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SHORT REPORT

Remote proctoring in complex percutaneous coronary intervention aided by mixed reality technology

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Aims Percutaneous coronary intervention (PCI) of chronic total occlusions (CTOs) has a lower success rate and a higher complication rate compared to PCI of non-occluded coronary arteries. Co-operation and supervision by a more experienced operator (proctoring) are associated with improved success of CTO procedures. This study aims to assess the feasibility of remote proctoring using web-based communication and mixed reality technology in CTO procedures.

Methods and results The PCI operator was equipped with a Microsoft HoloLens 2 head-mounted display enabling visual and verbal interaction including holographic annotations with a remote proctor. Ten CTO procedures were performed by a single PCI operator assisted by a remote proctor. Audio and video communication was successfully established in all procedures. All procedures were possible to perform with a Microsoft HoloLens 2 head-mounted display. The PCI operator experienced the remote proctoring as useful.

Conclusion Remote proctoring of CTO procedures using mixed reality technology was feasible. The impact of the method regarding procedural and patient outcomes needs to be assessed in new studies.

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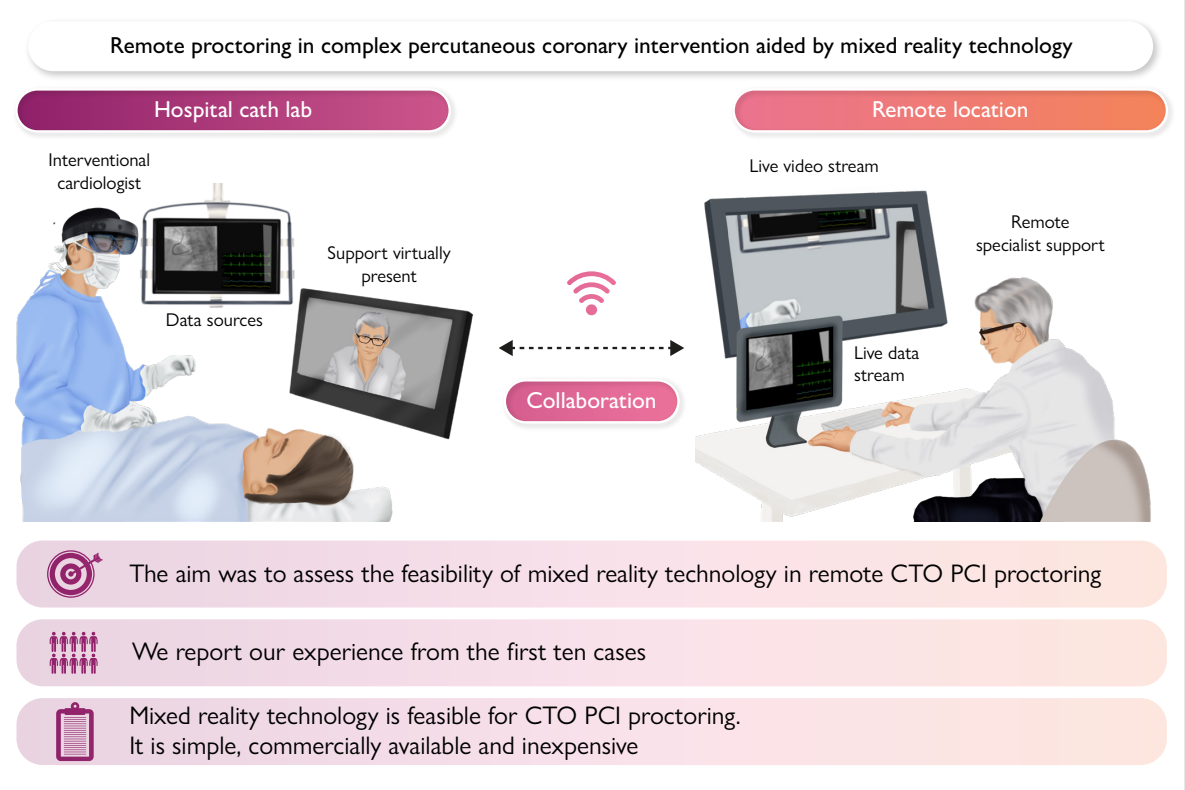
Graphical Abstract



