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Minimizing cross transmission of SARS-CoV-2 in obstetric ultrasound during COVID-19 pandemic

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Abstract: Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2)-associated infection (COVID-19) is affecting populations worldwide. This statement may serve as guidance for infection prevention and safe ultrasound practices during the COVID-19 pandemic. Ultrasound examination is a fundamental part of obstetric care, yet it is a potential vector for transmission of SARS-CoV-2. Decontamination methods should always be implemented for ultrasound equipment, especially in the presence of suspected or confirmed COVID-19 cases. There must be workflow policies to protect pregnant women and healthcare providers from nosocomial cross transmission of SARS-CoV-2. Cleaning and disinfecting of equipment must be in accordance with their potential of pathogen transmission. Consider using telemedicine and genetic technologies as an adjunctive of obstetric ultrasound to reduce patient crowding. Patient triage and education of healthcare providers of infection prevention are crucial to minimize cross contamination of SARS-CoV-2 during obstetric ultrasound.

Keywords: acute respiratory distress syndrome; ARDS; coronavirus disease 2019; coronavirus; maternal morbidity; MERS; pandemic; SARS; severe acute respiratory syndrome; virus.

Introduction

Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2)-associated infection (coronavirus disease 2019 or COVID-19) is affecting populations worldwide. The virus is airborne and contagious. More severe outcomes are possible in pregnant women [1]. Ultrasound examination is a fundamental part of basic and advanced care in obstetrics [2]. Obstetric ultrasound unit is a potential vector for transmission of SARS-CoV-2 for several reasons. Ultrasound examination is subjected to close and prolonged personal contact. The examination suites tend to be small and restricted for natural ventilation. The central air conditioning is generally closed vented, and without High Efficiency Particulate Air (HEPA) filtration to arrest very fine particle. There are repeated handling of transducers, machine console, keyboards, touch screens, trackballs, and recording devices [3, 4]. Basic knowledge of infection prevention measures is usually lacking among ultrasound providers [5].

Guidelines for prevention of SARS-CoV-2 infection from transabdominal, transvaginal, and transrectal ultrasounds are readily available [6–8]. Guidance documents for management of COVID-19 in pregnant women have been published by authors from areas most affected by the virus thus far, such as China, Singapore, Hong Kong, and Italy [9–13]. These recommendations are based on limited, and rapidly-evolving, body of evidence. Although most elective obstetric ultrasound has been curtailed by administrative or governmental decree, there are emergency conditions and time-sensitive interventions which ultrasound in pregnant women is needed. This article may serve as a guidance to minimize cross transmission of SARS-CoV-2 among patients and healthcare providers (HCPs) when performing ultrasound examinations on pregnant women during global pandemic. The term HCPs used in this article is inclusive for sonologists, sonographers, nursing staffs, and all other staffs who provide obstetric ultrasound service. Local experiences in Thailand, where COVID-19 has been reasonably well controlled, are used as examples throughout this manuscript. This guidance is current at time of publication and further updates may be provided as new evidence emerges.

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Pandemic of COVID-19 and maternal-fetal health

Originated from animal, now SARS-CoV-2 is currently involved in human to human transmission at global pandemic scale [14, 15]. The SARS-CoV-2 is a relatively small ribonucleic acid (RNA) virus transmitted through respiratory droplets [16, 17]. The SARS-CoV-2 laden particles can remain suspended in the air for hours and on a static surface for a few days [18]. The SARS-CoV-2 mainly spreads when virus-laden droplets from a person's mouth or nose are transferred to mouth, nose, or eyes of other people. Other coronaviral infections such as the SARS-CoV-1 and Middle East respiratory syndrome (MERS) increased risks for preterm deliveries, stillbirths, pulmonary complications, and deaths in pregnant women [11, 19]. Recent evidence suggests SARS-CoV-2 may also cause more serious complications in pregnant women [11, 20–22]. Life-threatening complications during pregnancy from COVID-19 may be less than those observed from influenza A (H1N1). Basal atelectasis from gravid uterus, reduce functional residual capacity (lower lung reserves), and 30% increase oxygen consumption predispose pregnant women with COVID-19 to develop coronaviral pneumonias which could rapidly deteriorate to respiratory failure [23]. T-helper 2 (Th2) system is dominant during pregnancy to protect the fetus. This leaves pregnant woman more vulnerable to viral infections, which are more effectively contained by the T-helper 1 (Th1) system [24]. Although there was a report of placental injuries from COVID-19, there is not enough evidence to confirm spontaneous vertical transmission of SARS-CoV-2 [25, 26]. Placental changes in COVID-19 are decidual arteriopathy and maternal vascular mal-perfusion, which reflect a systemic inflammatory or hypercoagulable state influencing intervillous oxygenation and may increase occurrence of pre-eclampsia [27]. However, the actual consequences of COVID-19 to maternal and fetal health remained controversial at the time of writing this manuscript [28, 29].

