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Feasibility study of a mixed reality tool for real 3D visualization and planning of left atrial appendage occlusion

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ABSTRACT

In left atrial appendage occlusion (LAAO), pre-procedural imaging is pivotal to describe the highly variable LAA anatomy and to guide the operator in device sizing and interventional planning.
Multiplanar reconstruction and 3D rendering are used for the interpretation of 3D CT datasets. However, this method of review of such imaging, which is mediated by 2D screens, may be limited due to the lack of true 3D visualization of the structures of interest; Mixed Reality (MxR) may further improve the CT-based pre-procedural planning by allowing for real-3D visualizations with holographic replicas of anatomical models.
In this manuscript we present a novel software based on MxR and we evaluated its feasibility on different LAA morphologies. The morphological analysis of the holographic anatomical models was successfully applied for all the patients (n = 4) independently from the morphology and it was performed in less than 10 minutes.
Our findings suggest that with further developments MxR could have the potential to become a pivotal tool in LAA occlusion planning thanks to the real-3D perception, possibly leading to a more accurate and faster planning phase.

Dear Editor,

In this study we developed a novel software based on Mixed Reality (MxR) to help clinicians in pre-procedural left atrial appendage (LAA) occlusion planning starting from computed tomography (CT) images and we evaluated its feasibility on four patients.

The importance of CT for LAA occlusion planning has been demonstrated in multiple publications.[1,2] Tools such as multiplanar reconstruction or 3D real-time rendering techniques allow for navigating 3D CT acquisitions. However, images viewed on 2D screens may be misleading due to the limited 3D perception. Approaches that exploit Mixed Reality (MxR) could further improve CT-based planning because MxR allows for real 3D visualizations, 3D quantifications and interactions with holographic replica of the anatomy.[3–5]

The workflow we are proposing for planning LAA occlusion through MxR includes two phases:

1) Using a custom computer software an isosurface of the left atrium together with the LAA, the left circumflex artery (LCx) and the left upper pulmonary vein (LUPV) is identified by the user on the CT acquisition and processed using a marching cube algorithm to obtain a patient-specific 3D model (Fig. 1A).
2) The model is then analyzed on our MxR platform following these steps:

   i. Qualitative analysis of the anatomy by moving and zooming its holographic replica through dedicated gestures (Fig. 1B).
   ii. Quantitative morphological analysis: ostium plane and landing zone are identified by moving a holographic plane that interpolates the CT volume and cuts the holographic model. Measurements of the minimum and maximum landing diameters are taken on the identified planes through dedicated gestures (Fig. 1C).
   iii. Simulation of the implant of a virtual replica of a transcatheter occluder, whose size is determined based on the measurement of the landing zone maximum diameter (Fig. 1D).

The four patients analyzed in this study were randomly selected among those clinically referred for a CT scan prior to transcatheter aortic

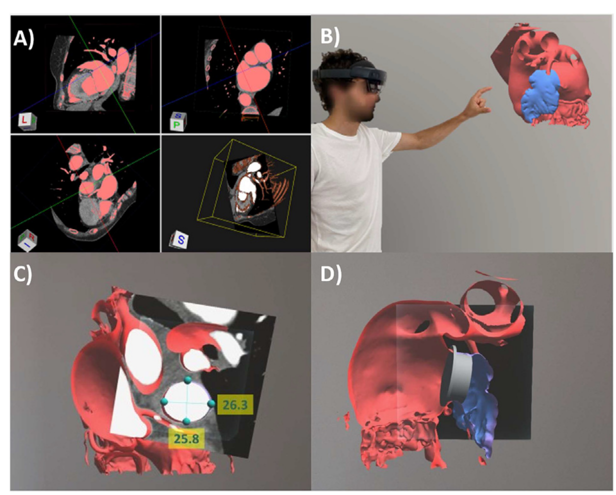

Fig. 1. Workflow for the generation and the analysis of the holographic model: **(A)** 3D model generation: creation of an endocardial isosurface; **(B)** 3D Model Visualization: MxR application with the left heart model displayed; **(C)** Quantitative analysis of the morphology: identification of the maximum and minimum diameter of the landing zone; **(D)** Virtual implantation of the LAA occluder into the holographic model.

