The smart angiography suite

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BACKGROUND
To meet the growing demand for interventional radiology (IR), more hospitals are investing in state-of-the-art angiography suites, but these are expensive investments. Both the initial construction cost and the ongoing operational costs are significant. For health services, it is important to commission an angiography suite that can satisfy both present and future healthcare demands to maximize the value of the initial expenditure and the opportunities provided by this ongoing investment. Smart angiography suites (SAS) could be the solution that future-proof angiography services. Similar to the smart operating theatre, SAS refers to the incorporation of audio-video technology and internet connectivity into the angiography suite.1 SAS has the ability to record high resolution audio-visual data from the angiography suite and stream it to a remote audience at low latency to enable bi-directional communication and collaboration. SAS, alongside other telemedicine concepts, have also gained newfound interest and relevance in light of the global coronavirus pandemic and the travel restrictions associated with this. We reviewed the current literature to provide an overview of the SAS, its potential, and associated legal and ethical considerations.

SAS SOLUTIONS
For hospitals, SAS can be as rudimentary as a webcam or as advanced as a comprehensive commercial solution such as Olympus MedPrescence, Proximie, Tegus Medical, Sony Nucleus or InTouch Health VisitOR. In general, commercial solutions will include audio-video equipment setup, internet streaming and broadcasting setup, and an end-user viewing software. Most commercial solutions are compatible with pre-existing equipment (vendor neutral) (see figure 1 for an example solution). Different solutions also offer varying features of different video layouts, video freezing, telestration with or without augmented reality, integration with picture archiving and communication system, and security. The cost of a commercial SAS solution varies with each company offering a different type of license.

SAS POTENTIALS
The value of an SAS investment can be realized through its education and research potential. Most importantly, SAS can promote an integrated model of care in IR.

EDUCATION
SAS can revolutionize the way IR is learnt and taught, transforming it from a face-to-face model to a video streaming model. Traditionally, to learn a new interventional procedure, radiologists will travel to a selected center to observe an experienced operator perform the procedure (preceptorship) and then emulate it under supervision (proctorship). Alternatively, these experienced operators will travel to other centers to share their knowledge. Invariably, the process is time consuming, costly and, more recently, rendered impractical by pandemic-related travel restrictions and social distancing measures. With SAS, new interventional procedures can be learnt and taught through video streaming. This is particularly advantageous in the field of IR, where experienced operators of subspecialized procedures or novel devices can be few and far between. With video streaming, both the preceptor and the proctor benefit from a more efficient medium of learning and teaching. Besides radiologists, other staff such as nurses and industry representatives can also join the video stream to learn or provide support, without having to be physically present in the angiography suite. A smaller staffing requirement in the angiography suite decreases distraction, reduces radiation exposure and reduces infection risk, which is of paramount importance in our current pandemic. While the educational benefit of video streaming has been affirmed by

Figure 1 An example of a smart angiography suite solution, from Tegus Medical. A high-definition standalone camera allows a remote proctor to zoom into different aspects of the room to facilitate telecollaboration.

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the gradual rise of live case demonstrations at international IR conferences, the pandemic has truly accelerated the use of SAS solution with several successful teleproctoring cases. In many cases ranging from angiographic neurointervention to cardiac intervention, SAS has demonstrated its potential to facilitate novel IR procedures and device deployment, safely and efficiently. Ultimately, the transformed education paradigm will benefit patients as radiologists expand their scope of practice faster to deliver the latest innovation in procedures or devices.

Beyond international collaboration, SAS can facilitate intra-hospital radiology training. SAS enables video capture of uncommon procedures, rare anatomical variations or special device features. Some SAS solutions, such as Proximie, have a built-in library function that archives video for future training and education. Video captured in an SAS can also be an objective tool used by a radiology trainee for self-evaluation or peer assessment. The educational opportunities afforded by SAS also extend to other staff, including radiographers, nurses and medical students.

RESEARCH
The ability of the SAS to record video has the potential to make it an important research tool. Currently, IR research still relies on written procedural notes and fluoroscopic images to record data despite their limited ability to capture the complexity of the procedures, especially when novel devices are involved. With SAS, a video registry offers a more comprehensive data source that industries and radiologists can retrospectively analyze to refine product design, improve procedural technique, optimize workflow processes, detect near misses, and reduce errors. The video registry from the research trial can also be submitted to external regulatory authorities to corroborate patient safety information. Furthermore, subsequent research publication can be enhanced with the inclusion of video supplements. Finally, video registry can continue to play a role in ensuring safety of novel devices through post-market monitoring.