Detection and confirmation of COVID-19

Approximately 80% of SARS-CoV-2 infections are asymptomatic [30]. For those who are symptomatic, it takes an average of 6 days, to up to 14 days, after infection with SARS-CoV-2 for symptoms to show. Clinical presentations of COVID-19 can be varied. Most patients develop mild to

moderate flu-like symptoms, i.e., fever, dry cough, and tiredness, which overlap with symptoms of other viral respiratory diseases. Some may experience myalgia, sore throat, diarrhea, conjunctivitis, headache, loss of taste or smell, skin rashes, and discoloration of fingers or toes, which can be self-remission. Serious pulmonary manifestations are uncommon. The SARS-CoV-2 can be found in feces, [15, 31] but not in vaginal secretion [32]. Fecal-oral and sexually transmission do not appear to be a major route of transmission of SARS-CoV-2.

During the pandemic of COVID-19, attention must be paid at collecting clinical and epidemiological indicators, i.e., respiratory symptoms, fever, recent travel history to area with serious outbreak, or contact with confirmed cases [33]. Patient under investigation (PUI) is defined as a suspected case on the basis of the followings; [1] pneumonia of unknown origin, or [2] fever ($\geq 37.5^{\circ}\text{C}$) and/or respiratory symptoms, or [3] epidemiological correlation with the domestic mass outbreak or contact with a confirmed case of COVID-19 and exhibiting fever and/or respiratory symptoms within 14 days. Infection can be confirmed within 90 min by nasopharyngeal swab for detection of viral-specific RNA with real-time reverse transcription polymerase chain reaction (RT-PCR) [34]. Serologic strip test to detect antibody (IgG and IgM) in the blood serum and plasma takes only 15 min, but the clinical roles of antibody testing remained controversial at the time of writing this manuscript [35]. Further managements of pregnant women who are tested positive for SARS-CoV-2 are not within the scope of this article.

Cross transmission of SARS-CoV-2 during obstetric ultrasound

Although most of the reported COVID-19 outbreaks are in a household or a workplace rather than in a health care facility; ultrasound providers are particularly at higher risk of contracting SARS-CoV-2. Preventing HCPs from getting SARS-CoV-2 is particularly important because HCPs are able to transfer the virus to many vulnerable patients before they become symptomatic. Special attention should be paid at HCPs who are at higher risk for severe complications if they get COVID-19, i.e., those older than 60 years, and those with underlying conditions such as hypertension, diabetes mellitus, cardiovascular disease, chronic respiratory disease, and cancer [36]. Advanced obstetric ultrasounds and prenatal interventional procedures increase the exposure time of HCPs to the patients [2, 37, 38].

It is important to note that the viability of SARS-CoV-2-laden droplets on surfaces depends on the type of surface and temperature [39]. The virus may survive on dry inanimate surfaces from two to nine days [8, 39]. Training, practicing, and auditing basic infection prevention and control within the obstetric ultrasound unit are important [40]. Recent survey indicated that upto 60% of ultrasound providers do not receive adequate training for sanitization of the equipment. In addition, 33% do not have an access to written infection control policies [4]. As the SARS-CoV-2 status of pregnant women is not often disclosed prior to an obstetric scan; infection control protocols during the global outbreak may include appropriate use of personal protective equipment (PPE) (Table 1). Cleaning and disinfection of ultrasound equipment can mitigate the risk of potential infection [41]. Training materials for infection control should be easy to understand and available in the appropriate language and literacy level for all HCPs. The steps of ‘cleaning’, ‘low-level disinfection’ (LLD), ‘high-level disinfection’ (HLD), and sterilization are described in Table 2.

