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■ GENERAL ORTHOPAEDICS

Theatre efficiency in COVID-19 pandemic conditions: The collaborative experience of four level 1 major trauma centres in the UK

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Aims

As the world continues to fight successive waves of COVID-19 variants, we have seen worldwide infections surpass 100 million. London, UK, has been severely affected throughout the pandemic, and the resulting impact on the NHS has been profound. The aim of this study is to evaluate the impact of COVID-19 on theatre productivity across London's four major trauma centres (MTCs), and to assess how the changes to normal protocols and working patterns impacted trauma theatre efficiency.

Methods

This was a collaborative study across London's MTCs. A two-month period was selected from 5 March to 5 May 2020. The same two-month period in 2019 was used to provide baseline data for comparison. Demographic information was collected, as well as surgical speciality, procedure, time to surgery, type of anaesthesia, and various time points throughout the patient journey to theatre.

Results

In total, 1,243 theatre visits were analyzed as part of the study. Of these, 834 patients presented in 2019 and 409 in 2020. Fewer open reduction and internal fixations were performed in 2020 (33.5% vs 38.2%), and there was an increase in the number of orthoplastic cases in 2020 (8.3% vs 2.2%), both statistically significant results (p < 0.000). There was a statistically significant increase in median time from 2019 to 2020, between sending for a patient and their arrival to the anaesthetic room (29 vs 35 minutes; p = 0.000). Median time between arrival in the anaesthetic room and commencement of anaesthetic increased (7 to 9 minutes; p = 0.104).

Conclusion

Changes in working practices necessitated by COVID-19 led to modest delays to all aspects of theatre use, and consequently theatre efficiency. However, the reality is that the major concerns of impact of service did not occur to the levels that were expected.

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Introduction

As the world continues to fight successive waves of COVID-19 variants, we have seen global infections surpass 100 million, with over two million deaths at the time of writing.[1] The UK has been one of the worst affected regions and currently stands fifth in the world in terms of infections and deaths.[1]

London, UK, has been severely affected throughout the pandemic.[2] The resulting impact on the NHS during peaks of COVID-19 cases has been profound, with emergency trauma and orthopaedic care being severely impacted. Delivery of trauma care across all four of London's major trauma centres (MTCs; The Royal London Hospital, King's College Hospital, St George's Hospital, and St Mary's Hospital) was restructured as part of an emergency response, diverting resources to manage the COVID-19 burden.[3]

Operating theatre staff and anaesthetists were redeployed to critical care units, reducing capacity. There were also major amendments to anaesthetic protocols, infection control measures, and use of personal protective equipment (PPE), which appeared to impact productivity and reduce efficiency and turnover.

The aim of this study is to evaluate the impact of COVID-19 on theatre productivity across London's MTCs, and to assess how the changes to normal protocols and working patterns impacted trauma theatre efficiency.

Methods

This was a collaborative study across all four of London's MTCs. A two-month period was selected to compare to a period just prior to and during the first lockdown, from 5 March to 5 May 2020. The same two-month period in 2019 was used to provide baseline data for comparison.

Inclusion criteria were any individual undergoing a surgical procedure during the defied time periods, and patient and theatre records for all the pre-defined assessment parameters. Any incomplete records and non-emergency cases were excluded.

Data was collected at individual sites and collated for analysis as a single dataset. Data sampling for each site was standardized. All patients were identified by searching computerized theatre records, with all those undergoing procedures during the defined timeframe included in the study. Data regarding demographics was obtained by retrospective review of the computerized patient record. This was also used to review the operation notes and to document the exact procedures that were performed. All timings data was collected by review of the electronic theatre records, where data is input at the time of the procedure by theatre scrub staff. These practices and records are standardized across all four sites.

Every emergency surgical case performed during the study periods was included, provided that full data was available on the electronic record. Baseline demographic information was collected, as well as surgical speciality, procedure, time to surgery, type of anaesthesia, the time between sending for and arrival in the anaesthetic room, time between anaesthetic room arrival and start of anaesthesia, overall anaesthesia time, overall procedure time, and overall theatre time.

Once individual site data was collected, the data was pooled for all four sites. Further records that were incomplete were removed from the data set. The final, complete four-site data set was then statistically analyzed (as described below). The study was registered with the research and audit department of each participating UK centre. As we were using routinely collected anonymized data, formal research ethics approval was not required.

