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Surgical Technique

Clinical Application of an Ergonomic Holographic Device to Optimize Port Placement in Robotic Mitral Valve Surgery: Proof-of-Concept Study

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Abstract

Robotic assistance in mitral valve surgery is being increasingly adopted; however, standardized port placement does not yet account for patient-specific anatomy. Augmented reality (AR) can provide real-time, holographic views of anatomy based on preoperative imaging, yet its application in robotic cardiac surgery is unreported. We tested the clinical use of the HoloLens 2 device to create dynamic hologram overlays on patients during robotic-assisted mitral valve surgery to optimize robotic port placement. Using a three-dimensional (3D) slicer and Unity software, a pipeline generated patient-specific 3D holographic models from preoperative computed tomography scans. An experienced robotic cardiac surgical team tested the prototype in October 2024 at Gavazzeni Hospital (Bergamo, Italy). Feedback highlighted its comfort, confidence enhancement, and user-friendliness. This proof-of-concept study demonstrates the feasibility and user-friendliness of an ergonomic, AR-based holographic device to optimize port placement in robotic mitral valve surgery.

Keywords

robotic mitral valve surgery; DaVinci; HoloLens; port positioning; augmented reality; preoperative planning

Introduction

The application of augmented reality (AR) in surgical environments aims to improve precision, reduce errors, and enhance decision-making [1–3]. The Microsoft HoloLens 2 device—an ergonomic, holographic, AR-based device (Microsoft Co., Redmond, WA, USA)—has shown promise in providing a hands-free, interactive, user-friendly interface for overlaying three-dimensional (3D) models onto real-world structures [4]. This device combines high-resolution imaging, hand gesture recognition, and real-time spatial mapping, making it potentially suitable for the operating room; however, its role in robotic cardiac surgery, specifically in port placement planning, remains unexplored. We developed and validated a protocol (Fig. 1) for the clinical use of the HoloLens 2 device to assist in intraoperative decision-making for port placement in patients undergoing robotic-assisted mitral valve repair. The protocol was approved by the Humanitas Gavazzeni Hospital ethics committee (Approval No. 05/24).

Technique

Preoperative chest computed tomography (CT) scans were obtained and formatted in a Digital Imaging and Communications in Medicine (DICOM) file type, a standard format for digital storage and medical image transmission. Images were then processed by multiple software programs:

(1) *Unity 2021.3.4f1* (Unity Technologies, Copenhagen, Denmark), a versatile game development platform widely used for creating both two-dimensional (2D) and 3D games, as well as interactive experiences across a variety of platforms. This software supports C# as its primary scripting language, which is also widely used and appreciated for its readability and performance [5].

(2) *Visual Studio 2021* (Microsoft Co., Redmond, WA, USA), an Integrated Development Environment by Microsoft often used in conjunction with Unity because it provides a powerful environment for writing, testing, and debugging coding on the same programming language C# [6].

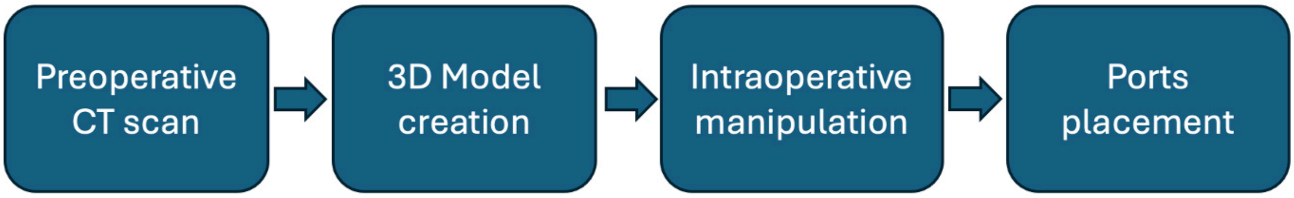

Fig. 1. Workflow. 3D, three-dimensional; CT, computed tomography.

(3) *Mixed Reality Toolkit* (MRTK) (Microsoft Co., Redmond, WA, USA), an open-source software that offers a set of components and features to speed up the development of mixed reality applications in Unity including spatial interactions, gestures, and related controls [7].

(4) *3DSlicer 5.6.1* (BWH, Boston, MA, USA), an open source, cost-free, multi-platform software that can run on multiple operating systems and is known for its ease of use, specific features, performance, regulatory certification for clinical use, or integration with other systems.