Considerations for healthcare providers to prevent cross transmission of SARS-CoV-2 during obstetric ultrasound

Since most of the SARS-CoV-2 infections are asymptomatic; standard precautions should be undertaken as part of every examination. They include [1] hand hygiene before and after each examination, [2] appropriate use of PPE, [3] maintenance of clean equipment and working

environment, and [4] correct disposal of waste. Washing with warm water and soap >20 s remains the gold standard for hand hygiene, especially if hands are visibly soiled, because it removes oils from the skin that can harbor microbes. Soap can kill SARS-CoV-2 and most viruses by attacking at the lipid bilayer capsid of the viral nanoparticles [42]. Soap to be used for frequent hand washing should not contain any harsh ingredients or fragrance that may be irritating to the skin. Alternatively, the use of hand sanitizers in between touching the patients is a good substitute in a busy practice. Hand sanitizers are either alcohol-based or alcohol-free. Alcohol-based products contain between 60 and 95% of isopropyl alcohol, ethyl alcohol (ethanol), or n-propyl alcohol (n-propanol). This concentration of alcohol can destroy envelop protein and kill most viruses including coronaviruses. Incorrect use of hand sanitizer, i.e., inadequate volume or wiping off before it dries, is common and is jeopardizing its germicidal effects [43]. Alcohol is highly flammable and irritant to some. Alcohol-free products contain quaternary ammonium compounds (usually benzalkonium chloride), which have a weaker antimicrobial efficacy than alcohol, but still is effective against coronaviruses [44]. Hand hygiene should also be performed when donning and doffing of gloves and other PPE.

Scanning should be performed with one clean hand holding a transducer, while the other hand is semi-clean to operate the machine’s dashboard and to handle the coupling gel bottle. Gloves may be used with the scanning hand and changed after each examination. The PPE may be used as appropriate and as per the institutional protocols, as shown in Figure 1. Shorter working hours and work in rotation can minimize the number of essential HCPs present in each location. Older (>60 years old) HCPs or those with underlying medical conditions should not be allocated to work with PUI or confirmed COVID-19 patients, or in areas with high-volume patient contact, i.e., emergency department. Because a number of HCPs have already been off work after exposure to COVID19 cases, small teams should be consolidated and scheduled to work on alternating weeks to lessen the exposure. It is important to understand levels of anxiety and depression in HCPs working in obstetric ultrasound at this time.

Table 1: Personal protective equipment (PPE) relevant to providers of obstetric ultrasound in the context of coronavirus disease 2019 (COVID-19) [41, 69, 72].

PPE	Remarks
Face mask	Surgical face mask is adequate in most circumstances N95 and FFP3 (higher level of protection) in possible presence of infected aerosol, i.e., point-of-care ultrasound during labor and delivery
Eye protection	Goggles, face shield
Gloves	Preferably latex-free.
Gowns, hair, and shoe covers (fluid impermeable)	This is to minimize the transfer of pathogens to the clothing and shoes.

Prioritizing the indications of obstetric ultrasound

During COVID-19 pandemic, the prior anxiety associated with diagnosis of serious obstetric or fetal conditions can

Table 2: Cleaning, disinfection, and sterilization relevant to obstetric ultrasound equipment in the context of coronavirus disease 2019 (COVID-19) [7, 52].

