Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

The American Journal of Surgery 222 (2021) 67–85

Contents lists available at ScienceDirect

The American Journal of Surgery

journal homepage: www.americanjournalofsurgery.com

Review Article

Impact of hospital lockdown secondary to COVID-19 and past pandemics on surgical practice: A living rapid systematic review

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ARTICLE INFO

Article history:
Received 13 October 2020
Received in revised form
2 November 2020
Accepted 7 November 2020

Keywords:
COVID-19
Surgical outcomes
Epidemic
Health care worker
Lockdown

ABSTRACT

Background: The COVID-19 pandemic has disrupted surgical practice worldwide. There is widespread concern for surgeon and provider safety, and the implications of hospital lockdown on patient care during epidemics.

Methods: Medline, EMBASE, CENTRAL, and PubMed were systematically searched from database inception to July 1, 2020 and ongoing monthly surveillance will be conducted. We included studies that assessed postoperative patient outcomes or protection measures for surgical personnel during epidemics.

Results: We included 61 studies relevant to the COVID-19 pandemic and past epidemics. Lockdown measures were noted globally including cancellation of elective surgeries and outpatient clinics. The pooled postoperative complication rate during epidemics was 21.0% among 2095 surgeries. 31 studies followed the health of surgical workers with the majority noting no adverse outcomes with proper safety measures.

Conclusions: This review highlights postoperative patient outcomes during worldwide epidemics including the COVID-19 pandemic and identifies specific safety measures to minimize infection of healthcare workers.

Introduction

The current COVID-19 pandemic has disrupted health services worldwide.[1,2] There is a concern of nosocomial transmission, shortage of personal protective equipment (PPE), and limited resources for critical patients.[3–6] As a result, many hospitals have undergone lockdown procedures in which staffing and services are limited. These lockdown procedures have inconsistent policies, often occurring on an urgent basis with little notice or preparation. In previous outbreaks such as severe acute respiratory syndrome (SARS) and Ebola, these precautionary measures have lasted several months with downstream effects on health outcomes.[7,8]

Surgical practice is particularly at risk for lockdowns during outbreaks and epidemics.[9] In particular, there may be a heightened risk for transmission of airborne pathogens during aerosolizing procedures in laparoscopic surgeries, though current evidence is unclear. In addition, there is risk of transmission of blood-borne viruses such as Ebola during accidental injuries.[9,10] Operation techniques and equipment management may also be altered to reduce contact with potential vectors.[9] In addition, intensive care units and emergency departments are often overwhelmed with critical care patients, with a limited supply of ventilators and bedspace.[4] As such, the Centers for Disease Control and Prevention recently published an interim recommendation that all elective procedures should be cancelled during the COVID-19 pandemic.[11] Surgical residents and staff may also be diverted to other specialties to provide frontline care if needed, as hospital volumes drastically increase.[9,12]

While there are numerous guidelines and editorials on the topic, there has not yet been a systematic assessment of the literature regarding surgical care and epidemics. Our living rapid systematic review aims to assess all research literature related to changes in

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https://doi.org/10.1016/j.amjsurg.2020.11.019
0002-9610/

surgical practice during disease outbreaks and epidemics, especially during the current COVID-19 pandemic.

Methods

Outcomes

The primary research question for the review was to investigate the impact of epidemics on surgical outcomes of patients undergoing urgent or elective surgery amidst periods of hospital lockdown. The specific outcomes included: (1) the number and type of surgical procedures performed during lockdowns (urgent, elective, or oncologic) (2) the number of non-OR procedures performed and its complications (3) the incidence of infected patients (confirmed and presumed) at the time of the procedure, or after the procedure, and the number of patients testing negative for infection after procedure.

The secondary aim of the review was to investigate the impact of an epidemic-caused lockdown on surgical practice. The following outcomes were collected: (1) the number of HCW, the incidence of HCW infected or not infected after procedures, and the incidence of mortality among HCW (2) the type of PPE items used by HCW, modified perioperative logistics, precautionary measures and interventions enforced for HCW protection, modified OR arrangements, and duration of protection (3) the description of lockdown, and outpatient clinic volume.

Data sources and search strategy

Medline, EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), and PubMed were systematically searched from database inception to April 2020, and ongoing surveillance was carried out until May 29, 2020. The search strategy (see Appendix 1) was designed in consultation with a medical librarian. This systematic review is reported in accordance with the Preferred Reporting items for Systematic Reviews and Meta-Analyses (PRISMA), with the PRISMA flow diagram presented in Fig. 1.[13]

Eligibility criteria and data abstraction

Studies reporting outcomes of patients undergoing surgery during an epidemic-caused hospital lockdown and studies investigating the impact of lockdown on surgical HCW and surgical practice were included. Articles were excluded from our review if they (1) were a review article, case report, letter to the editor, opinion, commentary, or editorial (2) did not contain at least one relevant outcome of interest (3) investigated a lockdown caused by a local hospital outbreak. No language or geographical restrictions were applied. Titles, abstracts, and full-text citations were screened, and conflict was resolved by the third reviewer. Two investigators extracted study data using a standardized spreadsheet, and verification of the extracted data was carried out by a third investigator. The following variables were abstracted from the included studies: study characteristics (e.g. author, year of publication, study design, study duration, country, type of epidemic, type of institution), patient demographics (e.g. number of patients included, age, sex), and study outcomes. Surgical outcomes were reported using the Clavien-Dindo Classification.[14] The Accreditation Council of Graduate Medical Education (ACGME) Staging System was used reflect the degree of disruption caused by epidemics.[15]

Study quality assessment

Risk of bias of included studies was assessed using the Methodological Index for Non-Randomized Studies (MINORS), a 12 items-tool that evaluates the methodological quality of non-randomized studies.[16] Discrepancies were discussed until consensus was reached. Studies were not excluded on the basis of quality.

Data synthesis

A narrative synthesis of study findings is provided along with a tabular summary of our primary and secondary outcomes of interest. Findings were reported and grouped into the following four outcome categories: (1) surgical procedures and outcomes, (2) surgical clinics and non-surgical procedures, (3) protection measures during outbreaks, and (4) patient exposures and HCW outcomes. Patient demographic data and quantitative outcomes across studies were pooled and reported using descriptive statistics. Measures of protection employed by HCW during outbreaks were further categorized into four groups: (1) PPE, PRE-OR, OR SETUP, LOGISTICS. These categories were developed via content analysis of the included studies. The synthesis without meta-analysis (SWiM) reporting guideline was followed closely for this systematic review.[17]

Living and rapid review

Due to the timing and relevance of our research questions during the ongoing COVID-19 pandemic, both rapid and living review approaches were employed to streamline the systematic review process, and to ensure that relevant emerging data was not omitted from our study.[18–20] Ongoing surveillance for studies will be maintained on a two-to three-month basis, and updates to our manuscript will be made accordingly. Methods for study selection and data abstraction will remain consistent.

Results

Patient and hospital characteristics

34 retrospective studies, 16 case series, 5 descriptive studies, and 6 prospective studies represented a combined 3948 patients across 17 countries up to June 2020 (Table 1). Studies conducted during COVID-19 accounted for 98.6% of the included patients, while 1.2% were from studies during SARS, and 0.15% were from studies during MERS. Among papers describing patient demographics, 53.9% were female and median age was 62.0 years (range 1–100 years). A total of 455 health care workers were also represented with 70.1% HCW included during COVID-19, 28.1% included during SARS, and 1.8% included during Ebola epidemics.

Hospital lockdown measures were described in 26 studies (Table 2). The most common measures included cancelation of elective surgery as specified in 84.6% of those studies, and a reduction or cancellation altogether of outpatient clinics specified in 23.1% of studies. One study reported stopping all planned activities to convert its center into a dedicated COVID-19 hospital.[21] Another study described a MERS outbreak resulting from an index case admitted to the cardiac surgery ward with no specific precautions described.[22] None of the included studies reported complete stoppage of educational activities to focus solely on patient care, as reflected by the ACGME Staging System scores.

