Current Concepts Review

Operating in a Pandemic

Lessons and Strategies from an Orthopaedic Unit at the Epicenter of COVID-19 in Singapore

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- With severe limitations in manpower, facilities, and equipment, and the concern for nosocomial transmission, operating in a pandemic is fraught with danger from multiple fronts.
- Strategies to mitigate nosocomial spread include prioritization of existing patients, triaging and treatment of new patient encounters, infection control protocols, perioperative considerations, manpower management, and novel strategies for interdisciplinary interaction and education.
- The decision to proceed with or postpone surgery should be based on the urgency of the surgical procedure and the physiological health of the patient.
- When performing an operation on a patient who has suspected or confirmed infection with novel coronavirus disease 2019 (COVID-19), personal protection equipment should include hair covers, face shields or goggles, N95 respirator masks, a blood-borne pathogen-resistant surgical gown, shoe covers, and double-gloving with single-use gloves.
- Loose-fitting, powered air-purifying respirators should be considered for prolonged surgeries.
- An astutely formulated and comprehensive business continuity plan is an orthopaedic unit's best strategy for maintaining critical standards, discipline, and morale in severe and prolonged outbreaks.

The year 2020, and perhaps the future of health care, is likely to be defined by the novel coronavirus disease 2019 (COVID-19). The World Health Organization declared COVID-19 to be a pandemic on March 11, 2020, and as of April 12, 2020, reported a total of 1,696,588 confirmed cases and 105,952 deaths in all 197 countries[1,2].

Singapore was among the first countries to be affected by COVID-19 when a tourist from Wuhan, China, was confirmed to be infected on January 23, 2020[3,4]. As one of the worst afflicted countries during the 2003 severe acute respiratory distress syndrome (SARS) outbreak[5], Singapore developed and adopted a Disease Outbreak Response System Condition (DORSCON) plan with clear leadership and oversight from a Multi-Ministry Task Force[6]. Health-care measures included limiting unnecessary cross-institutional movement of manpower, engaging private sector doctors, and aggressive contact tracing of infected individuals. The National Centre for Infectious Diseases (NCID) in Singapore, which was built for this purpose, became the epicenter of the national health-care response in combating COVID-19.

At the onset of the disease, orthopaedic surgeons at all levels were immediately deployed to the NCID frontline in 10-day rotations after a crash course in personal protective equipment (PPE) handling. The remaining surgeons maintained key orthopaedic services and consultations for infected patients with concomitant orthopaedic conditions before being

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rotated to the front line. With multiple considerations regarding prioritization of existing patients, initial contact with new patients, infection control strategies, perioperative considerations, manpower management, and novel communication technologies, the aim of this article was to outline the successful strategies that our department employed for the outbreak.

Prioritization of Existing Patients and Delaying Noncritical Surgery

Patients with conditions requiring elective surgeries form a large proportion of the caseload for a busy orthopaedic practice in a tertiary referral center. With a substantial reduction in resources and manpower, the risk of nosocomial COVID-19 infections, and the increased dangers of performing surgery on elderly individuals with multiple comorbidities[7,8], case selection needs to be even more stringent. Considerations for proceeding with surgery should be dependent on the current and projected COVID-19 cases in the region, PPE supply, staffing and bed availability (especially intensive care unit [ICU] beds), ventilator availability, age and health of the patient, urgency of the procedure, and COVID-19 clearance prior to performing surgery.

Elective surgeries requiring potential intensive care and prolonged hospitalization for recovery, such as joint arthroplasties and spinal surgery, were delayed. The decisions were made in consultation with the patients, surgeon, anesthetist, operating-room (OR) staff, and hospital management. A tiered approach[9] (Table I) to guide decision-making may be considered according to the urgency of surgery, fitness of the patient, and potential for ambulatory surgery.