Statistical analysis. The years 2019 and 2020 were compared in categorical variables using chi-squared test (test statistic denoted by χ^2; degrees of freedom by df). When

not valid, Fisher's exact test was used (test statistic denoted by FI; degrees of freedom by df). Where distributional assumptions could be made, the years 2019 and 2020 were compared in the mean of continuous variables using the independent-samples t-test (test statistic denoted by t; degrees of freedom by df); otherwise the Mann-Whitney U test (test statistic denoted by U; degrees of freedom by df) was used to test for differences between years in the distribution of variables. The critical level of significance was 5% (0.05). Traditional statistical hypothesis testing with a two-sided alternative was employed. No adjustment was made for multiple hypothesis testing.

Categorical data were presented as frequencies and percentages. When distributional assumptions could be made, then continuous variables were presented using the descriptive statistics of the mean, standard deviation, median, lower quartile and upper quartile, plus minimum and maximum. When distributional assumptions could not be made for in continuous variables, the descriptive statistics of the median, lower quartile and upper quartile, plus minimum and maximum were presented.

Results

In total, 1,243 theatre visits were analyzed as part of the study. Of these, 834 patients presented in 2019 and 409 in 2020, representing a 51% decrease in cases undergoing emergency surgery. The distribution of these cases is shown in Table I, along with baseline demographic data. No statistically significant difference was found between 2019 and 2020 for sex (p = 0.510, chi-squared test), age (p = 0.204, independent-samples t-test), or mechanism (p = 0.069, chi-squared test). Absolute figures do show a reduction in the number of sporting injuries treated from 3.8% in 2019 to 0.7% in 2020. Although no statistically significant differences in time to surgery were observed, there was a trend favouring reduction in same day surgery (categorized as same calendar day as admission), from 31.3% in 2019 to 26.2% in 2020. There were increases in delays of one calendar day (26.1% to 27.6%), two days (9.6% to 12.5%) and three days or more (33% to 33.7%), although not statistically significant overall (p = 0.178, chi-squared test).

Statistically significant increases were seen from 2019 to 2020 in percentage of thoracic (3.2% vs 0.7%; p = 0.011, chi-squared test), vascular (4.9% vs 2.3%; p = 0.013, chi-squared test), and plastics surgeries (18.1% vs 8.5%; p = 0.000, chi-squared test). Analysis of the nature of procedures revealed fewer open reduction and internal fixations (ORIFs) in 2020 (33.5% vs 38.2%) and an increase in the number of orthoplastic cases in 2020 (8.3% vs 2.2%), both statistically significant results (p < 0.000, chi-squared test). Table II summarizes details of procedures performed.

No statistically significant differences were found in American Society of Anaesthesiologists (ASA) score (p =

Table I. Demographic data for 2019 and 2020 cohorts.

Variable	2019 frequency	2020 frequency	Test statistics
Sex, n (%)			
Female	301 (36.1)	140 (34.2)	$\chi^2 = 0.44$
Male	533 (63.9)	269 (65.8)	df = 1
			p = 0.510
Age, yrs			
Total, n	834	409	$t = -1.27$
Mean (SD)	45.5 (23.67)	47.3 (23.27)	df = 1
Minimum	0.3	0.8	p = 0.204
Maximum	100.8	103.1	diff = −1.8
			95% CI -4.62 to 0.99
Individual MTC workload, n (%)			
MTC 1	360 (43.2)	119 (29.1)	
MTC 2	282 (33.8)	164 (40.1)	
MTC 3	86 (10.3)	43 (10.5)	
MTC 4	106 (12.7)	83 (20.3)	
Mechanism, n (%)			
RTC	213 (25.5)	104 (25.4)	$\chi^2 = 11.72$
Assault (blunt)	31 (3.7)	12 (2.9)	df = 6
Assault (penetrating)	57 (6.8)	29 (7.1)	p = 0.069
Fall < 2 m	224 (26.9)	109 (26.7)	
Fall > 2 m	85 (10.2)	52	
Sports	32 (3.8)	3	
Other	192 (100)	100	
Neurosurgery, n (%)			
No	788 (94.6)	383 (93.6)	$\chi^2 = 0.457$
Yes	45 (5.4)	26 (6.4)	df = 1
			p = 0.499
Thoracic, n (%)			
No	826 (99.3)	396 (96.8)	$\chi^2 = 10.96$
Yes	6 (0.7)	13 (3.2)	df = 1
			p = 0.01
General surgery, n (%)			
No	772 (92.7)	367	$\chi^2 = 3.11$
Yes	61 (7.3)	42 (10.3)	df = 1
			p = 0.078
Vascular, n (%)			
No	814 (97.7)	389 (95.1)	$\chi^2 = 6.12$
Yes	19 (2.3)	20 (4.9)	df = 1
			p = 0.013
ENTMF, n (%)			
No	790 (94.8)	386 (94.4)	$\chi^2 = 0.11$
Yes	43 (5.2)	23 (5.6)	df = 1
			p = 0.737
Plastics, n (%)			
No	762 (95.1)	335 (81.9)	
Yes	71 (8.5)	74	$\chi^2 = 24.28$
ASA grade, n (%)			df = 1
I	363 (43.7)	176 (43.0)	p = 0.000
II	304 (36.6)	126 (30.8)	
II	119 (14.3)	76 (18.6)	
IV	42 (5.1)	28 (6.8)	
V	2 (0.2)	3 (0.7)	
Time to surgery, n (%)			