Surgical procedures and outcomes

Data were reported for a total of 3850 surgeries, with 96.1% of those performed during COVID-19, 2.5% during Ebola, 1.2% during SARS, and 0.16% during MERS epidemics (Table 2). The following

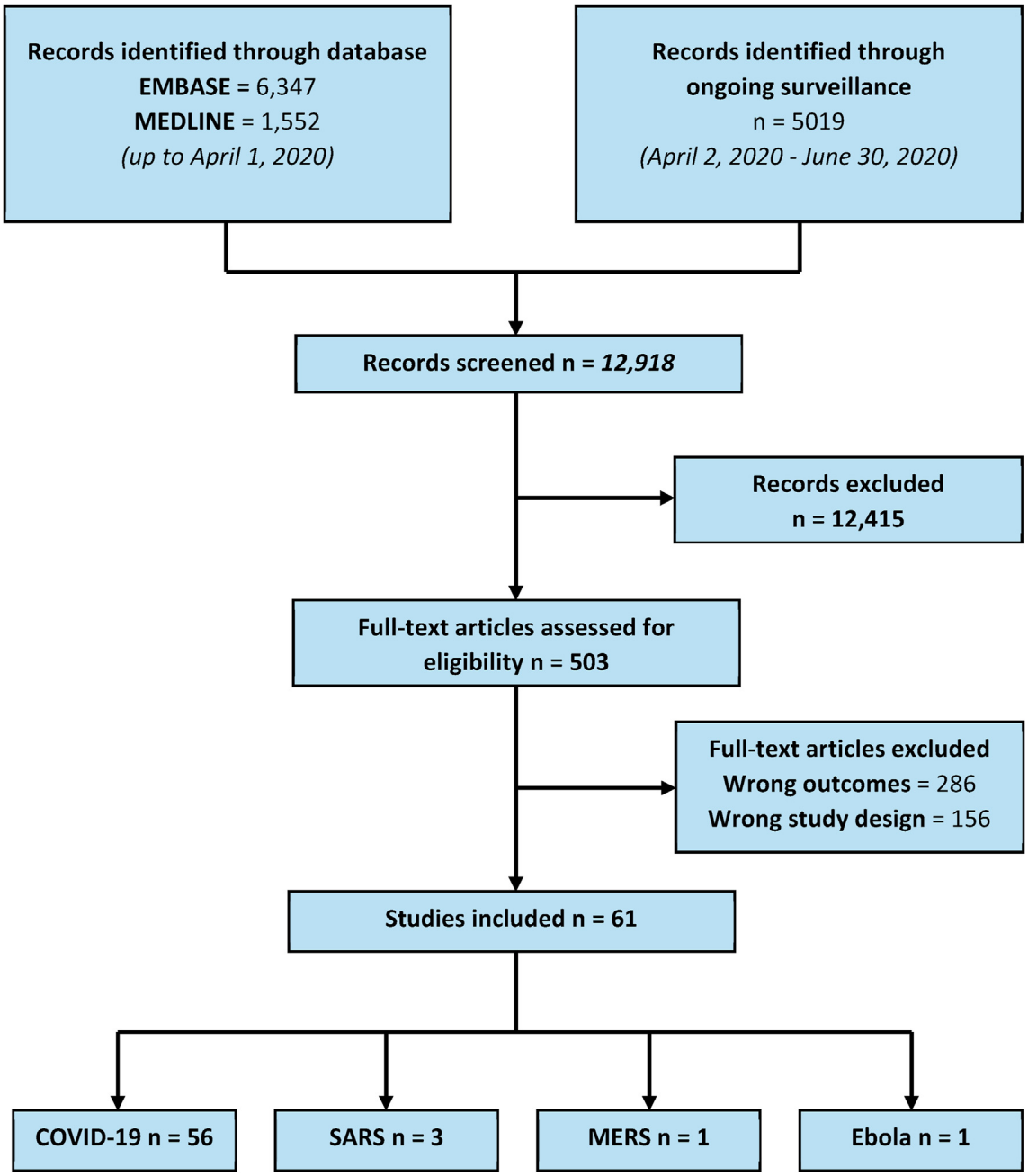

Fig. 1. PRISMA Diagram – transparent reporting of systematic reviews and meta-analysis flow diagram outlining the search strategy results from initial search to included studies. *Coronavirus disease 2019, COVID-19; Middle East respiratory syndrome-related coronavirus, MERS; Severe acute respiratory syndrome-related coronavirus, SARS.*

surgical specialties were represented in the included studies: otolaryngology and maxillofacial surgery (16.4%); orthopedics (13.1%); obstetrics and gynecology (9.8%); neurosurgery (9.8%); general surgery (8.2%); vascular surgery (6.6%); surgical ICU (6.6%); thoracic surgery (4.9%); hepatobiliary, pancreatic, and liver transplant (3.3%); urology (3.3%); surgical oncology (3.3%); kidney transplant (1.6%); cardiac surgery (1.6%); and spine surgery (1.6%). Of the included studies, 6.6% included data on more than one surgical specialty. Among all included surgeries, 36.5% were urgent, 23.2% were elective, and 10.8% were oncologic.

Post-operative complications were reported in 59.0% of studies. Four studies noted no complications following surgery.[23–26] A total of 440 complications were reported, with the most common ones being all-cause mortality accounting for 14.3% of complications, postoperative diagnosis of COVID-19 accounting for 12.0%, and hemorrhagic complications accounting for 7.3%. Of those studies reporting on complications, the pooled complication rate among 2095 surgeries was 21.0%. The pooled rate of minor complications (Clavien-Dindo Grades I-II) was 12.3%, the rate of major complications (Clavien-Dindo Grade III-IV) was 5.3%, and the rate of all-cause mortality (Clavien-Dindo Grade V) was 3.4%. The complication rate among COVID-19 surgeries alone was 20.9%. Mortality secondary to complications from COVID-19 was reported in 1.1% of postoperative patients during the COVID-19 pandemic. Of note,

Table 1
Study characteristics.

Author, year	Virus	Country	Institution type	Study type	N patients	N hospital personnel	% female	n female	Mean age (SD)
Angel, 2020	COVID-19	United States	Single institution	Retrospective chart review	98	8	18.0%	18	57
Barca, 2020	COVID-19	Italy	Single institution	Retrospective study	33		27.3%	9	60.53 (range 20–80)
Berardi, 2020	COVID-19	Italy	Single institution	Retrospective chart review	72		34.7%	25	64 (53–74)
Bogani, 2020	COVID-19	Italy	Single institution	Retrospective review	5		100.0%	5	Mean 68yrs (SD 7.1 yrs)
Bundu, 2014	Ebola	Sierra Leone	Single institution	Retrospective cohort		8			–
Cai, 2020	COVID-19	China	Single institution	Descriptive Study					–
Cai, 2020	COVID-19	China	Single institution	Case series	7		28.6%	2	Median age, 60 (IQR, 57–66)
Chao, 2020	COVID-19	United States	Multi-institution	Prospective cohort study	53		38.0%	20	Mean 62.0 years (±14.3yrs; range 23.5–81.7 yrs)
Chee, 2004	SARS	Singapore	Single institution	Retrospective chart review	41	124			–
Chen, 2020	COVID-19	China	Single institution	Case series	17	48	100.0%	17	Epidural anesthesia patients 29.5 (3.1); General anesthesia patients 28.7 (1.6)
Cheung, 2020	COVID-19	USA	Single institution	Retrospective cohort	10		20.0%	2	80.5 (67–90)
Chow 2020	COVID-19	Hong Kong	Single institution	Retrospective observational	5				–
Couto, 2020	COVID-19	United States	Single institution	Retrospective cohort study	300				Median 54.6 (range 1–90). Mean age 27.
Cruz, 2020	COVID-19	United States	Single institution	Retrospective review	14		14.3%	2	Median 61.9 (range 43–83)
Cui, 2020	COVID-19	China	Multi-institution	Case series	20		45.0%	9	Median age 63 (range, 32–72)
Deng 2020	COVID-19	China	Single institution	Retrospective Observational	4	15	50.0%	2	57.5 (14.1)
Doglietto, 2020	COVID-19	Italy	Single institution	Retrospective matched cohort study	42		56.1%	23	Mean 75.95 (SD 15.17)
Doran, 2020	COVID-19	United Kingdom	Single institution	Case series	3		0.0%	0	65 (10.4)
Fregatti, 2020	COVID-19	Italy	Single institution	Retrospective cohort	85		100.0%	85	
Gallego, 2020	COVID-19	Spain	Single institution	Prospective cohort study	189	49	57.2%	108	Elective surgery: 59.5; Urgent surgery: 81
Gao, 2020	COVID-19	China	Single institution	Case series	4		25.0%	1	56.8 (11.3)
Garcia-Portabella, 2020	COVID-19	Spain	Single institution	Retrospective case series	11		63.6%	7	Mean 64.8 (SD 13.5)
Gou, 2020	COVID-19	China	Single institution	Case series	26				–
Hassan 2020	COVID-19	USA	Single institution	Retrospective study	91		40.7%	37	52.9 (19.3)
He, 2020	COVID-19	China	Single institution	Case series	4		25.0%	1	55.75 (range, 51–62)
Huang, 2020	COVID-19	China	Single institution	Case series	3		66.7%	2	69.6 (14.6)
Khalafallah, 2020	COVID-19	USA	Single institution	Retrospective descriptive		51	–		–
LeBrun, 2020	COVID-19	USA	Multi institution	Retrospective cohort	59		75.0%	44	85 (65–100)
Lei, 2020	COVID-19	China	Single institution	Retrospective chart review	34		58.8%	20	Median age, 55 (IQR, 43–63)
Leong, 2020	COVID-19	Singapore	Single institution	Retrospective Descriptive Study					
Li 2020	COVID-19	China	Single-institution	Retrospective observational	18				–
Luong-Nguyen, 2020	COVID-19	France	Multi-institution	Retrospective study	15		40.0%	6	Median age, 62 (range, 35–68)
Madanelo, 2020	COVID-19	Portugal	Single institution	Retrospective chart review	122		32.7%	40	56.93
Maniscalco 2020	COVID-19	Italy	Multi-institution	Retrospective observational	121		73.5%	89	81.8 (NR)
Maniscalco, 2020	COVID-19	Italy	Single institution	Retrospective review		21		0	
Meyer 2020	COVID-19	France	Single institution	Prospective observational	62				–