One of the important but easily overlooked duties during the initial phases of the outbreak was informing patients about the postponement of their surgeries. While some patients called in to postpone on their own accord, most patients were still looking forward to their surgeries on the scheduled dates. Previous studies have shown that patients tend to react negatively to postponements in the form of anxiety and disappointment[10]. Multiple factors contribute to such negative perceptions, mainly if the patients thought that they were given inadequate information, were excluded from the decision-making process, felt that their medical well-being was threatened, were not rescheduled for surgery, and were informed by someone other than a doctor[11].

In our department, the senior surgeon spoke to the patient and/or family members directly to convey the information, answer questions, allay concerns, and reschedule to a date that was acceptable to both parties. Patients were advised to continue medications, such as blood thinners and antihypertensive drugs, and a suitable preanesthetic screening date was arranged if repeat investigations were required. Prescriptions were refilled for patient collection or home delivery while office procedures, such as joint blocks and nerve root injections, were offered to relieve unbearable pain.

Triage and Screening for Initial Patient Encounters

As a standard precaution, all patients were screened at a triage station, prior to being seen at outpatient clinics or the emergency department, to determine their travel and contact history and to assess for fever, cough, sore throat, anosmia, or coryzal symptoms. When in doubt, consultation was performed in full PPE and chest radiographs were ordered. Radiologists prioritized the reading of chest radiographs from the emergency department, which were reported within an hour. While patients with suspected or confirmed COVID-19 infection require urgent negative-pressure rooms with an anteroom, patients with other communicable diseases such as pulmonary tuberculosis also require isolation in a single room or placement in a dedicated isolation ward, with appropriate precautions being instituted on the basis of the known mode of spread (Table II).

Infection Control Protocols

Social Distancing

Social distancing has been identified as one of the best strategies to mitigate COVID-19 transmission[12]. Social gatherings during and after office hours were strongly discouraged, and pantry

TABLE I Adult Orthopaedic Surgery and Recommendations for Surgical Intervention During a Pandemic

Tier	Definition	Locations	Action	Examples
1a	Low-urgency surgery and healthy patient (outpatient surgery and not a life-threatening condition)	Ambulatory surgery center	Postpone surgery	Carpal tunnel release or trigger finger release
1b	Low-urgency surgery and an unhealthy patient	Ambulatory surgery center	Postpone surgery	Charcot foot reconstruction
2a	Intermediate-urgency surgery and a healthy patient (not a life-threatening condition but with potential for future morbidity and mortality)	Ambulatory surgery center and same-day admissions with inpatient stay	Consider postponing surgery	Hip or knee arthroplasty, elective spine surgery, cruciate ligament reconstruction, or shoulder Bankart repair
2b	Intermediate-urgency surgery and an unhealthy patient	Same-day admissions with inpatient stay	Postpone surgery if possible	Low-risk cancer or highly symptomatic patients
3a	High-urgency surgery and a healthy patient	Hospital	Do not postpone	
3b	High-urgency surgery and an unhealthy patient	Hospital	Do not postpone	Fractures

TABLE II Priority of Isolation of Patients

PPE Required	Requires Negative-Pressure Room with Anteroom	Requires Negative-Pressure Room	Requires Single Room	Requires Single Room or Dedicated Isolation Ward
Full precautions: N95 respirator, visor or goggles, gown and gloves	Suspected, probable, or confirmed infection with avian influenza (e.g., H7N9) or novel viruses (e.g., COVID-19)			
Airborne precautions: N95 respirator in addition to standard precautions	Suspected or confirmed multidrug-resistant pulmonary tuberculosis (PTB)	Chicken pox, disseminated herpes zoster, measles, suspected or confirmed PTB		
Droplet precautions: surgical mask in addition to standard precautions			Meningococcal or symptomatic influenza with nebulization	
Contact precautions: apron or gown and gloves in addition to standard precautions				*Clostridium difficile* infection with diarrhea, multidrug-resistant gram-negative organisms (e.g., *Pseudomonas aeruginosa*), Norwegian scabies, salmonellosis and other gastroenteritis (with diarrhea in persons who are incontinent or diapered), and vancomycin-resistant Enterococcus

areas were reconfigured to ensure at least 2 m (6 ft) of physical distancing between personnel. Health-care personnel were advised to eat alone or stagger mealtimes, minimize interaction when unmasked, and maintain effective hand hygiene when handling food.