Keywords Coronary intervention • Remote proctoring • HoloLens 2 • Mixed reality

Introduction

Up to 20% of patients with coronary artery disease (CAD) had at least one chronic total occluded (CTO) coronary artery.[1] Percutaneous coronary intervention (PCI) of CTO may be indicated to improve symptoms and achieve complete revascularization of the heart.[2,3] Percutaneous coronary intervention of CTO has a lower success rate and a higher complication rate compared to PCI of non-occluded coronary arteries.[4]Chronic total occluded procedures are time consuming, expensive, and associated with increased risk of complications.[5] Systematic procedure planning in a team of experienced PCI operators is recommended.[2,3] Systematic proctoring by experienced operators has demonstrated improved success rates and increased ability to treat complex coronary lesions.[6]

In traditional proctoring, an experienced CTO operator (proctor) performs the CTO procedure together with a less experienced operator. The feasibility of real-time remote proctoring using mixed reality technology tools has not been reported in interventional cardiology previously.

The aim of this pilot study was to evaluate the feasibility of remote proctoring using web-based communication and mixed reality technology in CTO procedures.

Methods

This prospective pilot study was conducted at Sorlandet Hospital Arendal, Norway, from November 2021 to June 2022. A total of 10 consecutive patients with elective CTO procedures at Sorlandet Hospital Arendal were included in the study after signing informed consent for participation. The proctor was located at Oslo University Hospital, Oslo, Norway, ~260 km from Arendal. Symptoms, medical history, medication, and previous coronary angiograms were assessed by the PCI operator and the proctor prior to the CTO procedure in a digital meeting. Operator's view, flouro-screen, electrocardiogram, other haemodynamic parameters, and verbal communication were transferred in real time between the operator and the proctor during the CTO procedures using Microsoft Teams. The PCI operator wore Microsoft HoloLens 2 during the entire procedure (*Figure 1*). The proctor used a conventional laptop computer connected to an additional screen. Guiding was performed by voice communication and holographic interaction through remote assist software integrated in Microsoft Teams. The proctor could point out specific parts of an angiogram and place holographic annotations in the operator's field of view. Seeing the operator's field of view also enabled the proctor to guide the operator's manipulation of wires and microcatheters, and aid in dealing with drainage of pericardial tamponade in one case. Other healthcare professionals in the catheterization lab were also able to hear the voice communication between the operator and the proctor. All patient identifiable data were removed from the data stream to ensure patient data safety and privacy.

Microsoft HoloLens 2 is a mixed reality head-mounted display, which allows users to interact with their environment using voice, holograms, and virtual screens, creating a fusion between a digital and a physical world. Mixed reality is a new class of experience and allows 3D visualization of imaged data and contact-free interaction with the data in a sterile environment, without obstructing the normal visual field.[7]

Figure 1 The operator is wearing a HoloLens 2, head-mounted display during the whole procedure. HoloLens 2 is connected to an external power source. It is possible to combine HoloLens 2 and lead glass without compromising the comfortability of the operator.

The CTO procedures were performed according to recommended strategies according to the hybrid algorithm, applying both antegrade and retrograde techniques.[4] The study involved no follow-up after the CTO procedure. The study was approved by the Regional Committee for Medical Research Ethics Northern Norway, REK North (242527).

Results

Ten patients (mean age 66 ± 8 years, 80% male) were included in the study (*Table 1*).

The J-CTO (Multicenter CTO Registry of Japan) score has been suggested to estimate complexity and procedural success of the CTO procedures, and mean J-CTO score of the target lesion was 3.6 (range 3–5).[3]

Six CTOs were successfully treated in the primary procedure. In one patient, an investment procedure was performed, and the CTO was successfully treated 6 weeks later without proctoring. Complex pathology in the left main stem was discovered in one patient, and the strategy was changed to bifurcation stenting of this lesion. One patient with a right coronary artery (RCA) CTO also had a significant left anterior descending artery (LAD) stenosis, and we decided to treat the LAD stenosis first and postpone the CTO procedure. The CTO was revascularized 2 weeks later, without proctoring. One procedure was unsuccessful, partly due to extensive calcification.

Perforation of a coronary artery with development of acute cardiac tamponade occurred in one case. This severe complication was treated successfully with pericardial drainage. The remote proctor guided the treatment of the complication. After stabilizing the patient, the procedure was continued, and the CTO was successfully treated, without the use of covered stents.