Table 1 (*continued*)

Author, year	Virus	Country	Institution type	Study type	N patients	N hospital personnel	% female	n female	Mean age (SD)
Morrison 2020	COVID-19	USA	Single institution	Retrospective observational	103				–
Nazer, 2007	MERS	Saudi Arabia	Single institution	Case series	6		0.0%	0	63 (18.2)
Ng 2020	COVID-19	Singapore	Single institution	Retrospective study	144	8	–		–
Oh, 2020	COVID-19	Korea	Single institution	Case series	8		100.0%	8	30 (25–39)
Paramore 2020	COVID-19	UK	Single institution	Prospective observational	52		13.5%	7	66 (NR)
Patel, 2020	COVID-19	UK	Single institution	Retrospective review	75		45.0%	34	Median 47 (32–63); Mean 59
Peng, 2020	COVID-19	New Zealand	Single institution	Case series	11		27.3%	3	Median age, 61 (51–69)
Ralli, 2020	COVID-19	Italy	Single institution	Retrospective study	96				–
Rossi, 2020	COVID-19	Italy	Single institution	Descriptive Study	79				NR
Saban, 2020	COVID-19	Israel	Single institution	Retrospective Review	142	11	54.2%	77	Mean 72.8 (13.6); Median 74 (range 21–98)
Schneider, 2020	COVID-19	Germany	Single institution	Retrospective review		66			
Shrikhande, 2020	COVID-19	India	Single institution	Prospective observational study	494		65.0%	321	Median 48 (range 27–85)
Taha, 2020	COVID-19	USA	Single institution	Prospective cohort study	152				–
Tan, 2020	COVID-19	China	Single institution	Descriptive study					–
Tankel, 2020	COVID-19	Israel	Multi-institution	Retrospective comparative study	130		45.4%	64	23.3 (16.8)
Tien, 2005	SARS	Canada	Single institution	Case series	4	4	25.0%	1	Median age of 3 patients 58; age of last patient 54
Turri-Zanoni, 2020	COVID-19	Italy	Single institution	Case series	32		33.0%	11	62 (range, 32–74)
Valdivia, 2020	COVID-19	Spain	Single institution	Retrospective chart review	50	14	–		–
Wang, 2020	COVID-19	USA	Single institution	Case series	5		20.0%	1	52.8
Wong, 2004	SARS	Hong Kong	Single institution	Case series	3		100.0%	3	–
Yang, 2020	COVID-19	China	Single institution	Retrospective chart review	3		100.0%	3	Median age, 48 (range, 47–59)
Yang, 2020	COVID-19	China	Single institution	Retrospective cohort	55	28	32.7%	18	65.1 (13.1)
Zagra 2020	COVID-19	Italy	Single institution	Retrospective chart review	664				
Zhang 2020	COVID-19	China	Single institution	Retrospective observational	11		36.4%	4	66.2 (range 32–93)
Zhang, 2020	COVID-19	China	Single institution	Retrospective comparative study	61		100.0%	61	(24–40 yrs)

multiple complications occurred in a single patient in some instances.

Non-surgical procedures and surgical clinics

Non-surgical procedures (defined in this study as procedures performed outside of an OR) were performed in 21.3% of studies and included tracheostomy, nasal endoscopy, central venous catheterization, balloon dilatation of hepaticojejunostomy, intravitreal injections, peritoneal dialysis, and percutaneous drainage of various anatomical compartments (Table 3). A total of 346 procedures were specified during epidemics, with a pooled post-operative complication rate of 14.5% among studies reporting on complications. The most common complications included death accounting for 41.9% of complications and post-procedural bleeding accounting for 29.0%. As described above for surgical complications, multiple complications may have been reported following a single procedure.

Seven studies (11.5%; 7/61) reported active outpatient clinics during epidemics, though there was an overall reduction of clinic volume by 50%–75%. Eight studies, all during the COVID-19 epidemics, also reported the use of telemedicine and virtual care modalities for outpatient consults and follow-up appointments.[26–34]

Protection measures during outbreaks

Measures to protect surgical personnel during outbreaks were reported in 45 studies (see Table 4; detailed overview provided in Supplementary Table 1). For the purpose of analysis, protection measures were classified into one of the following categories: PPE (any form of physical protection used by HCW); PRE-OR (any precautions taken preoperatively including modified patient screening and disinfection processes); OR SETUP (measures taken during surgical intervention, such as the use of negative-pressure or

Table 2
Surgical data and patient outcomes.

Author, year	Surgical service	Study Duration	Description of lockdown	N total number of surgeries	N elective surgeries (total; before outbreak; during outbreak)	N urgent surgeries (total; before outbreak; during outbreak)	N cancer surgeries (total; before outbreak; during outbreak)	CD I-II	CD III-IV	CD V	ACGME Stage
Angel, 2020	ICU	Mar 10 to Apr 15, 2020	–	–	–	–	–				2
Barca, 2020	Maxillofacial surgery	Feb to Apr 2020	–	33	0	20	13				2
Berardi, 2020	Surgical oncology, transplant surgery	Mar 9 2020 to Apr 24 2020	Only major oncologic surgeries and transplantations. Outpatient clinics were significantly reduced. Multidisciplinary meetings were moved to a webinar platform.	2019: 115; 2020: 72	0	12	60		Major complications not specified (n = 5)	Death due to hyperacute allograft dysfunction (n = 1)	2
Bogani, 2020	Gynecologic oncology	Feb to Mar 2020	–	5			5	Prolonged hospital course (n = 2); Post-op COVID-19 diagnosis (n = 5)		Death (n = 2)	–
Bundu, 2014	Various	Jun 2013 to Feb 2015	Elective surgeries cancelled starting July 2014	1444	–	–	–				–
Cai, 2020	Head and Neck	Feb 1 to Mar 10, 2020	In-hospital treatment of benign or slow-progressing tumors postponed until after epidemic stabilization	97			97	Postop fever (n = 7)			2
Cai, 2020	Thoracic	Jan 2020	None (before the outbreak was official declared)	139	–	–	7			Death due to COVID-19 pneumonia (n = 3)	–
Chao, 2020	ICU	–									2
Chee, 2004	Various	Feb to Apr 2003	Elective surgeries cancelled	41	–	–	–				–
Chen, 2020	Obstetrics	Jan to Feb 2020	–	17	14	3	0	None	None		–
Cheung, 2020	Orthopedics	Mar 1 to May 22 2020	–	10	0	10	0	Supplemental oxygen (n = 5); blood transfusion (n = 10); presumed VTE (n = 1)	Acute Kidney injury (n = 1)	Death due to respiratory failure (n = 1)	–
Chow 2020	ENT	Apr 1, 2020 and Apr 17, 2020	–	5	–	–	2/5 during outbreak				–
Couto, 2020	Various	Mar to Apr 2020	Elective aesthetic and reconstructive surgery cases were stopped after recommendations by the state of Texas.								–
Cruz, 2020	ICU	Apr 2020	–								–
Cui, 2020	ENT	Jan to Mar 2020	Outpatient clinics and emergency departments were closed for two of the hospitals. The larger hospital eliminated nonurgent visits, cancelled elective surgery, and	3	1/6 as many elective surgeries performed during the pandemic	3	0		Coma (n = 2)	Death due to epistaxis (n = 1)	–

