42.3	43.2	-0.9 (-2.9 to 1)	42.1	40.5	1.6 (-0.9 to 4.2)	40.8	47.3	-6.4 (-11.4 to -1.5)
Jul	60.6	45.2	15.4 (7.7 to 23.1)	52.0	43.3	8.7 (2.9 to 14.5)	70.7	50.1	20.6 (11.7 to 29.5)
Aug	67.0	43.2	23.8 (14.2 to 33.3)	62.1	37.8	24.3 (14.7 to 34)	75.0	47.8	27.2 (16.9 to 37.4)
Sep	55.3	43.2	12.1 (5.3 to 19)	48.6	38.7	9.9 (3.7 to 16)	62.2	47.4	14.8 (7.3 to 22.3)
Oct	66.9	43.0	23.9 (14.3 to 33.4)	58.9	42.5	16.4 (8.5 to 24.4)	76.1	43.8	32.3 (21.2 to 43.4)
Nov	63.4	46.0	17.4 (9.2 to 25.6)	54.3	44.7	9.6 (3.5 to 15.7)	75.0	50.3	24.7 (15 to 34.5)
Dec	62.0	44.9	17.1 (9.0 to 25.2)	63.3	38.4	24.9 (15.1 to 34.6)	59.5	52.8	6.7 (1.6 to 11.8)
Jan, 2021	64.7	45.6	19.1 (10.5 to 27.6)	59.8	43.7	16.1 (8.2 to 24.0)	72.7	51.9	20.9 (11.9 to 29.8)
Feb	60.5	43.2	17.3 (9.1 to 25.4)	51.1	36.4	14.7 (7.2 to 22.2)	67.1	52.8	14.3 (6.9 to 21.7)
Mar	61.0	41.9	19.1 (10.6 to 27.7)	53.7	38.0	15.7 (8.0 to 23.5)	71.8	48.1	23.7 (14.2 to 33.3)

Table S9: The percentage difference between the monthly laparoscopic appendectomy rate, by the 10-24s, during the pandemic and the monthly mean laparoscopic appendectomy rate for the previous five years

	All			Simple			Complex		
	O	E	% Diff (95% CI)	O	E	% Diff (95% CI)	O	E	% Diff (95% CI)
Feb, 2020	90.3	80.4	9.9 (3.8 to 16.1)	91.4	81.1	10.3 (4.0 to 16.5)	87.9	77.7	10.2 (4.0 to 16.5)
Mar	83.0	81.0	2.0 (-0.8 to 4.7)	84.2	82.7	1.5 (-0.9 to 3.9)	80.9	77.3	3.5 (-0.1 to 7.2)
Apr	35.3	80.1	-44.8 (-57.9 to -31.6)	32.4	81.9	-49.5 (-63.3 to -35.7)	38.4	76.2	-37.9 (-49.9 to -25.8)
May	60.7	82.2	-21.5 (-30.5 to -12.4)	58.0	83.2	-25.2 (-35.0 to -15.3)	62.2	80.5	-18.3 (-26.7 to -9.9)
Jun	80.3	82.5	-2.2 (-5.1 to 0.7)	78.9	83.9	-5.0 (-9.4 to -0.6)	80.8	79.6	1.2 (-1.0 to 3.3)
Jul	88.1	83.1	5.1 (0.6 to 9.5)	88.8	83.7	5.0 (0.6 to 9.4)	86.9	81.3	5.6 (1.0 to 10.2)
Aug	89.1	82.9	6.2 (1.3 to 11.0)	89.4	84.2	5.2 (0.7 to 9.6)	89.7	78.8	11.0 (4.5 to 17.5)
Sep	88.9	82.6	6.3 (1.4 to 11.3)	88.9	84.1	4.8 (0.5 to 9.1)	88.5	79.2	9.3 (3.3 to 15.2)
Oct	90.6	83.8	6.8 (1.7 to 12.0)	90.8	84.8	6.0 (1.2 to 10.8)	89.6	81.0	8.6 (2.9 to 14.3)
Nov	91.2	83.1	8.0 (2.5 to 13.6)	92.6	84.5	8.1 (2.5 to 13.7)	88.7	80.4	8.3 (2.7 to 13.9)
Dec	91.6	82.6	9.0 (3.1 to 14.9)	93.1	83.5	9.6 (3.5 to 15.7)	91.0	80.0	11.0 (4.5 to 17.5)
Jan, 2021	91.2	83.0	8.2 (2.6 to 13.7)	91.2	84.4	6.8 (1.7 to 12.0)	90.8	79.2	11.6 (4.9 to 18.3)
Feb	93.1	80.4	12.7 (5.7 to 19.7)	93.0	81.1	11.9 (5.1 to 18.7)	93.3	77.7	15.7 (7.9 to 23.4)
Mar	90.9	81.0	9.9 (3.7 to 16.0)	91.0	82.7	8.4 (2.7 to 14.0)	90.1	77.3	12.8 (5.8 to 19.8)