PPE

The underlying principles for PPE components are that they must protect the health-care provider from inhalation of and contact with droplets that may be generated during procedures. The components used to accomplish this level of protection when dealing with patients with suspected or confirmed COVID-19 infection include gloves, gowns, eye protection, hair covers, shoe covers, and an N95 particulate respirator[13] (U.S. National Institute for Occupational Safety and Health-certified N95, European Union standard filtering face piece [FFP]2, or equivalent) that is fitted to the individual.

Health-care workers were given adequate training on when and how to use PPE as well as what PPE to use, and any PPE component that became heavily soiled during aerosol-generating medical procedures was replaced immediately. Special attention was paid to avoiding contact with one's hair or face while placing or removing the PPE, and used PPE was discarded into touch-free bins.

Surgical Masks and N95 Respirators

Surgical masks are loose-fitting devices that provide a physical barrier without restricting airborne contaminants and are used in our institution for health-care worker interaction with all patients unless they were suspected of or confirmed as having COVID-19 infection. An N95 respirator is a disposable, protective device that provides efficient filtration of airborne particles by forming a seal around the respiratory orifices. The N95 designation implies that the respirator blocks at least 95% of very small (<0.3 μm) test particles. There is considerable discrepancy among the recommendations for the use of face masks in community settings[14]. While the effect of N95 respirators on preventing COVID-19 infection requires further investigation, only N95 respirators are able to filter particles from 0.01 to 0.1 μm in diameter[15]. As viral sizes fall within this

range, well-fitted N95 respirators were used by all health-care workers in our institution when dealing with suspected or confirmed COVID-19 cases.

Visors and Goggles

Eye protection is another strategy to prevent ocular transmission of COVID-19 in health-care workers as the virus has been found in the tears of patients with ocular signs and symptoms[16]. The goggles provide maximal peripheral vision while adequately covering the frontal, lateral, and top surfaces.

Single-Use Gowns

Surgical gowns are classified under the Association for the Advancement of Medical Instrumentation (AAMI) grading (Table III) according to the liquid barrier performance[17,18]. For activities involving low or minimal bodily fluid exposure risk, such as intravenous cannulation, level-1 or 2 gowns, which resist penetration of water by spray impact and increasing hydrostatic pressure, may be used to provide barrier protection. Level-3 or 4 gowns, which resist synthetic blood and blood-borne pathogen penetration under continuous liquid contact, were utilized when performing surgical procedures, or when there was a medium to high risk of contamination, such as intubation and setting of central lines.

Shoe and hair covers theoretically reduce the risk of disease transmission by decreasing the exposed lower-body surface area and keeping hair away from the procedural field. Coveralls are a form of barrier protection that provide 360° of continuous protection by covering the whole body, limbs, and typically the head and feet. In our institution, single-use gowns with shower caps appear sufficiently protective against COVID-19 transmission.

Single-Use Gloves

Disposable patient-examination gloves are appropriate for examining and caring for patients with suspected or confirmed COVID-19 infection. In our institution, patients requiring general or contact precautions are handled with single gloves. When managing patients with COVID-19, double gloves are utilized to preserve PPE, and not to reduce the risk of viral transmission, such that only the outer gloves need to be changed when soiled or when managing multiple patients[19].

Hand Sanitizers

Hand washing mechanically removes microorganisms, and laboratory data have demonstrated that alcohol-based hand sanitizers with ≥70% isopropanol or ≥60% ethanol inactivate viruses that are genetically similar to COVID-19. While the quantitative effect of hand hygiene in reducing direct and indirect spread of coronaviruses between humans is indeterminate, both hand washing and alcohol-based hand sanitizers can reduce the number of viable pathogens that transiently contaminate an individual's hands[20,21].