			avoided upper tract endoscopic exams								
Deng 2020	ENT	Feb to March 2020	–	–	–	–	–				–
Doglietto, 2020	Various	Feb to Apr 2020	Most elective surgeries were stopped.	41	4	37		Local complications n = 3); post-op COVID-19 diagnosis (n = 8)	Thrombotic complications (n = 4), hemorrhagic complications (n = 15), pneumonia (n = 18), delirium (n = 1)	Acute respiratory failure (n = 6), cardiogenic shock (n = 2),	–
Doran, 2020	HPB and Liver Transplant	Mar 2020	Routine patient isolation for 7 days before surgery	2	0	0	2	Post-operative COVID pneumonia requiring oxygen (n = 1)			–
Fregatti, 2020	Surgical oncology	Mar 9 to Apr 9 2020	–	85	0	0	85				2
Gallego, 2020	General Surgery	Mar 2020	Elective surgeries cancelled after pandemic declared	189 (number of admission and interventions decreased by 52.7%)	153	In the preceding month, 104 performed; after outbreak, 36 performed	NS but oncology procedures reported as urgent			Death due to respiratory failure from COVID-19 (n = 3)	2
Gao, 2020	General surgery	Jan 23 to Mar 23, 2020	–	4	0	4	0	None	None		–
Garcia-Portabella, 2020	Orthopedic Surgery	Mar to Apr 2020	–	11		11					–
Gou, 2020	Pancreatic	Feb 2020	–	1	0	1	–	Post-operative COVID-19 diagnosis (n = 1)			–
Hassan 2020	Neurosurgery	Mar 23 – Apr 2020	Elective procedures were cancelled	91	0	91				Death (n = 7)	2
He, 2020	Vascular surgery/ Anesthesiology	–	–	4	–	4	–				–
Huang, 2020	Thorascopic lung surgery	Jan 1 2020 to Mar 31 2020	Lung surgeries suspended since Jan 20 2020	3	–	–	3 (during outbreak)	COVID-19 infection (n = 3)		Death due to COVID-19 (n = 2)	–
Khalafallah, 2020	Neurosurgery	Mar 18 to Apr 17 2020	Elective and nonelective procedures were cancelled (7600 cancelled during study period). A 68.89% reduction in total cases between Apr 2019 and Apr 2020. Increased adoption of telemedicine in outpatient setting, and teleconferencing services for educational activities.	20		20					2
LeBrun, 2020	Orthopedic	Mar 20 to Apr 24 2020	–	59	0	59		Postoperative hypoxia (n = 18)	Hypoxia requiring intubation and	Death due to COVID-19 (n = 5), 2/5 preoperative 3/5 postoperative;	–

(continued on next page)

Table 2 (*continued*)

Author, year	Surgical service	Study Duration	Description of lockdown	N total number of surgeries	N elective surgeries (total; before outbreak; during outbreak)	N urgent surgeries (total; before outbreak; during outbreak)	N cancer surgeries (total; before outbreak; during outbreak)	CD I-II	CD III-IV	CD V	ACGME Stage
									admission to ICU (n = 3)	Death due to cardiac arrest intraoperatively (n = 1);	
Lei, 2020	Various	Jan to Feb 2020	–	34	29	0	5	COVID pneumonia (n = 34), secondary infection (n = 10), arrhythmia (n = 8)	Acute respiratory distress syndrome (n = 11), shock (n = 10), acute cardiac injury (n = 5), acute kidney injury (n = 2)	Death (n = 7)	–
Leong, 2020	Neurosurgery	Feb to Apr 2020	All non-essential leave (inclusive of overseas and local conference leave) was cancelled. Strict social distancing policy.								2
Li 2020	Kidney Transplant	Jan 20 to Mar 1, 2020	0	18	–	18 (100%) during outbreak	–	Delayed recovery of transplanted kidney function (n = 1)	Acute transplant rejection (n = 1)		–
Luong-Nguyen, 2020	General surgery	Mar to Apr 2020	–	11	–	–	5	One unspecified post-op complication (n = 11)		Death secondary to respiratory failure (n = 1), death from candidal septicemia (n = 1)	–
Madenelo, 2020	Urology	Mar 11th 2020 to Apr 1st 2020	State of emergency declared and social isolation instituted	11	–	11; 18 during same period in 2019;	–				–
Maniscalco 2020	Orthopedics	Feb 22 2020–Apr 18 2020	–	121; 169 during same period in 2019	–	121 (100%) during outbreak	–			Death (cardiac arrest n = 8; multi-organ failure n = 3; progression of neoplasm n = 2; renal failure n = 1; brain hemorrhage n = 1; septic shock n = 1; total n = 17); Death total n = 6 during same period in 2019	–
Maniscalco, 2020	Orthopedics and Traumatology	Feb 25 to Mar 31 2020	All planned activities stopped, ICU capacity troped, hospital converted into designated "COVID-19 hospital"	96; 125 same time period 2019	–	96	–				–
Meyer 2020	Spine	Mar 17 2020–Apr 17 2020	Elective surgeries were cancelled	62	0	62 (100%) during outbreak	–				–
Morrison 2020	ENT	Mar 18 – Apr 21 –2020	Elective surgeries were cancelled, limited OR space, limited clinics	103	0	103 (100%) during outbreak	–				2
Nazer, 2007	Cardiac	Jan to Feb 2015	None	6	1	5	0		Subdural hematoma (n = 1), perioperative MI (n = 1)		
Ng 2020	Vascular		Elective surgeries were cancelled	291							2

		Feb–Mar 2020									
Oh, 2020	Obstetrics	Feb 26 to Apr 3 2020	The hospital's delivery center was designated for suspected or confirmed mothers of COVID-19 only	8	0	8	0	No complications			–
Paramore 2020	Urology	Mar 23 2020–Apr 9 2020	Cancellation of routine elective surgery, limit surgical resources to risk-stratified patients	52	–	6 (11.5%) during outbreak	–	UTI (n = 2)			–
Patel, 2020	General Surgery	Mar to Apr 2020	Outpatient clinics and endoscopic procedures decreased to limit spread of virus; elective non-cancer surgery cancelled.	20		20					–
Peng, 2020	Thoracic	Jan 2020	Elective surgeries cancelled on last day of study period	121; 11	84 cancelled	121; 0	4/11 patients in case series had cancer surgery; 11	Prolonged air leak (n = 1)	Sudden cardiac arrest from hypokalemia (n = 1)	Death from respiratory failure due to COVID-19 (n = 3)	–
Ralli, 2020	Otolaryngology	Feb to Apr 2020	Elective surgeries cancelled. Emergent and oncology cases only.	96 (50.77% decrease in overall number of surgical procedures)	0	22	Same timepoint 1 year ago, 195 procedures; 74 after outbreak				–
Rossi, 2020	Orthopedic Oncology	Dec 2019 –Apr 2020	Elective orthopedic surgery was forced to stop to allow the healthcare system to face the emergency.	79			79	0	0	0	–
Saban, 2020	Ophthalmology	–	–	3							–
Schneider, 2020	Orthopedic Surgery	–	Temporary ban on elective surgery and outpatient clinics, rigorous visitor restrictions, and compulsory facemasks for all HCW								–
Shrikhande, 2020	Various	Mar to Apr 2020		494			494	Minor CDI-II + postop COVID-19			–
Taha, 2020	Otolaryngology	Mar to Apr 2020	Elective surgeries cancelled	12	0	12	0				–
Tan, 2020	Neurosurgery	- (published Mar 2020)	Operations for patients with relatively stable condition postponed	–	–	–	–				–
Tankel, 2020	General Surgery	Feb to Apr 2020	–	130	0	130 (202 in 7 wks preceding)	0		"Serious complication " (n = 1)		–
Tien, 2005	ICU; Emergency OR	May 2013	–	1	0	1	0			Death from presumed abdominal compartment syndrome (n = 1)	–
Turri-Zanoni, 2020	Otolaryngology	Feb to Apr 2020	–	13	13 (tracheostomy procedures labeled as elective in the study, performed in OR)	–	–			Death due to COVID-19 (n = 5)	–
Valdivia, 2020	Vascular surgery	Mar 14 to May 14 2020	Only urgent surgeries were performed, vascular surgery department was partially converted to COVID-19 unit	60	0	60	0			Death due to acute respiratory distress syndrome (n = 1)	2
Wang, 2020	Neurosurgery	–	–	5	0	5	0			Death due to COVID-19 related complications (n = 3)	–

(continued on next page)

Table 2 (*continued*)

Author, year	Surgical service	Study Duration	Description of lockdown	N total number of surgeries	N elective surgeries (total; before outbreak; during outbreak)	N urgent surgeries (total; before outbreak; during outbreak)	N cancer surgeries (total; before outbreak; during outbreak)	CD I-II	CD III-IV	CD V	ACGME Stage
Wong, 2004	Obstetrics	Apr-03	–	3	0	3	–	Wound infection (n = 2)			–
Yang, 2020	Gynecologic oncology	Jan to Feb 2020	–	189	0	0	189	COVID pneumonia (n = 3)			–
Yang, 2020	Neurosurgery	Jan 23 to Mar 7 2020	–	55	0	55	0				–
Zagra 2020	Orthopedics	February 24th to April 10th, 2020	Cancellation of elective surgeries	823	664	268					2
Zhang 2020	ENT	Jan 23 2020 –April 6 2020	–	–	–	–	–				–
Zhang, 2020	Obstetrics	Jan to Feb 2020	–	61	–	61	–	Neonatal bacterial pneumonia (n = 3/10)			–

segregated ORs); and LOGISTICS (all other measures including modification of work areas, modification of procedures, new hospital protocols and processes, and limitation/modification of HCW roles to help limit and prevent nosocomial disease transmission).