Outside of a research trial, video captured by SAS can also be used for hospital internal audit processes such as quality improvement meetings and mortality and morbidity meetings. A similar black box concept for operating suites has already been tested in several centers to improve surgical safety. For the angiography suite, a video black box has been used to improve radiation safety.

The research potential of SAS videos will increase when combined with technologies such as video motion analysis (VMA). Several studies have used VMA to improve workflow processes, similar to the way professional football teams analyze gameplay videos to improve their future performance. Researchers are also using VMA to study catheter movement on fluoroscopic images for potential applications. Besides VMA, creative video compression algorithms can also be used to select out relevant highlight clips for efficient research analysis or audits. Video processing algorithms will further maximize the research value of SAS video records.

INTEGRATED MODEL OF CARE
SAS can be the nexus of a new synergistic model of care that integrates industrial partners and academic medical centers together to advance the common goal of research and development of novel procedures and devices in order to improve patient care and outcome. By investing in an SAS, academic medical centers can accelerate their training to broaden existing scopes of practice. At the same time, they can participate in higher quality research, potentially with international collaboration using SAS. Medical device industries are incentivized to work with hospitals equipped with SAS to build trials that have rigorous safety standards and generate rich data for regulatory purposes. When a particular device is approved, SAS also expedites uptake and deployment of devices. Proctors working in hospital with SAS can demonstrate the novel devices and technique worldwide while a proctor in a hospital with SAS can be easily telementored during the rollout. Industry and hospitals will both benefit from the enhanced safety monitoring provided by SAS video recording, as new devices or techniques are being introduced. These industrial–academic medical center collaborations will open up new financial opportunities for health services. While remaining centered on patient care and welfare, industrial–academic medical center collaboration may attract appropriate reimbursements that can make an angiography service more financially sustainable—a prerequisite for hospitals to continue delivering angiography services to the population.

LEGAL AND ETHICAL CONSIDERATIONS
The introduction of an SAS will require considerations of several legal and ethical issues (see table 1).

The ethical aspects of SAS, specifically live video streaming, have been widely considered. Medical societies have published guidelines regulating the use of live video streaming. Clinicians should actively manage potential ethical concerns that can arise from live case demonstrations including scheduling issues and minimizing distractions to focus on optimal patient outcome. Several studies, such as...
the VERITAS (Transcatheater Aortic Valve Intervention-Live Transmission) study, have examined the outcomes of live case demonstrations, finding no negative influence, and representing important groundwork for ethical video streaming from SAS."

**FUTURE POTENTIAL**

In the future, the value of SAS is likely to expand alongside advances in robotic technology. SAS will be the foundation for training in medical robots including endovascular robotics implementation, where training curves are steep and where shared experience from multiple centers and procedural experts is likely to accelerate progress and promote safety. Beyond this, SAS connectivity will facilitate tele-robotic applications to remote locations to expand patient accessibility to complex robotic procedures.

**CONCLUSIONS**

SAS presents a strong value proposition with the potential to transform the way we deliver education, research and service in IR. SAS can connect radiologists from across the globe, enabling telementoring and teleproctoring to hasten the dissemination of knowledge and technology uptake. SAS can also archive videos for training and education, quality improvement initiatives or safety monitoring in new medical device research. Valued by both industry and academic medical centers, SAS can become a new avenue of synergistic industrial–academic medical center collaboration that accelerates device innovation, aiming to improve patient outcomes while providing new integrated and globally connected models of patient care. The value of SAS is likely to expand alongside rapidly advancing technology in IR such as endovascular robotics.

**Contributors**

DZL and GM are responsible for manuscript drafting and revision. JM, NK, NH contributed significantly to the study conception including the setup of smart angiography suite at different hospitals, as well as manuscript revision. AJ, DR, HKH, RVC, MB and CB all contributed to critical manuscript revision, including the response to reviewer document. HA is the overall project supervisor, who first conceptualized the paper and critically revised the manuscript before giving his approval for final publication.

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