Table S10: Absolute differences in monthly laparoscopic appendectomy counts, by the 0-4s, between the pandemic and the monthly mean counts for the previous five years

	All			Simple			Complex		
	O	E	Diff (95% CI)	O	E	Diff (95% CI)	O	E	Diff (95% CI)
Feb, 2020	12.0	10.8	1.2 (-0.9 to 3.3)	Supp*	2.6	Supp*(-0.8 to 4.3)	12.0	8.2	3.8 (0.0 to 7.6)
Mar	14.0	12.2	1.8 (-0.8 to 4.4)	Supp*	2.3	Supp*(-0.8 to 4.3)	10.0	9.8	0.2 (-0.7 to 1.1)
Apr	Supp*	13.8	Supp*(-17.2 to -4.4)	Supp*	4.0	Supp*(0.1 to 7.9)	Supp*	9.0	Supp*(-10.8 to -1.2)
May	7.0	13.2	-6.2 (-11.1 to -1.3)	Supp*	2.8	Supp*(-4.4 to 0.8)	6.0	10.0	-4.0 (-7.9 to -0.1)
Jun	13.0	11.2	1.8 (-0.8 to 4.4)	Supp*	3.0	Supp*(-3.0 to 1.0)	10.0	8.2	1.8 (-0.8 to 4.4)
Jul	12.0	13.8	-1.8 (-4.4 to 0.8)	Supp*	4.2	Supp*(-6.7 to 0.3)	10.0	8.6	1.4 (-0.9 to 3.7)
Aug	11.0	13.8	-2.8 (-6.1 to 0.5)	7.0	3.6	3.4 (-0.2 to 7.0)	Supp*	9.8	Supp*(-10.5 to -1.1)
Sep	26.0	13.0	13.0 (5.9 to 20.1)	Supp*	4.8	Supp*(-6.1 to 0.5)	20.0	7.4	12.6 (5.6 to 19.6)
Oct	21.0	11.8	9.2 (3.3 to 15.1)	5.0	4.4	0.6 (-0.9 to 2.1)	16.0	7.4	8.6 (2.9 to 14.3)
Nov	15.0	13.2	1.8 (-0.8 to 4.4)	Supp*	2.8	Supp*(-0.7 to 1.1)	12.0	10.2	1.8 (-0.8 to 4.4)
Dec	13.0	14.4	-1.4 (-3.7 to 0.9)	Supp*	2.2	Supp*(-1 to 2.6)	10.0	11.4	-1.4 (-3.7 to 0.9)
Jan, 2021	14.0	12.8	1.2 (-0.9 to 3.3)	Supp*	2.8	Supp*(-0.5 to 6.1)	14.0	8.8	5.2 (0.7 to 9.7)
Feb	20.0	10.8	9.2 (3.3 to 15.1)	6.0	2.6	3.4 (-0.2 to 7)	13.0	8.2	4.8 (0.5 to 9.1)
Mar	13.0	12.2	0.8 (-1.0 to 2.6)	Supp*	2.3	0.8 (-0.9 to 2.4)	10.0	9.8	0.2 (-0.7 to 1.1)