Modified peri-operative logistics were reported in 40 studies describing protection measures. Examples of workspace modifications as described in 20 studies included establishing ultrasound workstations in areas managing infected patients to perform point-of-care lung imaging, having a designated corner in a dialysis unit for the treatment of patients who were suspected/confirmed infected, and designating doctors' and nurses' workstations as the "clean" area of a ward while other areas were considered contaminated.[21,30,35] Procedural and management modification for the purpose of minimizing exposure risk was reported in 25 studies and included measures such as slowing the speed of drilling intraoperatively in neurosurgical procedures, favoring use of percutaneous drainage over ERCP where possible for biliary drainage, and temporarily turning off mechanical ventilation during tracheal incision.[35–37] Modified hospital rules, protocols and patient transfer processes were described in 26 studies and included limiting or preventing visitations for patients, transferring patients between the ward and OR in a negative-pressure isolation transfer cabin, and use of designated transfer "lanes" between sections of the hospital to limit nosocomial spread.[23,29,35] Fourteen studies described modifying the roles of HCW during epidemics, including formation of an "Emergency Incident Command Team" to identify and separate infected patients from other patients, allowing only essential personnel to be present during procedures, and assigning staff to conduct patient screening full-time.[30,38,39]

PPE use was the next most frequently reported measure and was implemented in 36 studies describing protection measures. Common PPE items included hair covers, N95 or PAPR masks, surgical masks, face shields, goggles, waterproof gowns, two layers of gloves, and shoe covers. More rigorous measures included use of the Stryker T4 Personal Protection system consisting of standard PPE with the addition of a helmet, short hood, and toga-style gown; use of hoods with built-in HEPA units; and powered air-purifying respirators for anesthesiologists. One study reported that PPE was changed every 3–4 h.[40] Another study reported use of surgical masks for patients before and after operation.[41] Of note, no HCW infections were described among studies implementing PPE measures.

Measures taken preoperatively for infection control were also described in 36 studies describing protection measures. The majority of these measures focused around improving screening to identify infected patients and HCW prior to operation and implementing rigorous disinfection and equipment preparation processes. Examples of preoperative measures included setting up multi-level triage systems in clinics and prior to patient admission to hospital to identify patients with fevers or concerning epidemiological history, having HCW take their temperature 4 times a day and undergo nucleic acid viral testing multiple times a week, use of disposable anesthetic devices for respiratory procedures, and enhanced decontamination procedures using chlorine disinfectant and anesthesia circuit sterilizer for anesthesia workstations.[23,28,38,40]

Modification of OR setup to reduce infectious exposure risk was noted in 17 studies describing protection measures. The most common modifications included use of a negative-pressure OR for patients suspected or confirmed to be infected, as reported in 10 of these studies. Other measures included geographically segregating OR complexes to reduce cross-infection, reducing humidity level and temperature of ORs to reduce HCW perspiration, and using plastic drapes around the tracheostomy operative field to create a closed sterile environment.[40,42,43]

Table 3
Non-OR procedures and outpatient clinics.

Author, year	Surgical service	Study duration	Non-surgical procedures performed (e.g. endoscopy, tracheostomy)	N of procedures performed (total; before outbreak; during outbreak)	Complications	Outpatient clinic volumes (total; before outbreak; after outbreak)
Angel, 2020	ICU	Mar to Apr 2020	Percutaneous dilational tracheostomy (PDT)	98	Post-tracheostomy bleeding (n = 5), Accidental tracheostomy tube removal (n = 2), death (n = 7) due to respiratory and multiorgan failure	–
Barca, 2020	Maxillofacial surgery	Feb to Apr 2020	–	–	–	–
Berardi, 2020	Surgical oncology, transplant surgery	Mar 9 2020 to Apr 24 2020	–	–	–	–
Bogani, 2020	Gynecologic Oncology	Feb to Mar 2020	–	–	–	–
Bundu, 2014	All	Jun 2013 to Feb 2015	–	–	–	–
Cai, 2020	Head and Neck	February 1 to March 10, 2020	–	–	–	–
Cai, 2020	Thoracic	Jan-20	–	–	–	–
Chao, 2020	ICU	–	Tracheostomy	53	Minor: cellulitis (n = 1), bleeding (n = 1). Death (n = 6)	–
Chee, 2004	All	Feb to Apr 2003	–	–	–	
Chen, 2020	Obstetrics	Jan to Feb 2020	–	–	–	–
Cheung, 2020	Orthopedics	March 1 to May 22 2020	–	–	–	–
Chow 2020	ENT	April 1, 2020 and April 17, 2020.	–	–	–	–
Couto, 2020	Various	Mar to Apr 2020	–	–	–	–
Cruz, 2020	ICU	Apr-20	Peritoneal Dialysis	14	bleeding (n = 1), catheter non-function (n = 1)	
Cui, 2020	ENT	Jan to Mar 2020	Percutaneous dilatational tracheotomy	3	Bleeding and obstruction of extracorporeal membrane oxygenation (ECMO) flow leading to death (n = 1)	¼ as many outpatient visits during pandemic, 5765 telemedicine encounters
Deng 2020	ENT	Feb to March 2020	Tracheotomy	4 during outbreak	Postop incision bleeding (n = 1)	–
Doglietto, 2020	Various	Feb to Apr 2020	–	–	–	–
Doran, 2020	HPB and Liver Transplant	Mar-20	Biliary drainage and balloon dilatation of hepaticojejunostomy	1	Asymptomatic post-operative COVID pneumonia (n = 1; CD I)	–
Fregatti, 2020	Surgical oncology	Mar 9 to Apr 9 2020	–	–	–	–
Gallego, 2020	General Surgery	Mar-20	–	–	–	–
Gao, 2020	General surgery	Jan to Mar 2020	–	–	–	–
Garcia-Portabella, 2020	Orthopedic Surgery	Mar to Apr 2020	–	–	–	–
Gou, 2020	Pancreatic	Feb-20	Central venous catheterization and percutaneous drainage of the thoracic cavity, abdominal cavity, retroperitoneum, and gallbladder	7	Hypoxemia during percutaneous retroperitoneal drainage (n = 1)	–
Hassan 2020	Neurosurgery	March 23 2020 –April 20 2020	–	–	–	–
He, 2020	Vascular surgery/ Anesthesiology	–	–	–	–	–
Huang, 2020	Thorascopic lung surgery	Jan 1 2020 to March 31 2020	–	–	–	–
Khalafallah, 2020	Neurosurgery	Mar 18 to Apr 17 2020	–	–	–	NR; 281 (Apr 2019); 9 (Apr 2020)
LeBrun, 2020	Orthopedics	Mar 20 to Apr 24 2020	–	–	–	–
Lei, 2020	All	Jan to Feb 2020	–	–	–	–
Leong, 2020	Neurosurgery	Feb to Apr 2020	–	–	–	–
Li 2020	Transplant	January 20 to March 1, 2020	–	–	–	220 telemedicine appointments (during pandemic); 68 outpatient visits (during pandemic)
Luong-Nguyen	General Surgery	Mar to Apr 2020	–	–	–	–

(*continued on next page*)

Table 3 (*continued*)

Author, year	Surgical service	Study duration	Non-surgical procedures performed (e.g. endoscopy, tracheostomy)	N of procedures performed (total; before outbreak; during outbreak)	Complications	Outpatient clinic volumes (total; before outbreak; after outbreak)
Madanelo, 2020	Urology	Mar to Apr 2020	–	–	–	122 during COVID; 263 during same period in 2019
Maniscalco 2020	Orthopedics	Feb 22 2020–Apr 18 2020	–	–	–	–
Maniscalco, 2020	Orthopedics and Traumatology	Feb to Mar 2020	–	–	–	100 (per day?) until Feb 21st; 30 (per day?) since Mar 13th; Outpatient clinic activity reduced by 50%
Meyer 2020	Spine	March 17 2020 –April 17 2020	–	–	–	–
Morrison 2020	ENT	March 18 – April 21–2020	–	20 before outbreak, 16 after outbreak	–	158 before pandemic, 39 after pandemic
Nazer, 2007	Cardiac	Jan to Feb 2015	–	–	–	–
Ng 2020	Vascular	Feb–March 2020	–	–	–	Reduced from 10 half-days a week to 5 half-days a week
Oh, 2020	Obstetrics	Feb 26 to Apr 3 2020	–	–	–	–
Paramore 2020	Urology	Mar 23 2020–Apr 9 2020	–	–	–	–
Patel, 2020	General surgery	Mar to Apr 2020	–	–	–	0
Peng, 2020	Thoracic	Jan-20	–	–	–	–
Ralli, 2020	Otolaryngology	Feb to Apr 2020	–	–	–	–
Rossi, 2020	Orthopedic Oncology	Dec 2019–Apr 2020	–	–	–	–
Saban, 2020	Ophthalmology	–	Intravitreal injection, panretinal photocoagulation laser therapy	116	–	–
Schneider, 2020	Orthopedic Surgery	–	–	–	–	–
Shrikhande, 2020	Various	Mar to Apr 2020	–	–	–	–
Taha, 2020	Otolaryngology	Mar to Apr 2020	Nasal endoscopy	>100	–	–
Tan, 2020	Neurosurgery	–	–	–	–	–
Tankel, 2020	General surgery	Feb to Apr 2020	–	–	–	–
Tien, 2005	ICU; Emergency OR	May-13	Tracheostomy	4	None	–
Turri-Zanoni, 2020	Otolaryngology	Feb to Apr 2020	Percutaneous dilatational tracheostomy	19	No procedure mortality observed	–
Valdivia, 2020	Vascular surgery	Mar 14 to May 14 2020	–	–	–	–
Wang, 2020	Neurosurgery	–	–	–	–	–
Wong, 2004	Obstetrics	Apr-03	–	–	–	–
Yang, 2020	Gynecologic Oncology	Jan to Feb 2020	(200 non-surgical hospitalizations)	–	–	–
Yang, 2020	Neurosurgery	Jan 23 to Mar 7 2020	–	–	–	–
Zagra 2020	Neurosurgery	Jan 23 to Mar 7 2020	–	–	–	–
Zhang 2020	ENT	Jan 23 2020–April 6 2020	Tracheostomy	11 (during outbreak)	Wound infection (n = 2); subcutaneous emphysema (n = 1)	–
Zhang, 2020	Obstetrics	Jan to Feb 2020	–	–	–	–