Disinfectant Solutions and Wipes

Disposable gloves and disinfectant wipes were utilized and discarded after cleaning equipment such as stethoscopes. Products with Environmental Protection Agency approval for use against emerging viral pathogen claims are expected to be effective against COVID-19[22]. Disinfection with 62% to 71% ethanol, 0.5% hydrogen peroxide, or 0.1% sodium hypochlorite appears to be effective for surfaces on which the virus may persist.

Hydrogen peroxide vaporization has been deployed in addition to terminal cleaning to enhance disinfection of patient rooms and ORs in our hospital. This method utilizes the vapor form of the antimicrobial chemical to decontaminate a sealed area. For intricate machines such as arthroscopic devices, ultraviolet cleaning machines were used to decontaminate the equipment safely instead.

Powered Air-Purifying Respirators (PAPRs)

A PAPR is a type of respirator that protects its user by filtering out airborne contaminants using a battery-powered blower. Tight-fitting PAPRs require fit testing, while loose-fitting PAPRs do not. The components of a PAPR (Fig. 1) include a face piece, hood or helmet, breathing tube, canister or cartridge with filter, and a battery-powered blower. When PAPRs were

TABLE III Summary of Association for the Advancement of Medical Instrumentation (AAMI) Classification for Medical Gowns and Drapes

Level	Type of Apparel	Description
1	Gowns, protective apparel, surgical drape, and drape accessories	Demonstrated liquid penetration resistance with laboratory-based testing using impact penetration tests
2	Gowns, protective apparel, surgical drape, and drape accessories	Demonstrated liquid penetration resistance in 2 laboratory tests: impact penetration and hydrostatic pressure tests
3	Gowns, protective apparel, surgical drape, and drape accessories	Demonstrated liquid penetration resistance in 2 laboratory tests—impact penetration tests and hydrostatic pressure tests—with test criteria performance level set to a higher value than for level 2
4	Gowns	Demonstrated liquid and viral penetration resistance in laboratory tests—synthetic blood penetration resistance and blood-borne pathogen penetration resistance—and designated as the highest possible rating