	Cleaning		LLD ^a	HLD	Sterilization
Efficacy	Removal of visible soil or extraneous coupling gel that jeopardize efficacies of LLD, HLD, and sterilization		Destruction of most bacteria, some viruses, and some fungi, EXCEPT <i>Mycobacterium tuberculosis</i> or bacterial spores.	Destruction of all microorganisms, EXCEPT bacterial spores.	Destruction of all forms of microorganisms
Equipment	Damp soft cloth and mild liquid soap		Quaternary ammonium 0.5% H ₂ O ₂ 0.1% sodium hypochlorite 0.05–0.2% benzalkonium chloride 0.02% chlorhexidine digluconate	Manual 0.55% ortho-phthalaldehyde 2% glutaraldehyde Automatic Vaporized hydrogen peroxide (Trophon® EPR system, Nanosonics, Alexandria, Australia) Peracetic acid (STERIS, Antwerpen, Belgium) Chlorine dioxide (Tristel wipes system, Cambridge, UK) After high-risk exposures ^b Yes	Pressurized steam Dry heat EtO gas H ₂ O ₂ gas plasma, and liquid chemicals
Frequency	After each examination		62–71% ethyl alcohol		
Destruction of SARS-CoV-2	Yes		After each examination Yes		For intraoperative use Yes
Advantages	Inexpensive Easily applicable High skin tolerance Suitable to most parts of ultrasound machine		Inexpensive Easily applicable High skin tolerance Suitable to most parts of ultrasound machine	Destruction of most microorganisms	Destruction of all microorganisms
Disadvantages	Not for disinfecting		Not destruction of all microorganisms	Expensive Manual HLD is performed only in appropriate setting due to immersion procedure that involves toxic and irritant chemicals Manual HLD is impractical in routine operations for outpatient facility with high number of examinations. Not suitable to many parts of ultrasound machine, and may increase wear of the transducer head membrane.	Expensive Performed only in appropriate setting due to involvement of extreme physical or chemical methods Not suitable to most parts of ultrasound machine

LLD = low-level disinfection, HLD = high-level disinfection, HIV = human immunodeficiency virus, EtO = ethylene oxide, H₂O₂ = hydrogen peroxide. ^a spray or wipes. ^b [1] Exposure with confirmed cases of COVID-19 without the use of transducer cover or [2] disruption of transducer cover during transvaginal or transrectal scans, or during prenatal procedures, and transducer came to direct contact with body fluid or blood.

Figure 1: Arrangement of obstetric ultrasound services during COVID-19 pandemic.

(1) Ultrasound provider wears makeshift cover-all gown from disposable raincoat (water-proof), with mask and face shield. Also note that non-essential items in the examination suite have been removed, (2) Makeshift transducer cover from store-bought plastic bag and rubber band. (3) Enforcement of alternate seating in waiting area to ensure distance keeping ≥ 1 m apart (Source; Tuangsit Wataganara, Division of Maternal Fetal Medicine, Department of Obstetrics and Gynecology, Faculty of Medicine Siriraj Hospital).

be heightened by the concern of contracting SARS-CoV-2. To minimize the chance of having an asymptomatic carriers attending the obstetric ultrasound unit, triage is best undertaken before the patient arrival. Patients should be contacted by phone before the appointment date to check for symptoms. Those who are symptomatic, considered a PUI, or have been diagnosed with COVID-19 within 14 days should be instructed to postpone their non-urgent ultrasound examination [12]. Before entering the waiting area, everyone must be checked with thermo screening and questioning with standardized checklists as per recommendations of local or institutional authorities (i.e., www.thaicovids.com) at ≥ 1 m away. [45] Thermo screening is not always truthful since some women took antipyretics medication before the screening.

It is important to [1] triage of patients to routine or emergent examination [2] delay or cancel non-essential examinations (Table 3), to minimize patient crowding, [3] space the waiting room seats to ≥ 1 m apart, [4] limit the

number of entourages in waiting area to ≤ 1 , and none in the examination suite, [5] prohibit school-age children from entering the waiting area because they are more likely to be asymptomatic carriers of SARS-CoV-2, [6] encourage the use of telemedicine and genetic technologies, such as noninvasive prenatal testing (NIPT) as an adjunctive or replacement of first trimester scan, [46] and [7] prohibit or reduce trainees on site.

Digital technologies have been put to use during the COVID-19 pandemic. For example, the Ministry of Digital Economy and Society (Thailand) recently released a smartphone application “Thai Chana” (Thailand Wins, downloadable from www.thaichana.com) to facilitate safety for both clients and establishments during the COVID-19 era [47]. Another smartphone application “Skan & Go” is also available for patients of Faculty of Medicine Siriraj Hospital (Thailand) (downloadable from https://www.si.mahidol.ac.th/th/news_covid19.asp) [48]. The use of QR codes generated from these smartphone applications

Table 3: Schedule management for obstetric ultrasound during coronavirus disease 2019 (COVID-19) pandemic according to the essentialness [13, 53, 73, 74].