Table S11: Absolute differences in monthly laparoscopic appendectomy counts, by the 5-9s, between the pandemic and the monthly mean counts for the previous five years

	All			Simple			Complex		
	O	E	Diff (95% CI)	O	E	Diff (95% CI)	O	E	Diff (95% CI)
Feb, 2020	95.0	82.6	12.4 (5.5 to 19.3)	36.0	33.2	2.8 (-0.5 to 6.1)	44.0	41.4	2.6 (-0.6 to 5.8)
Mar	81.0	85.0	-4.0 (-7.9 to -0.1)	29.0	37.2	-8.2 (-13.8 to -2.6)	47.0	37.6	9.4 (3.4 to 15.4)
Apr	34.0	77.2	-43.2 (-56.1 to -30.3)	10.0	32.2	-22.2 (-31.4 to -13.0)	21.0	37.2	-16.2 (-24.1 to -8.3)
May	51.0	81.4	-30.4 (-41.2 to -19.6)	23.0	34.4	-11.4 (-18.0 to -4.8)	25.0	40.6	-15.6 (-23.3 to -7.9)
Jun	82.0	89.8	-7.8 (-13.3 to -2.3)	48.0	42.0	6.0 (1.2 to 10.8)	29.0	40.2	-11.2 (-17.8 to -4.6)
Jul	126.0	90.6	35.4 (23.7 to 47.1)	51.0	44.6	6.4 (1.4 to 11.4)	70.0	39.4	30.6 (19.8 to 41.4)
Aug	136.0	79.0	57.0 (42.2 to 71.8)	64.0	33.8	30.2 (19.4 to 41)	66.0	37.8	28.2 (17.8 to 38.6)
Sep	114.0	85.8	28.2 (17.8 to 38.6)	52.0	35.0	17.0 (8.9 to 25.1)	56.0	42.2	13.8 (6.5 to 21.1)

Oct	111.0	83.0	28.0 (17.6 to 38.4)	53.0	39.4	13.6 (6.4 to 20.8)	51.0	35.4	15.6 (7.9 to 23.3)
Nov	97.0	90.4	6.6 (1.6 to 11.6)	44.0	43.8	0.2 (-0.7 to 1.1)	48.0	38.0	10.0 (3.8 to 16.2)
Dec	116.0	81.6	34.4 (22.9 to 45.9)	62.0	31.8	30.2 (19.4 to 41.0)	44.0	42.2	1.8 (-0.8 to 4.4)
Jan, 2021	108.0	92.6	15.4 (7.7 to 23.1)	55.0	42.2	12.8 (5.8 to 19.8)	48.0	44.8	3.2 (-0.3 to 6.7)
Feb	115.0	82.6	32.4 (21.2 to 43.6)	47.0	33.2	13.8 (6.5 to 21.1)	57.0	41.4	15.6 (7.9 to 23.3)
Mar	122.0	85.0	37.0 (25.1 to 48.9)	58.0	37.2	20.8 (11.9 to 29.7)	56.0	37.6	18.4 (10 to 26.8)

Table S12: Absolute differences in monthly laparoscopic appendectomy counts, by the 10-24s, between the pandemic and the monthly mean counts for the previous five years