A summary of protection measures is provided in Table 4. All studies which implemented more than 3 of the listed measures and also reported on HCW outcomes had an infection rate of 0% among HCW.

Patient exposures and HCW outcomes

At the time of operation during epidemics, a total of 381 patients were reported to have confirmed infection (369/381 COVID-19, 6/381 SARS, 6/381 MERS) and 85 patients were presumed to be infected (85/85 COVID-19) (Table 5). Following operation, 192 patients (192/192 COVID-19) were confirmed to be infected, while 557 patients (557/557 COVID-19) tested negative for infection. No HCW contracted the illness in studies reporting on HCW outcomes with patients presumed infected during operation. Among studies where patients were confirmed infected after operation and HCW

outcomes were also reported, 50.0% (4/8) noted infections in HCW.

HCW outcomes were reported in 31 studies with 11 studies reporting the number of HCW included in the study. A total of 405 HCW were represented in these 11 studies, with 6.2% (25/405) having been infected during epidemics. During the COVID-19 pandemic, 8.6% (23/269) of HCW were infected. The other two infections among HCW occurred during the Ebola epidemics, where 25% (2/8) contracted the illness. Both of these HCW had died from the illness and were the only instances of death reported among the 405 HCW included in this review. One study did report the death of a nurse in its traumatology department during COVID-19, though the total number of HCW in the department was not specified and this instance was not captured in the pooled analysis.[21] No infections or adverse outcomes were reported for HCW during the SARS epidemics (0/128) from the included studies.

The rate of HCW infection based on the number of surgeries performed was 3.61% (41 HCW/1136 surgeries) among studies that reported both the number of HCW infected, and the number of surgeries conducted. One HCW was infected for every 27.7 operations performed. Among studies during the COVID-19 pandemic, the HCW infection rate was 3.92% (39 HCW/995 surgeries) and one HCW was infected for every 25.5 operations performed.

Risk of bias assessment

The methodological index for non-randomized studies (MINORS) was used to assess risk of bias in the included studies (Supplementary Table 2). 56 studies included in this review were non-comparative with a mean global score of 10.2 (SD 1.7), indicating fair methodological quality.[16] All 56 studies had a clearly stated aim and a loss to follow-up of less than 5% (56/56). The majority of the studies adequately included consecutive patients (45/56), had adequate endpoints in relation to the stated aims (42/56), and had an appropriate follow-up period (44/56). One study adequately conducted a prospective calculation of study size (1/56). The remaining 5 studies included in this study were comparative studies with a mean global score of 14 (SD 2.9). Two of these studies had adequate control groups, 2 had adequate baseline equivalence of groups, and 3 had adequate statistic calculations. Prospective collection of data was reported in 7 studies (7/61). Adequately unbiased assessments of study endpoints were found in 7 studies (7/61).

Discussion

This rapid, living systematic review investigated the impact of hospital lockdown secondary to epidemics on surgical practice. We included 61 studies relevant to the Ebola, SARS, COVID-19, and MERS outbreaks. Lockdown measures, including cancellation of elective surgeries, surgical outpatient clinics, telehealth services, and hospital-based referrals were noted in approximately half of studies. Measures to protect surgical personnel, including adequate PPE and OR modifications, were reported in 45 studies. 31 studies followed the health of surgical HCWs during the epidemic, with the majority noting no adverse health outcomes with proper safety measures. However, there was minimal research on how epidemics impacted surgical practice in terms of patient care, healthcare workers, and waitlists. Specifically, there was no information reported regarding the clinical impact of delaying surgical care during lockdowns. In addition, there was insufficient comparative evidence related to institutional transmission control policies. As such, there remain significant evidence gaps for health systems to implement evidence-based surgical care during epidemics.

Overall, our findings contribute to the growing literature on surgical care during the current COVID-19 pandemic.[44] The worldwide shortages in PPE as well as the numerous cases of HCW infection have highlighted the importance of infection control, which has been outlined in our review.[44] In addition, as the novel coronavirus can be transmitted via aerosol particles, there is particular risk of exposure during certain procedures such as endoscopy. Our review outlines potential strategies that have been used to mitigate risk in previous outbreaks, such as the use of negative pressure ORs for intubation. There is also concern for triaging surgical oncology cases, due to preliminary evidence that COVID-19 is dangerous for patients for cancer.[45,46] As a result, the American College of Surgeons has released recommendations for both the triage of non-emergent surgical procedures as well as recommendations for management of elective procedures.[47,48] Many of their guidelines, such as the limitation of non-essential visitors, were similar to the strategies reported in our included studies. The American College of Surgeons especially stresses the importance of PPE, which was highlighted in the included studies that discussed infection control.

However, while the American College of Surgeons recommends the postponement of elective surgeries, this systematic review demonstrates that there is a lack of long-term evidence regarding the potential impact on patient outcomes, particularly patient morbidity and mortality due to cancellations.[47] Of note, our review also found that the overall complication rate did not seem to be increased based on the distribution of elective and emergency cases, as any association with elective surgeries is most likely due to the volume of patients rather than the distribution. In addition, while the American College of Surgeons has oncology-specific guidelines regarding deferral of surgeries and guidelines for multidisciplinary care, more pandemic-specific research is required to substantiate recommendations.[49] Of the included studies, 8 reported on postoperative outcomes following cancer surgeries. None of these studies examined oncology-related outcomes, such as remission rates or changes to chemotherapy cycles.

In addition, none of the included studies analyzed the motivations of surgeons to continue working during epidemics. During the COVID-19 pandemic, there has been increasing concern regarding HCW absenteeism and willingness to work in hazardous environments, particularly due to shortages in PPE. Previous literature has demonstrated that perceived personal safety was a large factor in whether HCW continue to practice during the previous SARS and influenza outbreaks.[50,51] As our review outlines several strategies to protect surgical HCW, implementation could be useful in alleviating the anxieties of HCW and encourage frontline practice.

Finally, we did not review the impact of COVID-19 on surgical graduate medical education, which is an emerging area of concern. There is growing evidence that surgical residencies and postgraduate medical education has been significantly impacted by the COVID-19 pandemic.[52–54] Literature has suggested that residents have decreased opportunity to participate in surgical cases. Similarly, one of our included studies noted that operations were more likely to be performed by staff surgeons in comparison to trainees during epidemics. This may be due to university-based safety guidelines, the redirection of trainees to other specialties, as well as reduced surgical volume. Technological options such as virtual curriculums and simulations have been posed in the interim to maintain the education of surgical residents.[55]

The main limitation of our systematic review is the lack of published research on surgical care during epidemics. Due to the unpredictable and demanding nature of epidemics, it is often difficult for physicians to prioritize research while in the midst of disease outbreaks. This significantly limits the ability to collect prospective information. As such, much of the available literature was limited to case series and smaller scale retrospective reviews. In addition, considerations from previous pandemics may not

Table 4
Summary of protective measures.