Indications	Scheduling management	Remarks
Bleeding in early pregnancy	Point-of-care ultrasound to determine fetal life and location of pregnancy	Consider re-scheduling for ultrasound according to the clinical suspicion.
Dating (re-assurance) scan at 6–10 weeks'	Cancel	Consider re-scheduling for first trimester scan at 11–13 + 6 weeks'
First trimester screening at 11–13 + 6 weeks'	Postpone for 1–2 weeks, but not after 13 + 6 weeks'	Consider informing the low-risk results of combined first-trimester screening by phone
Transvaginal scan for cervical length assessment	Cancel in those clinically low-risk for spontaneous preterm birth	Consider transabdominal assessment of the cervix at the time of second trimester scan. Confirmation with transvaginal assessment in those with cervical length <35 mm or funneling of the internal os. Short cervix may warrant intervention i.e., cervical cerclage, progesterone supplement
Anomaly scan at 18–20 weeks'	Scan without delay in those clinically high-risk for spontaneous preterm birth (i.e., history of previous spontaneous preterm birth, cervical conization)	Second trimester scan should be given priority over first trimester scan
Prenatal diagnostic and therapeutic procedures	Postpone for 1–2 weeks, but not after legal gestational weeks for termination.	These essential procedures do not generate aerosol particles.
Routine growth scan in the third trimester in low-risk women	Scan without delay	Routine third trimester scan is not proven to reduce perinatal morbidity
Fetal well-being, amniotic fluid index, and Doppler studies from 28–41 weeks' in high-risk pregnancies	Cancel or postpone until 36 weeks'	The scan is critical for decision making for prenatal intervention or early delivery. High-risk pregnancies include, but not restricted to, fetal growth restriction, red blood cell iso-immunization, monochorionic twins
Suspected abnormal placentation i.e., low-lying and placenta previa, placenta accreta, or vasa previa	Scan without delay	Scan interval depends on the severity of the condition. The scan is critical for decision making and early notification with blood bank, especially in shortage of blood products supplies during the pandemic.
Research recruitment	Cancel	Consider re-scheduling only for interventional research that may benefit the patients.

help managing crowding and facilitate contact tracing in case of cluster outbreaks in the establishment.

Sanitization of ultrasound equipment

Reusable medical devices such as ultrasound transducers are potential vector in the cross transmission of healthcare-associated infection. Approximately 60% of transabdominal and 14% of transvaginal transducers are contaminated with pathogen after use [49]. Reprocessing requires cleaning, followed immediately by disinfection or sterilization depending on the procedure and risk. Sanitization can reduce the number of, but not completely eliminate, viruses present on a surface. Damp cloth and small amount of mild non-abrasive liquid soap are used to

clean the remaining coupling gel that barrier and diminish the efficacy of disinfectant agents that will be followed. There are non-critical (low-risk), semi-critical (medium-risk), and critical (high-risk) levels of disinfection for obstetric ultrasound transducers, as per the Spaulding Classification system (Table 4) [50, 51]. The number of transducers connected to the ultrasound machine should be reduced to a minimum. Non-essential transducers, i.e., linear, three-dimensional, and electronic transducers, should be stored away in a clean closed cabinet and brought out as needed.

Transabdominal transducers can then be disinfected with antimicrobial sprays and wipes (antiseptic-impregnated towel), such as Clorox® Disinfecting Wipes, Clorox® Healthcare Bleach Germicidal Disinfectant Wipes, Super Sani-Cloth Germicidal Disposable Wipes, or Lysol® spray, and allow the surface to air dry [52, 53]. Be careful when

Table 4: Categorization of equipment in obstetric ultrasound based on their potential for pathogen transmission [50, 51, 73].