In all 10 cases, successful voice and visual communication was established between the remote proctor and the PCI operator. The setup with Microsoft HoloLens 2 and remote assist software provided bidirectional audio and video communication in real time in all cases. The video and audio quality was generally acceptable. The connection between the locations was interrupted sometimes, but reconnection was performed in <1 min using holographic tools in HoloLens without compromising the operator's sterility. The PCI operator was not disturbed by the head-mounted device, and he experienced the remote proctoring as useful. The operator experienced little fatigue caused by the HoloLens, and the equipment was worn from start to finish in all procedures.

Table 1 Patient characteristics

Patient characteristic	
Mean age (SD)—years	66 ± 8
Male sex—no (%)	8 (80)
Hypertension—no (%)	8 (80)
Diabetes—no (%)	2 (20)
Previous myocardial infarction—no (%)	1 (10)
Renal failure—no (%)	1 (10)
Previous PCI—no (%)	7 (70)
Previous CABG—no (%)	0 (0)
Angina (CCS)—median (range)	2 (2–3)
Dyspnoea (NYHA class)—median (range)	2 (2–3)

Discussion

This prospective pilot study demonstrated the feasibility of remote proctoring during CTO procedures using web-based communication and mixed reality technology. The importance of proctoring to increase success rate and reduce complications in CTO procedures is well established.[6] The method described may lower the threshold for using a proctor, mitigating cost and time consumption. To our knowledge, this is the first report on a series of remote proctored complex CTO using a mixed reality technology-based communication tool.

One strength of this study was the use of standard production equipment available over the counter at a moderate cost, which does not require fixed installation or technical expertise. Communication was also established through a standard digital meeting platform most professionals are familiar with. Although a remote proctor can never be hands on, the quality of audio and visual guidance in real time was felt by both the operator and the proctor to be of high value.

This study has several limitations. It was a single-centre pilot study with only 10 participants and 2 physicians, who might be positively biased towards the concept of remote proctoring, and there is no control group with a physically present proctor. The operator has previous experience performing CTO-PCI, and proctoring of early cases may be experienced differently. Also, in terms of safety and handling complications, a virtual proctor can never fully replace an experienced proctor on site. We report only the experience from one operator and one proctor, making it difficult to assess the level of expertise need to benefit from virtual proctoring. Larger studies with different operators and proctors would give information on the generalizability of our findings. Neither the hardware nor the software is developed primarily for medical use. Dedicated applications are likely to give more options for the proctor to guide the operator and for the operator to ask specific questions to the proctor, thus improving the quality of assistance. There will also always be a risk of malfunction of technical equipment, which would leave the operator without help from the proctor. Naturally, this concept relies on a stable internet connection, which is not available everywhere.

Conclusion

This study verified the feasibility of remote proctoring through a mixed reality device in CTO procedures. Remote proctoring may be a good supplement in training of new CTO operators. The benefit for patient outcomes should be assessed in new trials.

Lead author biography

Slobodan Calic, MD, is currently working as an interventional cardiologist and head of the Department of Interventional Cardiology at the Sorlandet Hospital, Norway. He has a medical degree from a university in Belgrade (2001) and a university in Oslo (2007). He is an approved specialist in internal medicine and cardiology. Calic is particularly interested in complex PCI, intracoronary imaging, and the introduction of new technologies in interventional cardiology. Since 2019, he has worked actively with the implementation of mixed reality technology in training within complex PCI, especially in CTO procedures.

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Author contributions

S.C.: conception and design, analysis and interpretation of data, drafting, and final approval of the manuscript. J.J.: analysis and interpretation of data, critical revision, and final approval of the manuscript. J.O.A.: conception and design, analysis and interpretation of data, critical revision, and final approval of the manuscript. C.H.E.: conception and design, analysis and interpretation of data, critical revision, and final approval of the manuscript.

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Conflict of interest: S.C., J.O.A., and C.H.E. report no disclosures. J.J. reports lecture fees from Pfizer, BMS, Boehringer Ingelheim, and Sanofi and advisory board fees from Amarin and AstraZeneca.

Data availability

The data underlying this article cannot be shared publicly due to privacy of individuals that participated in the study. The data will be shared on reasonable request to the corresponding author.

Consent

A total of 10 consecutive patients with elective CTO procedures at Sorlandet Hospital Arendal were included in the study after signing informed consent for participation.

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