Author, Year	Virus	Enhanced PPE	Modified screening practices (confirmed negative test prior to surgery, etc.)	Enhanced disinfection and equipment preparation	Negative-pressure OR/ procedure rooms; Dedicated ORs for patients presumed/ confirmed infected	Modification of workspace (separate patient notes from patient, etc.)	Procedural modification (open tracheostomy, avoidance of diathermy and suction, etc.)	Modified hospital and patient transfer processes (filters applied prior to transfer, no visitor policy, etc.)	Limit HCW, modified staff roles
Angel, 2020	COVID-19	✓					✓		✓
Barca, 2020	COVID-19	✓	✓	✓		✓	✓	✓	✓
Berardi, 2020	COVID-19	✓	✓	✓			✓	✓	✓
Bogani, 2020	COVID-19								
Bundu, 2014	Ebola	✓	✓					✓	
Cai, 2020	COVID-19	✓	✓			✓		✓	✓
Cai, 2020	COVID-19								
Chao, 2020	COVID-19	✓		✓	✓	✓	✓	✓	✓
Chee, 2004	SARS	✓	✓	✓	✓	✓	✓	✓	
Chen, 2020	COVID-19	✓	✓	✓	✓			✓	
Cheung, 2020	COVID-19	–	–	–	–	–	–	–	–
Chow 2020	COVID-19	✓	–	✓	–	✓	✓	–	–
Couto, 2020	COVID-19	✓	✓			✓	✓	✓	✓
Cruz, 2020	COVID-19								
Cui, 2020	COVID-19	✓	✓	✓					
Deng 2020	COVID-19	✓	✓	✓	–	✓	✓	–	✓
Doglietto, 2020	COVID-19		✓						
Doran, 2020	COVID-19	–	–	–	–	–	–	–	–
Fregatti, 2020	COVID-19	✓	✓					✓	
Gallego, 2020	COVID-19	✓	✓	✓					
Gao, 2020	COVID-19	✓	✓				✓	✓	
Garcia-Portabella, 2020	COVID-19	✓	✓		✓		✓	✓	✓
Gou, 2020	COVID-19	✓	✓	✓		✓	✓	✓	
Hassan 2020	COVID-19	✓	✓	✓	✓	✓	–	✓	✓
He, 2020	COVID-19	✓		✓		✓	✓		
Huang, 2020	COVID-19	–	–	–	–	–	–	–	–
Khalafallah, 2020	COVID-19	✓	✓						✓
LeBrun, 2020	COVID-19	–	–	–	–	–	–	–	–
Lei, 2020	COVID-19	–	–	–	–	–	–	–	–
Leong, 2020	COVID-19	✓	✓		✓	✓	✓	✓	✓
Li, 2020	COVID-19	✓	✓	✓		✓		✓	✓
Luong-Nguyen, 2020	COVID-19		✓					✓	
Madanelo, 2020	COVID-19	–	–	–	–	–	–	–	–
Maniscalco 2020	COVID-19	–	–	–	–	–	–	–	–
						✓			✓

Table 4 (*continued*)

Author, Year	Virus	Enhanced PPE	Modified screening practices (confirmed negative test prior to surgery, etc.)	Enhanced disinfection and equipment preparation	Negative-pressure OR/ procedure rooms; Dedicated ORs for patients presumed/ confirmed infected	Modification of workspace (separate patient notes from patient, etc.)	Procedural modification (open tracheostomy, avoidance of diathermy and suction, etc.)	Modified hospital and patient transfer processes (filters applied prior to transfer, no visitor policy, etc.)	Limit HCW, modified staff roles
Maniscalco, 2020									
Meyer 2020	COVID-19	✓	–	–	✓	–	✓	✓	✓
Morrison 2020	COVID-19	✓	✓	✓	–	–	–	✓	✓
Nazer, 2007	MERS	–	–	–	–	–	–	–	–
Ng 2020	COVID-19	✓	✓	✓	–	✓	✓	–	✓
Oh, 2020	COVID-19	✓	✓	✓	✓	✓		✓	
Paramore 2020	COVID-19	✓	✓	–	–	–	–	✓	–
Patel, 2020	COVID-19								
Peng, 2020	COVID-19	–	–	–	–	–	–	–	–
Ralli, 2020	COVID-19	–	–	–	–	–	–	–	–
Rossi, 2020	COVID-19	✓	✓	✓		✓	✓	✓	✓
Saban, 2020	COVID-19	✓		✓	✓	✓	✓	✓	✓
Schneider, 2020	COVID-19	✓	✓			✓		✓	
Shrikhande, 2020	COVID-19								
Taha, 2020	COVID-19	✓	✓	✓			✓		✓
Tan, 2020	COVID-19	✓	✓	✓	✓	✓	✓	✓	✓
Tankel, 2020	COVID-19								
Tien, 2005	SARS	✓		✓	✓		✓		✓
Turri-Zanoni, 2020	COVID-19	✓	✓	✓	✓		✓		✓
Valdivia, 2020	COVID-19		✓		✓				✓
Wang, 2020	COVID-19		✓				✓		
Wong, 2004	SARS	✓		✓	✓	✓	✓	✓	✓
Yang, 2020	COVID-19	–	–	–	–	–	–	–	–
Yang, 2020	COVID-19	✓	✓		✓				
Zagra 2020	COVID-19	–	–	–	–	–	–	–	✓
Zhang 2020	COVID-19	✓	–	–	–	–	✓	–	✓
Zhang, 2020	COVID-19	✓	✓	✓	✓		✓	✓	

necessarily translate to relevance for the COVID-19 pandemic or any future epidemics. The included studies have diverse health systems and delivery models, which reduce generalizability of considerations such as infection control and lockdown guidelines. This is especially relevant for low-resourced health systems, which may face additional shortages. Another limitation of our review is that we were unable to stratify our results in terms of lockdown measures taken, given that this information was reported in fewer than half of the included studies. We are therefore unable to comment on the impact of specific lockdown measures on patient and HCW outcomes.

Ultimately, it is often difficult for institutions to balance providing timely surgical care while ensuring safety during epidemics. While lockdown precautions have been used in previous outbreaks, it is unclear how the reduced access to surgical care will affect patient care in the long-term. In addition, it is unclear how to prioritize surgical care when lockdown precautions are eventually lifted. Future research should analyze the impact of COVID-19 on surgical wait-times and related complications, as well as patient and provider satisfaction. In the meantime, institutions should cooperate with policymakers to determine best precautions for surgical care. Surgical practice during epidemics affects all levels of the hospital, from creating a new demand on PPE to alleviating burden within the emergency department. As such, decisions

Table 5
Patient exposures and healthcare worker outcomes.

Author, year	Surgical service	Virus	Timepoint	N (%) patients confirmed infected at time of procedure	N (%) of patients presumed infected at time of procedure	N (%) of patients confirmed infected after procedure	N (%) of patients confirmed not infected after procedure	N (%) HCW healthy after procedure	Outcomes of HCW
Angel, 2020	ICU	COVID-19	Mar to Apr 2020	100% (98/98)	–	–	–	8 (100%)	All were healthy
Barca, 2020	Maxillofacial surgery	COVID-19	Feb to Apr 2020	0/33 (100%)	–	–	–	–	–
Berardi, 2020	Surgical oncology, transplant surgery	COVID-19	Mar 9 2020 to Apr 24 2020	–	–	–	–	–	–
Bogani, 2020	Gynecologic oncology	COVID-19	Feb to Mar 2020	0/5 (0%)		5/5 (100%)			
Bundu, 2014	All	Ebola	Jun 2013 to Feb 2015	–				6 (75%)	2/8 surgeons died after contracting infection
Cai, 2020	Head and Neck	COVID-19	February 1 to March 10, 2020	0%	0%	0%	1	100%	No fever symptoms
Cai, 2020	Thoracic	COVID-19	Jan-20	–	–	7/139 (5.0%)	–	–	8 HCW contracted COVID-19
Chao, 2020	ICU	COVID-19		53/53 (100%)				100%	No cases COVID-19 among HCW
Chee, 2004	All	SARS	Feb to Apr 2003	–				124 (100%)	All were healthy
Chen, 2020	Obstetrics	COVID-19	Jan to Feb 2020	17/17 (100%)	–	–	–	48/48 (100%)	All were healthy
Cheung, 2020	Orthopedics	COVID-19	March 1 to May 22 2020	7/10 (70%)	–	3/10 (30%)	0/10 (0%)	–	–
Chow 2020	ENT	COVID-19	April 1, 2020 and April 17, 2020.	–	0 (0%)	–	–	–	–
Couto, 2020	Various	COVID-19	Mar to Apr 2020	0/300 (0%)	0/300 (0%)	0/300 (0%)	300/300 (100%)	100%	None tested positive for COVID-19
Cruz, 2020	ICU	COVID-19	Apr-20	11/14 (78.6%)					
Cui, 2020	ENT	COVID-19	Jan to Mar 2020	6/6 (100%)	–	–	–	NR (100%)	All were healthy
Deng 2020	ENT	COVID-19	Feb to March 2020	4 (100%)	–	4 (100%)	–	15 (100%)	–
Doglietto, 2020	Various	COVID-19	Feb to Apr 2020	33/41 (80.5%)		8/41 (19.5%)			
Doran, 2020	HPB and Liver Transplant	COVID-19	Mar-20	0 (0%)	1 (33%)	3 (100%)	0 (0%)	–	–
Fregatti, 2020	Surgical oncology	COVID-19	Mar 9 to Apr 9 2020	0/85 (0%)	–	–	–	–	No HCW developed COVID-19
Gallego, 2020	General Surgery	COVID-19	Mar-20	6/189 (3.2%)	–	7/189 (3.7%)	–	37/49 (75.5%)	12 HCW total diagnosed with COVID-19
Gao, 2020	General surgery	COVID-19	Jan to Mar 2020	0 (0%)	4 (100%)	–	4 (100%)	–	–
Garcia-Portabella, 2020	Orthopedic Surgery	COVID-19	Mar to Apr 2020	1/11 (9.1%)		0/10 (0%)		100%	No cases of COVID-19 among HCW
Gou, 2020	Pancreatic	COVID-19	Feb-20	0/8 (0%)				–	–
Hassan 2020	Neurosurgery	COVID-19	March 23 2020 –April 20 2020	–	–	–	–	–	–
He, 2020	Anesthesiology/ vascular surgery	COVID-19	–	2/4 (50%)	2/4 (50%)	–	–	–	–
Huang, 2020	Thoracopic lung surgery	COVID-19	Jan 1 2020 to March 31 2020	–	–	3 (100%)	–	–	–
Khalafallah, 2020	Neurosurgery	COVID-19	Mar 18 to Apr 17 2020	–	–	–	–	–	2/51 (3.9%) HCW tested positive for COVID-19. HCW have recovered and returned to work.
LeBrun, 2020	Orthopedics	COVID-19	Mar 20 to Apr 24 2020	7/59 (11.8%)	1/59 (1.7%)	2/59 (3.4%)	40/59 (68%)	–	–
Lei, 2020	All	COVID-19	Jan to Feb 2020	–	34/34 (100%)	34/34 (100%)	–	–	–
Leong, 2020	Neurosurgery	COVID-19	Feb to Apr 2020					100%	No cases COVID-19 among HCW
Li 2020	Transplant	COVID-19	January 20 to March 1, 2020	0 (0%)	0 (0%)	0 (0%)	51 (100%)	–	–
	General Surgery	COVID-19	Mar to Apr 2020	–	–	15 (4.9%)	–	–	7 HCW contracted COVID-19