Continued

Table I. Continued

Variable	2019 frequency	2020 frequency	Test statistics
Same day	261 (31.1)	107 (26.2)	$\chi^2 = 4.91$
Next day	217 (26.1)	113 (37.6)	df = 3
Two days later	80 (9.6)	51 (12.5)	p = 0.178
Three or more days later	275 (33.0)	138 (33.7)	
Type of anaesthesia, n (%)			
General anaesthetic	820 (98.9)	402 (96.8)	FI = 1.48
Local anaesthetic	7 (0.8)	5 (1.2)	df = 3
Sedation	1 (0.1)	0 (0.0)	p = 0.795
Spinal	1 (0.1)	0 (0.0)	

χ^2, chi-squared test; ASA, American Society of Anaesthesiologists; CI, confidence interval; df, degrees of freedom; ENTMF, ear, nose and throat, maxillofacial; FI, Fisher's exact test; t, independent-samples t-test.

Table II. Comparison of operative case mix between 2019 and 2020.

Variable	2019 frequency, n (%)	2020 frequency, n (%)	Test statistics
Orthopaedic			
Upper limb	123 (15.2)	55 (13.4)	$\chi^2 = 11.29$
Lower limb	416 (51.4)	211 (51.6)	df = 6
Pelvis	98 (12.1)	57 (13.9)	p = 0.080
Elective	2 (0.2)	0 (0.0)	
Spine	24 (3.0)	17 (4.2)	
N/A	151 (18.1)	69 (16.9)	
Operation type			
IM nail	104 (12.5)	47 (11.5)	$\chi^2 = 38.73$
ORIF	318 (38.2)	137 (33.5)	df = 11
Ex-fix	38 (4.6)	24 (5.9)	p = 0.000
Soft tissue	54 (6.5)	20 (4.9)	
Abdominal	36 (4.3)	14 (3,.4)	
Head	26 (3.1)	4 (1.0)	
Chest	7 (0.8)	2 (0.5)	
Vascular	9 (1.1)	8 (2.0)	
Plastic	50 (6.0)	33 (8.1)	
ENT	5 (0.6)	4 (1.0)	
Other	168 (20.2)	82 (20.0)	
Orthoplastic	18 (2.2)	34 (8.3)	

χ^2, chi-squared test; df, degrees of freedom; ENT, ear, nose, and throat; IM, intramedullary; N/A, not applicable; ORIF, open reduction and internal fixation.

0.059, chi-squared test) nor type of anaesthesia used (p = 0.795, chi-squared test). Although no statistically significant differences in time to surgery were observed, there was a trend favouring reduction in same day surgery (categorized as same calendar day as admission), from 31.3% in 2019 to 26.2% in 2020. There were increases in delays of one calendar day (26.1% to 27.6%), two days (9.6% to 12.5%), and three days or more (33% to 33.7%), although not statistically significant overall (p = 0.178, chi-squared test).

Table III summarizes timings of various stages in the patient journey to theatre. There was a statistically

Table III. Timings of various stages in the patient journey to theatre, from sending to leaving theatre.