Category	Definition	Example	Cleaning strategy after each use	Remarks
Critical (high-risk)	Intended to penetrate skin or mucous membranes	Needle guidance	HLD/sterilization (depending on institutional guidelines)	Use sterile transducer cover
Semi-critical (medium-risk)	Come into contact with non-intact skin, blood, body fluids, and mucous membranes	Transvaginal and trans-rectal transducers	LLD/HLD (depending on the level of procedure sterility and known infectious status of the patients)	Use non-sterile transducer cover
		Intraoperative transducer	LLD/HLD	Use sterile transducer cover
Non-critical (low-risk)	Come into contact with clean, intact skin, but not mucous membranes	Transabdominal transducer	LLD	Use non-sterile transducer cover for PUI or confirmed COVID-19 cases
		Interventional percutaneous procedure transducer	LLD	Use sterile transducer cover

HLD, high-level disinfection; LLD, low-level disinfection; HIV, human immuno deficiency virus; PUI, patient under investigation.

spraying disinfectant agents on high contact surfaces such as registration counters as splashes can further disperse the virus. Sanitizing wipe may be more appropriate. Do not disinfect ultrasound transducer, cables, USB connectors, or strain reliefs with $\geq 70\%$ isopropyl alcohol as it can damage those parts and invalidate warranties or service contract. Hand sanitizer should not be used to disinfect ultrasound equipment. Products used for cleaning or disinfection must be checked for compatibility and contact time to ensure effective germicidal as per specified by the manufacturers. Gloves and eye protections are required for cleaning and disinfection. Type C ultraviolet light may be used to clean all transducer at the end of the day [54].

Transvaginal and transabdominal transducers used for prenatal intervention must be used with protective mechanical barriers to prevent direct contact with body fluid and blood. Transvaginal transducers are persistently tainted with pathogen because the use of latex condoms does not always prevent smear contamination [54]. Ideally, these transducers must undergo HLD after each use [55, 56]. In reality, HLD after each use or when there is disruption of the barriers is difficult due to limited time from a large caseload [5]. Ruptures of transducer cover sometimes are unrecognized, and the transducer comes into direct contact with body fluid and blood [52]. Choosing the optimal method to disinfect these transducers need to consider other pathogens aside from SARS-CoV-2 [7, 32]. Although most commercially available disinfecting wipes (LLD) cannot eliminate all microorganisms; they are still effective against common viral pathogens such as human papillomavirus (HPV), human immunodeficiency virus (HIV), and coronaviruses [57].

Protective mechanical barriers such as medical gloves, transducer cover, or condoms, are generally made with latex (natural rubber). Latex condoms effectively block most viruses, including HPV (0.05 μm), HIV (0.1 μm), and coronaviruses (0.11 μm) [58, 59]. Transducer covers with pore sizes of less than 0.03 μm (i.e., CIV-Flex™, Civco, Iowa, USA) are now available. The protective mechanical barrier must be carefully removed from the transducer after each scan, and disposed properly. Be careful not to smear contaminate the transducer during the removal. Gloves should be worn to remove the transducer cover and to clean the transducer, then hands should be thoroughly washed with soap and water. If disruption of condoms is found, the transducer should ideally undergo HLD with chemical agents.

In the context of COVID-19, the normal practices of cleaning and disinfection of ultrasound transducers used in obstetrics to denature SARS-CoV-2 are not changed (Table 4). Non-sterile cover can be put on transabdominal transducers to serve as a barrier during the diagnostic scan in patients with suspicious history, but not triaged as PUI (Figure 1). The use of bacteriostatic lubricant for coupling does not significantly reduce the rate of infection [60]. Latex sensitivity can be identified by questioning about itching, rash or wheezing after wearing latex gloves or inflating a toy balloon. Positive histories should be flagged in the patient's chart. Reaction to latex range from contact urticaria to systemic anaphylaxis which requires prompt treatment [61]. "Hypoallergenic" latex gloves do not necessarily prevent allergic reaction; therefore if latex sensitivity is suspected, consider using transducer covers made with alternative materials, such as plastic.

Contaminated ultrasound gel has been implicated in outbreaks of other nosocomial infections but coronaviruses [62]. Sterile single-use gel packet may be preferred in all invasive prenatal procedures, and for examination of PUI or confirmed COVID-19 cases. Multi-dose containers are more widely used. Empty containers should be discarded, and should not be refilled. The container should be sealed when not in use. Coupling gel is dispensed from its container with the semi-clean hand. Direct contact between the dispensing tip and other persons or equipment, including the ultrasound transducer, should be avoided. The container should be wiped with LLD agents after each examination.