Implementation of this protocol yielded a high-definition 3D model of the patient's thorax. To ensure accurate intraoperative placement of the 3D model, three reference points were identified and marked using radio-sensitive markers (e.g., electrocardiogram electrodes): the right midclavicular point, left midclavicular point, and sternal notch (Fig. 2). Once the HoloLens 2 device is worn, the 3D model can be manually resized and positioned over the patient's body, aligning the reference points of the model with the temporary markers placed on the patient. The system offers two virtual controls accessible via a digital menu, operated using the surgeon's dominant hand. The first control, a sphere collider, enables further adjustments to the model's position if needed. The second control fixes the model in place once it is accurately aligned, allowing the surgeon to proceed with identifying the optimal sites for port placement. These controls can be operated through hand gestures or commands. Each port location is represented visually as a shaded cone terminating at its tip. Once the positioning is finalized to the surgeon's satisfaction, the entry sites can be precisely marked on the patient's skin.

Clinical Experience

Minimally invasive surgeries are favored over open heart surgeries due to their reduced risk and improved post-operative recovery. One of the most established approach for mitral valve repair is non-resectional posterior leaflet remodeling [8], which was demonstrated to be effective and promising at follow-up studies [9] despite the well-known long learning curve associated with robotic mitral valve repair [10].

The experience in the minimally invasive and robotic sector of the Gavazzeni Hospital (Bergamo, Italy) has naturally evolved towards augmented reality, so a proof-of-concept study focused on the feasibility, utility, and user friendliness of this AR-guided approach (Figs. 3,4). The prototype was evaluated in October 2024 during robotic-assisted mitral valve repair procedures (to date, the prototype has been evaluated in 4 cases and is currently undergoing further technological advancement).

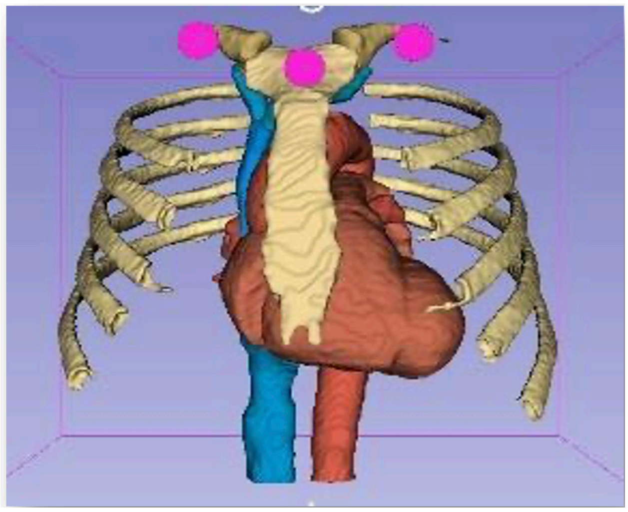

Fig. 2. Three-dimensional model with reference points (pink dots).

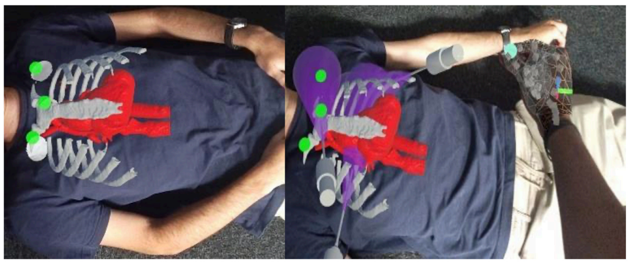

Fig. 3. Three-dimensional model, clinical application. Left, initial model set-up; right, virtual ports placement.

The surgeon tested the device in the presence of clinical engineers, and surgeons highlighted the potential of AR in improving surgical workflows. Specifically, they provided positive feedback regarding the anatomic accuracy and user-friendliness of the 3D models. Surgeons also experienced enhanced comfort and confidence in the process of port placement by using the HoloLens 2 device. The positioning of the ports was done by a single surgeon