Variable	2019	2020	Test statistics
Time between sending for and anaesthetic room arrival, mins			
Frequency, n	834	409	U = 190,704.0
Median (IQR)	29 (19 to 40)	35 (20 to 44)	p = 0.000
Minimum to maximum	0 to 1,420	0 to 975	
Time between anaesthetic room arrival and anaesthetic start, mins			
Frequency, n	834	409	U = 176,151.5
Median (IQR)	7 (5 to 14)	9 (5 to 15)	p = 0.104
Minimum to maximum	0 to 190	0 to 1,268	
Time between start of anaesthetic and patient left theatre, mins			
Frequency, n	834	409	U = 177,599.5
Median (IQR)	165 (110 to 230)	167 (124 to 250)	p = 0.091
Minimum to maximum	13 to 565	16 to 940	
Time between procedure start and stop time, mins			
Frequency, n	834	409	U = 171,192.0
Median (IQR)	98 (60 to 155)	101 (60 to 158)	p = 0.322
Minimum to maximum	6 to 462	6 to 747	
Time between arrival in anaesthetic room and patient leaving anaesthetic room and theatre, mins			
Frequency, n	834	409	U = 178,665.5
Median (IQR)	175 (119 to 242)	180 (136 to 263)	p = 0.061
Minimum to maximum	23 to 571	18 to 955	

IQR, interquartile range; U, Mann-Whitney U test.

significant increase in median time from 2019 to 2020, between sending for a patient and their arrival to the anaesthetic room (29 vs 35 minutes; p = 0.000, Mann-Whitney U test). Median time between arrival in the anaesthetic room and commencement of anaesthetic increased (seven to nine minutes; p = 0.104, Mann-Whitney U test). With regards to anaesthetic time, although not statistically significant, all descriptive statistics showed an increase between 2019 and 2020. The median anaesthetic time increased from 165 minutes in 2019 to 167 minutes in 2020 (p = 0.091, Mann-Whitney U test). Overall procedure time showed a non-statistically significant increase from 98 minutes in 2019 to 101 minutes in 2020 (p = 0.322, Mann-Whitney U test). Median overall theatre time, defined as time from arrival in the anaesthetic room to departure of theatre, showed a non-statistically significant increase from 175 minutes in 2019 to 180 minutes in 2020 (p = 0.061, Mann-Whitney U test), with an increasing trend in nearly all descriptive statistics.

Discussion

The four London level 1 MTCs are well prepared for major incidents, with rehearsed protocols for what typically are large casualty, single events within a short timeframe. The COVID-19 pandemic has presented a different challenge, with a prolonged and progressive pressure on healthcare services requiring longer-term restructuring of normal healthcare provision.

All four of the MTCs involved in this study underwent restructuring as part of an emergency response, rediverting resources to manage the COVID-19 burden. This restructuring and redeployment was described in a recent publication and was the same across the four units.[3]

The resultant reconfiguration has seen operating rooms used as extensions to critical care, with redistribution of ventilators and a resultant 50% to 75% reduction in operating capacity across all MTCs. Anaesthetic colleagues have been redeployed to intensive care for their airway skills and surgical teams were broken up. Modified anaesthetic protocols and PPE routines led to a perception of reduced productivity. At the outset, our expectation was that the disruption to normal routines and protocols would strongly adversely affect theatre efficiency.

In reality, however, although overall our data show that efficiency was negatively impacted, it also reveals only modest differences between the pre-COVID-19 and COVID-19 periods, and, in most cases, only differences of a few minutes throughout the patient journey. The reality of the situation was not as bad as had been expected, and the resilience of the emergency restructuring process is reassuring.

Our collaborative experience across London's MTCs during the first wave of COVID-19 has assessed the impact of pandemic on service provision, productivity, and theatre efficiency. During the COVID-19 study period, there was a 51% reduction in the number of surgical cases performed. Part of this related to the reduction in presentations due to the national lockdown; however, this may also reflect changes in decision-making and management of injuries to rationalize services and protect patients from COVID-19. This theory is supported by the statistically significant reduction in the percentage of ORIF procedures performed during the 2020 study period.

Time from admission to theatre, a marker for how quickly patients were operated upon, deteriorated during the COVID period. The number of same day procedures reduced, with resultant increases in those being operated one to three days post admission, the largest increase being in those waiting for two days for surgery. In the 2019 period, 478/834 patients (57.4%) were operated

on within two days of admission, compared to 220/409 patients (53.7%) in 2020. It stands to reason that reduced capacity, potentiated by reduced efficiency, led to delays in treatment.

There was a significant increase in the duration between sending for a patient and them arriving in the anaesthetic room. Raw data showed increases in anaesthetic start time after arrival in the anaesthetic room, overall anaesthetic time, overall procedure time, and overall time in theatre.