Ancillaries of ultrasound machine, i.e., track ball, touch screen, etc., are cleaned and disinfected much less frequently than the ultrasound transducer because it is time consuming. The use of plastic covers for the machine's console can be helpful, especially if the machine is to be used for examination of PUI or confirmed COVID-19 cases. If the plastic cover is visibly soiled, it must be cleaned. The use of a plastic cover does not preclude the need for cleaning the equipment at the end of daily service.

Point-of-care obstetric ultrasound during COVID-19 pandemic

The development of good quality and portable ultrasound machines has led to focused approaches for clinical decision making and for procedural guidance in obstetric patients who would otherwise have very limited or no access to standard imaging [63]. Point-of-care obstetric ultrasound can take place in labor and delivery ward, accident and emergency medicine units, and critical care services. Mobile ultrasound machines are often used for examination of PUI and confirmed COVID-19 patients due to simpler user interface, ease of transport, and easier cleaning. If active screening for SARS-CoV-2 for all in-house obstetric patients is not enforced in the establishment, it is important that all mobile ultrasound equipment must be regularly sanitized. All items should be cleaned and LLD immediately after each use on patient with unknown COVID-19 status. Portable ultrasound machines in labor and delivery unit is more vulnerable to viral contamination because aerosolized droplets are commonly generated during the process of vaginal births.

Although procedures conducted in obstetric ultrasound unit generally involve blood and amniotic fluid; they do not commonly generate aerosolized droplets. Ultrasound transducers for prenatal procedures require LLD

or HLD before and after use. Ultrasound transducers for the operating theater may require HLD [8]. Intraoperative cross transmission of SARS-CoV-2 may theoretically be increased with gas laparoscopy and procedures that require endotracheal intubation. Knowing the patient's preoperative SARS-CoV-2 status, either by nasopharyngeal swab or serologic strip test, would avoid or defer certain procedures while the patient is contagious and to protect HCPs appropriately. Some fetal conditions amenable for *in utero* interventions may alternatively be managed after birth in accordance with the context of local resources [64]. Procedures of unproven benefit should not be offered [65]. Fetal care team must weigh the risks and benefits to the fetus and the mother when the situation gets more complex with a continuous change of evidence and logistic challenges in individual healthcare system [66].

Physical arrangement of obstetric ultrasound unit in the context of COVID-19

Environment of each obstetric ultrasound unit is different. Ultrasound equipment needs to be kept air conditioned because critical elevation of internal system temperature can cause irreparable damages. Transmission of respiratory viruses like SARS-CoV-2 occurs more easily within closed setting. Clinical service model should be built around the principles of workplace segregation, responsible social distancing, containment of cross infection to HCPs, appropriate use of PPE, and telemedicine [11].

Ideally, a single unit air conditioning should be vent open mode (open to outside air). Physical barriers, i.e., plastic window panels, can be put on in reception areas to protect the patients and HCPs from exchanging aerosolized droplets. There should be hand sanitizing stations installed near the entrance to waiting area and registration counters. Data from a hospital in Wuhan, China during the first outbreak of COVID-19 showed that the most contaminated objects and are self-service printers (20.0%), hand sanitizer dispensers (20.3%), and glove boxes (15.4%) [67]. The risk of SARS-CoV-2 transmission via touching paper document is low [68]. Guest chairs in the waiting area must be spaced ≥ 1 m apart (Figure 1). Absorbent materials like bed linen, chair fabric covers, and unnecessary curtains should be removed. At the beginning and the end of daily service, wipe computer keyboard and mouse at registration counters, doorknobs, patient beds, guest chairs, sonographer chairs, countertops, cabinet door handles, and light switches with soap and water,

followed by LLD agents. If paper bed cover is used, it must be removed with gloved hands, folded, and disposed of immediately at the end of each examination.