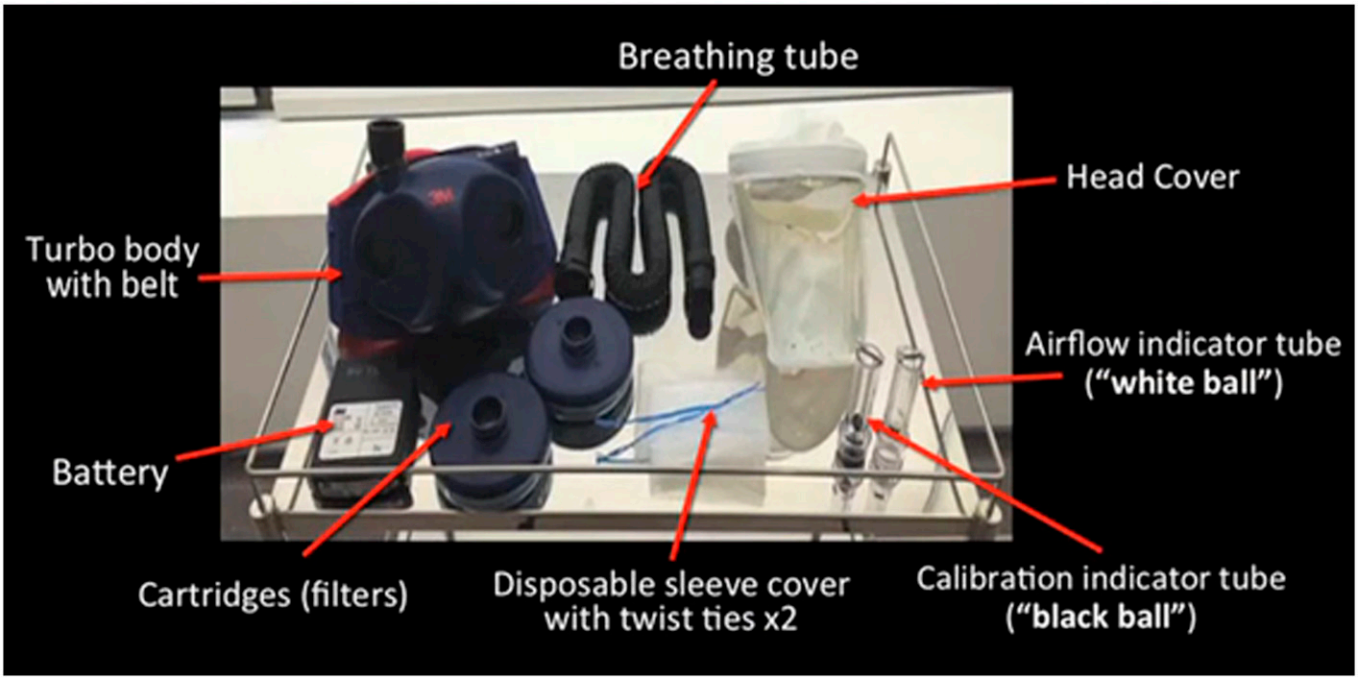

Fig. 1
Components of a loose-fitting powered air-purifying respirator.

considered for use during the pandemic, the efficacy, availability, familiarity with, and affordability of the device were considered in detail. The advantages of using a PAPR included its reusability and increased familiarity with repeated usage. Loose-fitting PAPRs also did not require fit testing and provided additional comfort for the health-care worker. The disadvantages of using a PAPR included its high cost, regular maintenance, considerable difficulties in hearing, reduced visual fields, and short battery life.

Positive-Pressure Exhaust Suits

Positive-pressure exhaust suits utilize a surgical helmet with a head-mounted fan to circulate air filtered through the hood material itself. This is in contrast to PAPRs, which utilize a high-efficiency particulate air (HEPA) filter and blow filtered air over the wearer's face at high flow rates[23]. Positive-pressure exhaust suits, while protective against splash injuries and blood-borne pathogens, are unable to filter particles of the coronavirus size range, and we do not recommend the utilization of positive-pressure exhaust suits alone to protect against COVID-19.

PPE Recommendations for Medical Staff Attending to Patients in Institutional Practice

While all medical staff should ideally be protected in full PPE when attending to all patients during a global pandemic, indiscriminate use of PPE may expedite its global shortage. To mitigate the potential of such a scenario, medical staff should demonstrate an understanding of when to use PPE and what PPE is necessary. Our institution's PPE protocols are outlined in Table IV and are based on the Singapore Ministry of Health guidelines and institutional practices[24].

We adhered strictly to our institution's PPE protocols and are encouraged to report that there were no cases of nosocomial transmission of COVID-19 among health-care workers and patients after 60 days of managing the pandemic, while simultaneously conserving precious PPE supplies.

Recommendations for Respirator Usage for Surgeons

Loose-fitting PAPRs were used in our surgical division for prolonged (>4-hour-long) surgery in patients with COVID-19 infection. This was due to the increased risk of transmission from prolonged exposure, considerable discomfort at pressure areas, potential loosening of N95 masks[25], and increased dead-space concentrations of carbon dioxide, which may compromise work performance[26]. For short surgeries in patients with COVID-19 infection, we utilized hair covers, goggles, N95 masks, AAMI level-4 gowns, shoe covers, and double gloving with sterile single-use gloves. Surgeons remained outside ORs during intubation until the airway was secured and connected to a closed-circuit ventilator because of the aerosolization of viral particles.