	All			Simple			Complex		
	O	E	Diff (95% CI)	O	E	Diff (95% CI)	O	E	Diff (95% CI)
Feb, 2020	780.0	813.0	-33.0 (-44.3 to -21.7)	476.0	476.6	-0.6 (-2.1 to 0.9)	211.0	210.2	0.8 (-1.0 to 2.6)
Mar	628.0	889.8	-261.8 (-293.5 to -230.1)	352.0	527.4	-175.4 (-201.4 to -149.4)	203.0	228.0	-25.0 (-34.8 to -15.2)
Apr	184.0	826.8	-642.8 (-692.5 to -593.1)	89.0	484.2	-395.2 (-434.2 to -356.2)	84.0	226.8	-142.8 (-166.2 to -119.4)
May	434.0	936.2	-502.2 (-546.1 to -458.3)	235.0	561.6	-326.6 (-362 to -291.2)	158.0	248.4	-90.4 (-109 to -71.8)
Jun	748.0	942.6	-194.6 (-221.9 to -167.3)	442.0	544.8	-102.8 (-122.7 to -82.9)	248.0	271.0	-23 (-32.4 to -13.6)
Jul	825.0	888.0	-63.0 (-78.6 to -47.4)	505.0	512.0	-7.0 (-12.2 to -1.8)	246.0	261.2	-15.2 (-22.8 to -7.6)
Aug	848.0	830.2	17.8 (9.5 to 26.1)	497.0	484.0	13.0 (5.9 to 20.1)	280.0	227.6	52.4 (38.2 to 66.6)
Sep	917.0	911.6	5.4 (0.8 to 10.0)	537.0	538.4	-1.4 (-3.7 to 0.9)	307.0	242.2	64.8 (49.0 to 80.6)
Oct	991.0	890.6	100.4 (80.8 to 120)	595.0	522.4	72.6 (55.9 to 89.3)	309.0	247.6	61.4 (46.0 to 76.8)
Nov	907.0	918.8	-11.8 (-18.5 to -5.1)	552.0	541.4	10.6 (4.2 to 17.0)	275.0	240.6	34.4 (22.9 to 45.9)
Dec	852.0	814.0	38.0 (25.9 to 50.1)	499.0	461.4	37.6 (25.6 to 49.6)	283.0	236.2	46.8 (33.4 to 60.2)
Jan, 2021	855.0	965.8	-110.8 (-131.4 to -90.2)	489.0	562.6	-73.6 (-90.4 to -56.8)	296.0	258.4	37.6 (25.6 to 49.6)
Feb	823.0	813.0	10.0 (3.8 to 16.2)	492.0	476.6	15.4 (7.7 to 23.1)	266.0	210.2	55.8 (41.2 to 70.4)
Mar	897.0	889.8	7.2 (1.9 to 12.5)	539.0	527.4	11.6 (4.9 to 18.3)	273.0	228.0	45.0 (31.9 to 58.1)

Coding definitions

Table S.A: Acute appendicitis ICD-10 definitions for the main and sensitivity analyses

Analyses	ICD-10	Description
Main		
All	K35 ^{1,2}	All acute appendicitis
	K37 ¹⁻³	Unspecified appendicitis
Simple	K35.8	Acute appendicitis, other and unspecified

Complex	K35.2	Acute appendicitis with generalised peritonitis
	K35.3	Acute appendicitis with local peritonitis
Sensitivity		
All	K35 ²	All acute appendicitis
	K36 ^{2,4}	Other appendicitis
	K37 ^{2,4}	Unspecified appendicitis
	K38 ⁴	Other diseases of appendix

Table S.B: Definition of appendectomy and laparoscopic appendectomy OPCS code definitions based on published literature

OPCS	Description
Appendectomy	
H011 ^{2,3,5,6}	Emergency excision of appendix, Emergency excision of abnormal appendix and drainage hfg
H012 ^{2,3,5,6}	Emergency excision of appendix, Emergency excision of abnormal appendix nec
H013 ³⁻⁶	Emergency excision of appendix, Emergency excision of normal appendix
H018 ²⁻⁶	Emergency excision of appendix, Other specified
H019 ^{2,3,5,6}	Emergency excision of appendix, Unspecified
H028 ^{2,3}	Other excision of appendix, Other specified
H029 ^{2,3}	Other excision of appendix, Unspecified
Laparoscopic appendectomy	
Y751 ⁵	Laparoscopically assisted approach to abdominal cavity
Y752 ⁵	Laparoscopic approach to abdominal cavity NEC

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Text S.C: Further detail on funnel plots

20 hospitals comprising 1062 (6.5%) and 22 hospitals comprising 645 admissions (4.1%) were excluded in the pre-pandemic and pandemic period, respectively.