Literature for comparison is limited. Our findings are supported by the data from available studies. Khadabadi et al[4] evaluated 45 full-day lists in 2019 and 50 full-day lists in 2020 during April and May. They found that operative time and anaesthetic time went up significantly in 2020 in comparison to 2019. Karia et al[5] presented some data on theatre usage in their paper on the outcome of COVID-19 in district general hospital practice. They found statistically significant increases in time to leave theatre (defined as the time between completing the procedure and leaving the operating theatre) from six to eight minutes (p < 0.001, Mann-Whitney U test). They also found that mean turn around (time between the patient leaving the operating theatre and the next patient arriving in the anaesthetic room) increased significantly by 46.5 minutes from 13.0 minutes in April 2019 to 59.5 minutes during lockdown (p < 0.001, Mann-Whitney U test).

Our data shows that delays were present at each step of the patient journey. Reduced theatre availability, redeployment of staff, and stringent infection control, including prolonged cleaning protocols, were all necessary steps in service and process reconfiguration but with the resultant impact of delays. Whether this influenced patient care is presently answered. However, further data pending publication from our collaborative, looking at outcomes patients during the COVID-19 first wave, shows resilience of the MTC healthcare system during the early COVID-19 pandemic. Despite the restructuring of services, the London MTCs were able to perform to their normal high standards, and were able to deliver care to the major trauma patients in an appropriate and timely fashion.

The widespread impact of reduced efficiency in theatre should not be underestimated. Fewer cases completed each day leads to, as we have demonstrated, patients waiting longer for their surgery. Extended periods of preoperative pain and increased risk of preoperative complications in immobile patients have both physical and psychological impact. Resultant prolonged hospital admissions potentially increase risks of hospital-acquired infections and currently, COVID-19.[6-8] There is also the financial consequence of inefficiency, with the operating theatre already identified as a prominent cause of financial waste in the NHS due to inefficiency.[9]

There are limitations to the study. The data relates to the first wave of the COVID-19 pandemic. As we approach a potential third wave now in 2021, it is important to appreciate that this has been a rapidly changing situation, and that protocols have evolved since the early days of the pandemic. In addition, the success of the vaccination programme in the UK has significantly improved the situation by, at very least, reducing hospitalizations and severity of the disease in vaccinated individuals. Appreciating the change in circumstances, it remains important to learn from our initial response to a large-scale, rapid evolving situation that pushed the resources of the NHS more than it has ever experienced.

The study was performed in the MTC setting and some questions may be raised regarding extrapolating results to the non-MTC setting. Regardless of size, many hospitals experienced the same problems with workload and restructuring/redeployment that we have discussed in this paper. Although the case mix may be different to other hospital settings, the workings of our remaining trauma provision would be no different, with the processes and associated delays expected to be similar in other settings.

Two further questions relate to the accuracy of the timing data, and whether these statistically significant and equally non-significant data are clinically meaningful. Each unit recorded the same 'timings' data as part of the electronic theatre record. These were all to the nearest second, with no evidence of rounding. However, we accept that there could well have been lack of precision in recording the measurements. Regarding clinical meaningfulness, this is difficult to categorically answer. Do changes of between two and six minutes actually have a clinical impact? Our data reflect our opinion that the changes seen were not as bad as were expected, given the severe restriction of service and new infectious disease protocols.

This study does goes some way to quantifying reduced productivity under the conditions set-out by COVID-19 restructuring, and we are the first multicentre MTC to do so. All of our centres experienced surges in COVID-19 admissions; reorganization of services was extensive to support this. This was not the case in other regions of the UK, where changes to services may have been less pronounced, meaning that extrapolation of these results may be challenging. Our circumstances did, at times, represent a worst-case scenario, which can now be planned for.

Understanding the nature of the delays will allow some mitigation of the effect (e.g. sending for patients earlier knowing that they take longer to arrive to theatre), as well as enabling better workload planning in further COVID-19 waves.

In conclusion, realistic insight into what can be achieved in in a trauma list and the delays that exists will better enable workload planning in further COVID-19 waves. The changes in working practices necessitated by COVID-19 led to modest delays to all aspects of theatre usage, and consequently, theatre efficiency. However, the reality is that the major concerns of impact of service did not occur to the levels that were expected.

Take home message

- Emergence of the COVID-19 pandemic resulted in dramatic changes in global healthcare provision.

- We describe the impact of this on the provision of major trauma care in a major capital city and have shown how this negatively impacted on theatre efficiency.

- Widespread delays were noted throughout the patient journey from admission to theatre. However, the reality ultimately was not as bad as was anticipated.

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