Patients with Suspected or Confirmed COVID-19 Infection Requiring Surgery

Surgeons will inevitably need to operate on patients with suspected or confirmed COVID-19 infection. Such a decision should be made in tandem with the patient, family members, intensivists, anesthetists, and OR staff as recovery from COVID-19 may require 2 weeks for milder forms and 3 to

TABLE IV Recommendations for PPE Usage for Areas with Patient Interaction in Institutional Practice

Patient Type and Location	Staff Category	Hand Hygiene	N95 Mask	Surgical Mask	Eye Protection	Gown and Shower Cap	Gloves
Patient with confirmed infection in isolation room	Medical and nursing	X	X		X	X	X
	Allied health	X	X		X	X	X
Patient with suspected infection in designated screening centers	Medical and nursing	X	X		X	X	X
	Allied health	X	X		X	X	X
Patient with suspected infection in emergency department	Medical and nursing	X	X		X	X	X
	Allied health	X	X		X	X	X
Asymptomatic patient in emergency department	Medical and nursing	X		X			X
	Allied health	X		X			X
Patient with suspected infection in general ward or outpatient clinic	Medical and nursing	X	X		X	X	X
	Allied health	X	X		X	X	X
Asymptomatic patient in general ward or outpatient clinic	Medical and nursing	X		X			X
	Allied health	X		X			X

6 weeks for severe or critical disease[27]. Surgical timing should be determined on the basis of whether the surgeries are urgent or life or limb-saving, and whether the patient's condition is stable or unstable.

Patients in stable condition requiring nonurgent surgery, such as a patient with a closed radial and ulnar fracture and a concomitant COVID-19 infection without oxygen requirements, should be isolated for treatment first. The fracture can be immobilized in a splint, and surgery should be delayed until the patient is deemed to be not infected by the infectious disease (ID) specialist.

Patients in unstable condition who require nonurgent surgery, such as a patient with patellar tendon rupture and concomitant COVID-19 pneumonia requiring oxygen supplementation, should be isolated in a negative-pressure ICU for optimization. Surgery should be delayed until the patient is deemed to be not infected by an ID specialist.

Patients in unstable condition who require urgent surgery, such as a patient with necrotizing fasciitis and concomitant COVID-19 pneumonia, should have the surgery performed in a surgical suite that is negatively pressurized relative to the corridor and adjacent spaces. After surgical stabilization, the patient should be monitored in a negative-pressure ICU.

Perioperative Considerations for Patients with Suspected or Confirmed COVID-19 Infection

Transfer of Patients

Transfer of patients with suspected or confirmed COVID-19 infection to the OR required careful planning and predesignated corridors to mitigate the risk of transmission. The patients were fitted with a surgical mask during transport to and from the operating room. Staff involved in the care and transport of the patient wore PPE, and the number of staff

TABLE V Chart Showing Orthopaedic Team Allocation During COVID-19 Pandemic

	Spine	Trauma	Sports	Adult Reconstruction	Foot and Ankle	Tumor
Team 1						
House officers (interns)						
Medical officers (nonresident doctors)						
Junior residents						
Senior residents						
Consultants (attendings)						
Team 2						
House officers (interns)						
Medical officers (nonresident doctors)						
Junior residents						
Senior residents						
Consultants (attendings)						

members involved was minimized with minimal exchange of staff. Patients were intubated, were extubated, and recovered in negative-pressure ORs, with a minimum of 15 air changes through a HEPA filter per hour. They were transported directly back to negative-pressure rooms without contaminating the postanesthesia care unit.

Recovery and Rehabilitation

After surgery, regular chest and ambulatory physiotherapy minimized pulmonary complications and relieved symptoms of dyspnea, anxiety, and depression. For patients who remained critically ill, pulmonary rehabilitation was not initiated until their condition stabilized[28]. Pulmonary rehabilitation guidance can be conducted through educational videos and remote consultation, if facilities are available, as patients are monitored and continuously reassessed. Even after patients have been discharged, internet-based telerehabilitation allows real-time interaction with a physical therapist during which remote guidance of self-applied exercises can be administered in the comfort of the patient's own home. Previous studies have shown that telerehabilitation with only common household equipment was comparable with conventional rehabilitation[29] and should be incorporated into practice for prolonged pandemics.