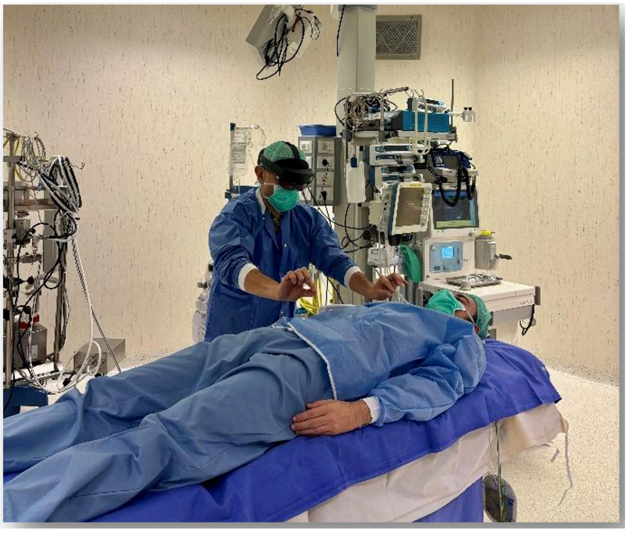

Fig. 4. Intraoperative demonstration.

per operation. The AR system was considered to potentially reduce intraoperative errors and improve decision-making during port placement. Additionally, three areas of improvements were reported: (1) manual alignment, as aligning holographic models with the patient's anatomy remains time-consuming and requires meticulous effort; (2) hardware limitations, as the HoloLens 2, though advanced, has limitations in spatial tracking accuracy and processing power, necessitating future hardware upgrades; and (3) model transparency, as surgeons requested transparent 3D heart models to better visualize the mitral valve plane, a critical factor in port placement. The use of the device allowed the entry of the ports to be tailor-made not only in the decision of choice of the intercostal space but also of the greater or lesser laterality of the thorax with respect to the positioning of the mitral valve, reducing the conflict of the robotic arms.

Conclusions

This study conceptually demonstrates the transformative potential of AR in robotic-assisted cardiac surgery. By improving port placement precision and minimizing intraoperative conflict of arms, AR technology aligns with the goals of technological development in minimally invasive surgery. Although this initial experience was positively reviewed by an experienced robotic cardiac surgery team (who appreciated the anatomic accuracy, user-friendliness, enhanced comfort and confidence provided by the HoloLens 2 device), several enhancements can be considered: (1) automated alignment, by incorporating markers such as Vuforia or ArUco for precise and automated model superimposition to streamline the workflow; (2) artificial intelligence (AI) integration, as leveraging AI for automated segmentation of CT scans would improve efficiency and accuracy in model creation; (3) utilization of advanced hardware, as transitioning to next-generation AR devices with superior tracking and computational capabilities would enhance the precision and usability of the system; and (4) improved visualization, as developing semi-transparent models with highlighted cardiac structures, such as the mitral valve plane, would further assist surgeons in their decision-making process (Fig. 5). This device has made it possible to facilitate the learning curve so that currently there are three surgeons who position the ports and not just one. Further studies are needed to explore the application of this technology to the preoperative planning of other critical steps (e.g., mitral valve repair) and additional procedures (e.g., robotic atrial fibrillation ablation). Future research should also prioritize cost-effectiveness analyses to evaluate the broader implementation of this innovation.

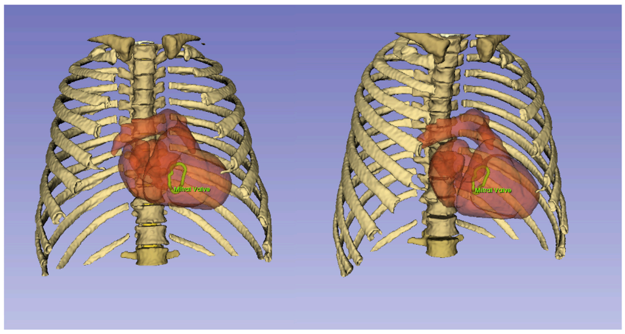

Fig. 5. Future directions: transparent model with mitral valve plane highlighted in green.

Availability of Data and Materials

The anonymized data that support the findings of this study are available upon reasonable request.

Author Contributions

AAgn, EL, GT designed the research study. AAma, VB, MV, GS, LG, AG provided substantial contributions to the conception or design of the work and to the acquisition, analysis, and interpretation of the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki. The protocol was approved by the Humanitas Gavazzeni Hospital ethics committee (No. 05/24). Patient's informed consent was obtained as regulated by the IRB protocol.

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Conflict of Interest

The authors declare no conflict of interest. The authors declare no conflict of interest. Giuseppe Santarpino is serving as editor-in-chief of this journal. We declare that Giuseppe Santarpino had no involvement in the peer review of this article and has no access to information regarding its peer review.

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