In Fig. 3A., 12 (10.4%) hospitals fell above and 19 (16.5%) fell below 2SD, while 12 (10.4%) hospitals fell above and 14 (12.2%) fell below 3SD. Among the hospitals with specialist paediatric services, 10 (47.6%) hospitals fell above and 1 (4.8%) fell below 2SD. For the same hospitals, 6 (28.6%) hospitals fell above and 1 (4.8%) fell

below 3SD. In Fig. 3B., 9 (7.8%) hospitals fell above and 18 (15.7%) fell below 2SD. 9 (7.8%) hospitals fell above and 16 (13.9%) fell below 3SD. Among the hospitals with specialist paediatric services, 11 (52.4%) and 1 (4.8%) hospital fell above and below the 2SD control limit respectively, with 9 (42.9%) and no hospitals falling above and below the 3SD control limit.

Before the pandemic, 52.4% (11/21) of specialist paediatric surgical centres and 33.0% (31/94) of hospitals without these specialist paediatric surgical centres treated significantly higher proportions (>2 CL above the mean) of CYP with complex appendicitis compared with the rest of the hospitals. There was a small shift during the pandemic period, with a slight increase in the proportion of specialist trusts (57.1%, (12/21)) but fewer non-specialist trusts (28.7% (27/94)) caring for a higher proportion of CYP with complex appendicitis.

Sensitivity

Figure S.D: Main and sensitivity monthly appendicitis admissions, by 0-4s, during the pandemic and the mean monthly admission trends for the previous five years

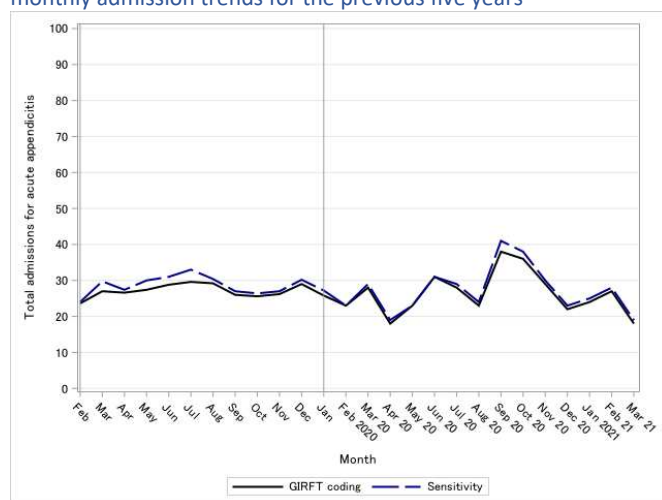


Figure S.E: Main and sensitivity monthly appendicitis admissions, by 5-9s, during the pandemic and the mean monthly admission trends for the previous five years

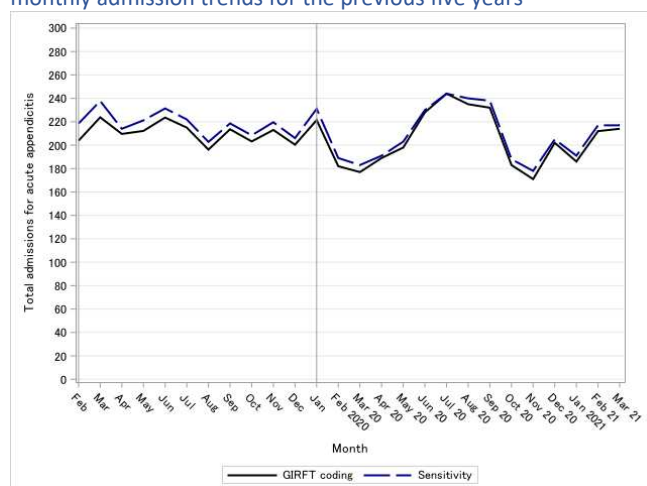


Figure S.F: Main and sensitivity monthly appendicitis admissions, by 10-24 year old's, during the pandemic and the mean monthly admission trends for the previous five years