Workflows for safe obstetric ultrasound services in suspected and confirmed COVID-19 cases

Medical institutions are activating COVID-19 protocols that are adapted from smaller-scale viral pandemics such as influenza A, SARS, and MERS [69]. There must be practical approaches and policies to provide optimal ultrasound services for confirmed COVID-19 pregnant women, and to prevent nosocomial spreading of the virus at the same time. This is also to protect expensive and potentially easily damaged ultrasound equipment. Protection of HCPs is also a priority during the work-up phase of PUI presenting for urgent obstetric scan. The PUI with non-urgent indications should be re-directed to 'respiratory clinic' for confirmatory testings. Ultrasound providers who unknowingly examine women who are subsequently confirmed with SARS-CoV-2 infection need to be self-quarantined for >14 days. Appropriate use of PPE, even if the HCPs are ≥ 1 m away from symptomatic patients, significantly decreases risk of contracting the virus [70, 71]. The level of PPE (PPE, N95 or FFP3 mask, goggle, face protective shield, surgical gown, and gloves) for PUI and confirmed COVID-19 cases is set by institutional guidelines (Table 1). Reusable PPE should be collected in a clean container for re-processing. Disposable PPE should be immediately discarded in a dedicated bin after use. All the PPE must be put on before entering the isolated examination suite, and discard (if disposable) immediately after use.

For tertiary (referral) medical institution, it is pragmatic to have one (or a few) dedicated machine(s) for PUI and confirmed COVID-19 patients. Essential obstetric ultrasounds (Table 3) should be performed bedside in COVID-19 designated area with minimal HCPs present. Always wear gloves when handling with transducers previously used in examining COVID-19 patients. The point-of-care ultrasound machine in COVID-19 obstetric ward may be fully draped with plastic cover and transducer cable sleeves to prevent contamination of the internal system. Barrier protection is crucial because HLD of components inside the system is difficult and expensive, or not possible at all. After each use, the transducer should be cleaned and LLD.

If PUI and confirmed COVID-19 pregnant women need to be examined in obstetric ultrasound unit, they should be scheduled at the end of the clinic list so that the equipment

and room will undergo vigorous cleaning and disinfection afterward. A designated isolation room in obstetric ultrasound should be arranged for the scanning. Single-used, non-sterile coupling gel packets may be used for any external ultrasound examination with a PUI or confirmed COVID-19 case. Any unused portion must be discarded. If gel bottle is used, it must not be topped off, refilled, or heated. The exterior of the bottle must be wiped with LLD agents after each use. For any prenatal procedures, only single use, sterile gel packets are to be used.

So far, there has been no recommendation that HLD is mandatory for ultrasound transducers after exposure to confirmed COVID-19 cases. The process of manual HLD is tedious, and requires the use of eye protection and gloves. The transducer has to be thoroughly rinsed with water after immersion in order to remove remnants of toxic disinfectants that pose contact- or inhalant-related health hazard during subsequent examinations. Automatic HLD systems for ultrasound transducer are currently available (Table 2). Automatic HLD system consists of a sealed chamber, where ultrasound transducer is placed and immersed with ultra-fine aerosol of disinfectant mechanically discharged from the system. The HLD disinfectant is neutralized after 7 min of exposure, and the transducer is dried and ready for immediate use [52]. The automatic HLD compact system is intended to be placed immediately next to the ultrasound machine so that the probe does not need to be disconnected from the base unit.

Conclusions

The COVID-19 pandemic is still dynamic and far from over. Obstetric ultrasound examination places HCPs and women at increased risk for cross transmission of SARS-CoV-2. This guidance is based on current, yet limited information. It aims to facilitate appropriate protection of patients and HCPs. The maintenance of infection control measures assists HCPs and health care facilities to provide optimal patient care while being prepared for COVID-19 infected obstetric patients requiring essential ultrasound services. There are variations in availability of PPE and confirmatory testing for SARS-CoV-2 infection in different jurisdictions, but minimum requirements need to be set. Local protocols should be updated accordingly, and shared frequently. It would be prudent to regard every HCP, pregnant woman, and their entourage as a potential source of infection. Despite the imposed limitations related to the necessity of social distancing; provision of optimal care in safe conditions should remain the primary goal of HCPs. Precautions need to extend way beyond after the pandemic of COVID-19. As disinfection technology is

rapidly evolving, it is essential to check with the manufacturers of the ultrasound machine and the disinfectant products, and always refer to the infection control policies and protocols of individual facility.

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