Manpower Management

Staff Health Protocols

During the SARs outbreak in 2003, 40% of the 238 reported cases were in health-care workers[30], a grim reminder that nosocomial infections can spread rapidly and cripple a health-care system. During the current pandemic, many initiatives were instituted to address the key risk factors. At an organizational level, there were dedicated isolation wards and triage areas, training and monitoring of hospital staff in infection-control procedures, strict enforcement of droplet precautions for COVID-19 patients, and minimization of staff exposure to high-risk aerosol-generating procedures. Alternative sites of accommodation were arranged to house potential health-care workers evicted from their residences and for those staying with vulnerable elderly individuals, infants, and pregnant partners.

At an individual level, all staff undertook mandatory twice-daily temperature surveillance and self-reporting of respiratory symptoms through a centralized online system. Occupational health clinics and COVID-19 screening centers were established for health-care workers to seek medical attention. To avoid unnecessary depletion of precious PPE supplies, no PPE or surgical masks were required for staff in administrative offices or where there was no direct patient contact except when in congregate settings (involving >10 personnel).

Manpower Segregation

Secondary transmission of COVID-19 among health-care workers has been well documented[31,32]. One of the key strategies to prevent this transmission was through manpower segregation. Manpower segregation strategies can be divided into temporal or spatial segregation. For departments with sizeable manpower and resources, temporal segregation by rotating shifts is a good option to prevent burnout and ensure service continuity in prolonged outbreaks.

For departments with more modest manpower and resources, spatial segregation may be a better option. Our department was divided into individual teams with a recognized chain of command and members of key subspecialty capabilities, seniorities, and experiences (Table V). Inpatient, outpatient, and OR duties were segregated and run by each individual team. These approaches allowed for preservation of business continuity and maintenance of core orthopaedic capabilities throughout the outbreak.

Teleconferencing

Multidisciplinary meetings and medical education have traditionally been conducted via face-to-face interactions. With the risk of transmission among personnel, such meetings were discontinued at the initial phases of the pandemic with the exception of small group discussions (involving <10 participants) on an as-needed basis. Such meetings have since been substituted with teleconferencing using web-based software such as Skype, Meet by Google Meet, and Amazon Chime. Our institution decided on ZOOM Cloud Meetings, as the program incorporated the following features.

The software allowed meetings to be initiated by any user, provided video and audio-conferencing features, allowed external guest participation with web links, included recording features, facilitated screen-sharing with presenter modes, and was available on smartphones. The video web conferencing software also provided technological assistance and fit into the budget.

Education and Continuing Medical Education

E-learning, in the field of surgical education, refers to the use of internet-based resources such as case studies and video recordings of surgical procedures to enhance teaching[33]. After an initial suspension of teaching activities, the curriculum was shifted online for residents across multiple affiliated hospitals. Clinical case scenario-based discussions and a structured oral examination using slides can be a way for most programs to transition their educational activities online in the initial phases as only digitalized content is required.

Conclusions

As they are physicians first, the orthopaedic surgeon and the department are obligated to serve the needs of the many during an outbreak, and they can do so only if there are established plans for maintaining business continuity. Performing surgery in a pandemic is fraught with danger and considerable restrictions from multiple fronts. Surgery can be performed safely only if the surgeon has an overarching view of the potential problems and strategies to mitigate them. In a prolonged outbreak, sustainability is essential for maintaining standards, discipline, and morale among health-care workers. By presenting the strategies utilized by a national institution

that prevailed at the epicenter of the pandemic, we hope that others may be able to incorporate them into their practices to respond, recover, and prevent the pandemic from escalating further. ■

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