Table 5 (*continued*)

Author, year	Surgical service	Virus	Timepoint	N (%) patients confirmed infected at time of procedure	N (%) of patients presumed infected at time of procedure	N (%) of patients confirmed infected after procedure	N (%) of patients confirmed not infected after procedure	N (%) HCW healthy after procedure	Outcomes of HCW
Luong-Nguyen, 2020									
Madanelo, 2020	Urology	COVID-19	Mar to Apr 2020	–	–	–	–	–	–
Maniscalco 2020	Orthopedics	COVID-19	Feb 22 2020–Apr 18 2020	32/121 (26.4%)	–	–	–	–	–
Maniscalco, 2020	Orthopedics and Traumatology	COVID-19	Feb to Mar 2020	–	–	–	–	12/21 (57.1%)	Of the 21 orthopedics and traumatology team members, 6 were COVID+, treated at home with hydroxychloroquine and antiviral therapy and recovered. 1 developed ARDS and was in ICU at time of writing. 2 also tested positive and were quarantined at time of writing. 37.5% of nursing staff also tested positive, though they were not specific to traumatology team. One nurse had died from the illness. Notably, there was a delay in PPE availability.
Meyer 2020	Spine	COVID-19	March 17 2020 –April 17 2020	1/62 (1.6%)	–	2/62 (3.2%)	–	100%	–
Morrison 2020	ENT	COVID-19	March 18 – April 21–2020	–	–	–	–	–	No confirmed COVID-19 cases
Nazer, 2007	Cardiac	MERS	Jan to Feb 2015	6 (100%)				–	–
Ng 2020	Vascular	COVID-19	Feb–March 2020	–	–	–	–	–	–
Oh, 2020	Obstetrics	COVID-19	Feb 26 to Apr 3 2020	1/8 (12.5%)	7/8 (87.5%)	–	8/8 (100%)	–	–
Paramore 2020	Urology	COVID-19	Mar 23 2020–Apr 9 2020	0 (0%)	–	0 (0%)	–	100%	–
Patel, 2020	General surgery	COVID-19	Mar to Apr 2020						
Peng, 2020	Thoracic	COVID-19	Jan-20	–	–	11/11 (100%)	–	–	–
Ralli, 2020	Otolaryngology	COVID-19	Mar to Apr 2020	–	0/96 (100%) didn't mention this explicitly but patients were all screened	–	–	–	–
Rossi, 2020	Orthopedic Oncology	COVID-19	Dec 2019 to Apr 2020	0/79 (0%)		0/79 (0%)		100%	No cases COVID-19 among HCW
Saban, 2020	Ophthalmology	COVID-19		0/142 (0%)			142/142 (100%)	11/11 (100%)	11 personnel had COVID-19 contacts. All quarantined for 14 days though none tested positive for COVID-19.
Schneider, 2020	Orthopedic Surgery	COVID-19						66/66 (100)%	Fourteen HCW (21%) reported clinical symptoms compatible with a SARS-CoV-2 infection, though all tested negative. Due to testing limitations, asymptomatic HCW were not routinely tested.
Shrikhande, 2020	Various	COVID-19	Mar to Apr 2020	0/494 (0%)	0/494 (0%)	6/494 (1.21%)			
Taha, 2020	Otolaryngology	COVID-19	Mar to Apr 2020	26/152 (17.1%)	35/152 (23%)	–	11/152 (7.2%)	NR (100%)	All were healthy
Tan, 2020	Neurosurgery	COVID-19	–	–	–	–	–	100%	No infections among doctors and nurses
Tankel, 2020	General surgery	COVID-19	Feb to Apr 2020						
Tien, 2005	ICU; Emergency OR	SARS	May-13	3 (100%)				4 (100%)	All were healthy
Turri-Zanoni, 2020	Otolaryngology	COVID-19	Feb to Apr 2020	32/32 (100%)	–	–	–	NR (100%)	All were healthy
Valdivia, 2020	Vascular surgery	COVID-19	Mar 14 to May 14 2020	–	–	–	–	–	Notably, there was considerable lack of testing capability in initial stages of pandemic.

(*continued on next page*)

Table 5 (*continued*)

Author, year	Surgical service	Virus	Timepoint	N (%) patients confirmed infected at time of procedure	N (%) of patients presumed infected at time of procedure	N (%) of patients confirmed infected after procedure	N (%) of patients confirmed not infected after procedure	N (%) HCW healthy after procedure	Outcomes of HCW
Wang, 2020	Neurosurgery	COVID-19	–	5/5 (100%)	–	–	–	–	–
Wong, 2004	Obstetrics	SARS	Apr-03	3 (100%)				100%	All were healthy
Yang, 2020	Gynecologic oncology	COVID-19	Jan to Feb 2020	–	–	3/189 (1.59%)	–	–	–
Yang, 2020	Neurosurgery	COVID-19	Jan 23 to Mar 7 2020	0/21 (0%)	1/21 (4.8%)	–	–	–	–
Zagra 2020	Orthopedics	COVID-19	February 24 – April 10 2020	–	–	79/664 (11.9%)	–	–	–
Zhang 2020	ENT	COVID-19	Jan 23 2020–April 6 2020	11 (100%)	–	–	–	100%	No confirmed infections
Zhang, 2020	Obstetrics	COVID-19	Jan to Feb 2020	16 (26.2%)	–	–	–	–	–

Health care workers, HCW; Intensive Care Unit, ICU; Coronavirus disease 2019, COVID-19; Severe acute respiratory syndrome-related coronavirus, SARS; Middle East respiratory syndrome-related coronavirus, MERS; Ear Nose and Throat, ENT; Hepato-pancreato-biliary, HPB; Acute respiratory distress syndrome, ARDS.

regarding surgical care during epidemics should not occur in isolation from other medical specialties.

Declaration of competing interest

The authors declare no conflict of interest.

†Age reported either as mean (standard deviation) or median (range).

Coronavirus disease 2019, COVID-19; Middle East respiratory syndrome-related coronavirus, MERS; Severe acute respiratory syndrome-related coronavirus, SARS; Not reported, NR; Interquartile Range, IQR.

Coronavirus disease 2019, COVID-19; Middle East respiratory syndrome-related coronavirus, MERS; Severe acute respiratory syndrome-related coronavirus, SARS; Ear Nose and Throat, ENT; Hepato-pancreato-biliary, HPB; Myocardial Infarction, MI; Urinary tract infection, UTI; Clavien-Dindo Classification, CD; Accreditation Council for Graduate Medical Education, ACGME.

Intensive Care Unit, ICU; Ear Nose and Throat, ENT; Hepato-pancreato-biliary, HPB; Coronavirus disease 2019, COVID-19.

Coronavirus disease 2019, COVID-19; Health care workers, HCW; Middle East respiratory syndrome-related coronavirus, MERS; Severe acute respiratory syndrome-related coronavirus, SARS; ✓, yes; blank, no; -, not reported.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjsurg.2020.11.019.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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