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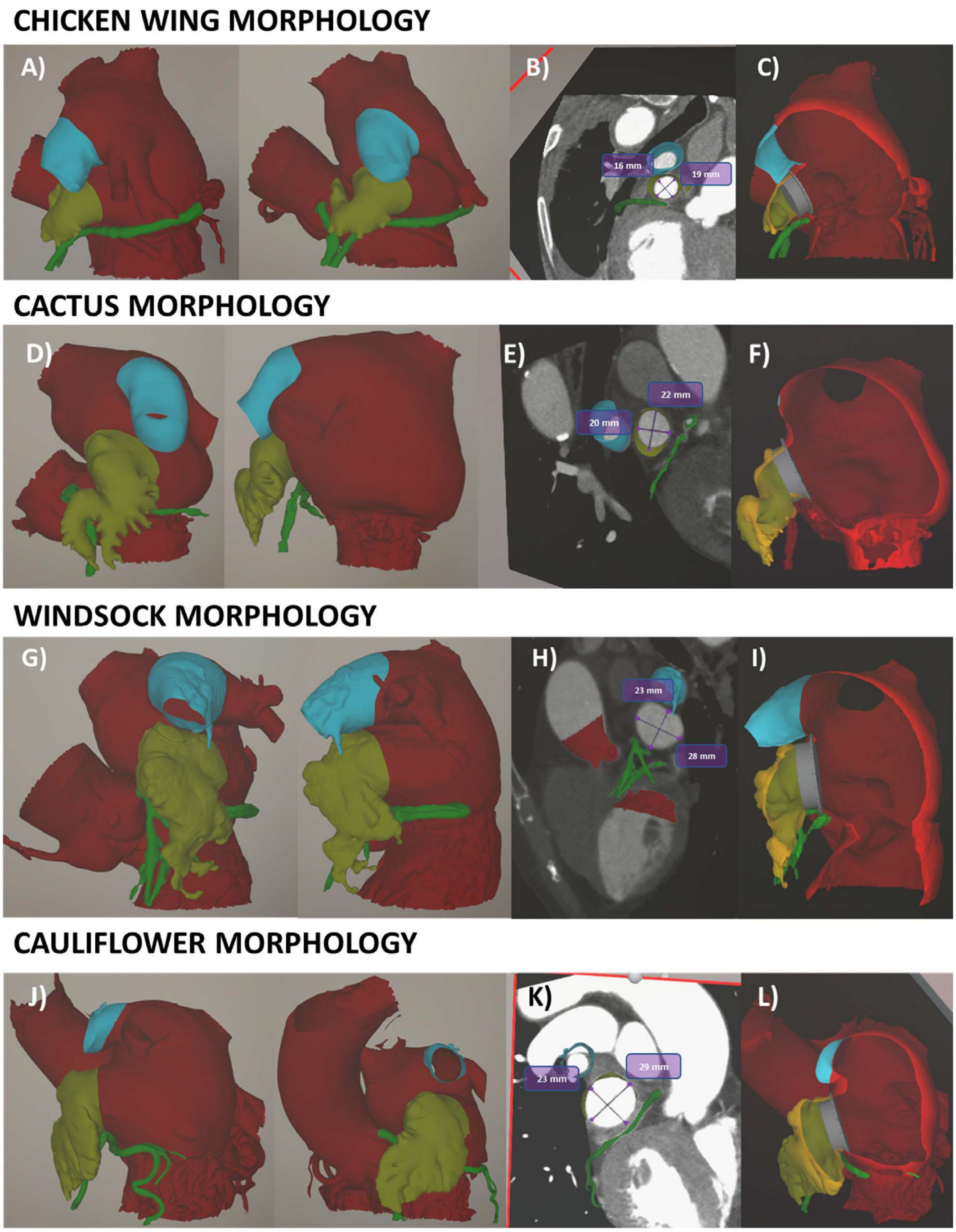

Fig. 2. Application of the MxR technology to four LAA morphologies (chicken wing, cactus, windsock, cauliflower): **(A,D,G,J)** lateral and frontal view of the holographic patient-specific model of the left heart: LAA in yellow, LUPV in light blue, LCx in green, other structures in red; **(B,E,H,K)** measurements of the two diameters of the LAA landing plane as depicted on its short axis view; **(C,F,I,L)** view of the model cropped with a 3D cropping tool to highlight the virtual replica of the LAA occluder placed by the operator. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

valve replacement. Each patient was characterized by a specific LAA morphology according to the classification by Wang et al.: cauliflower, cactus, chicken wing, windsock.[2]

The proposed workflow was successfully applied for all the patients independent of the morphological complexity. All the models were successfully uploaded in the MxR platform (Fig. 2A), and the analysis was performed in less than 10 minutes.

The ostial plane was identified using the LCx and LUPV as references, whereas the landing plane was positioned approximately 10 mm inside the LAA from the ostium plane perpendicularly to the LAA wall.[6] The realistic display in 3D of the anatomic structures provided by MxR and the ability to superimpose the CT images on the holograms were pivotal to achieve an optimal position of the forementioned planes.

The operators easily measured the minimum and maximum diameters of the identified planes using a dedicated measuring tool (Fig. 2B). Finally, they placed the holographic replica of a properly sized LAA occluder inside the LAA hologram (Fig. 2C).

Since clinical cases are handled by multiple specialists (the Heart Team), each with in-depth expertise of advances in their area,[7] the analyses were collaboratively performed by more than one operator (e.g., an interventional cardiologist and an imaging cardiologist). This was achieved through the possibility of our MxR platform to share in

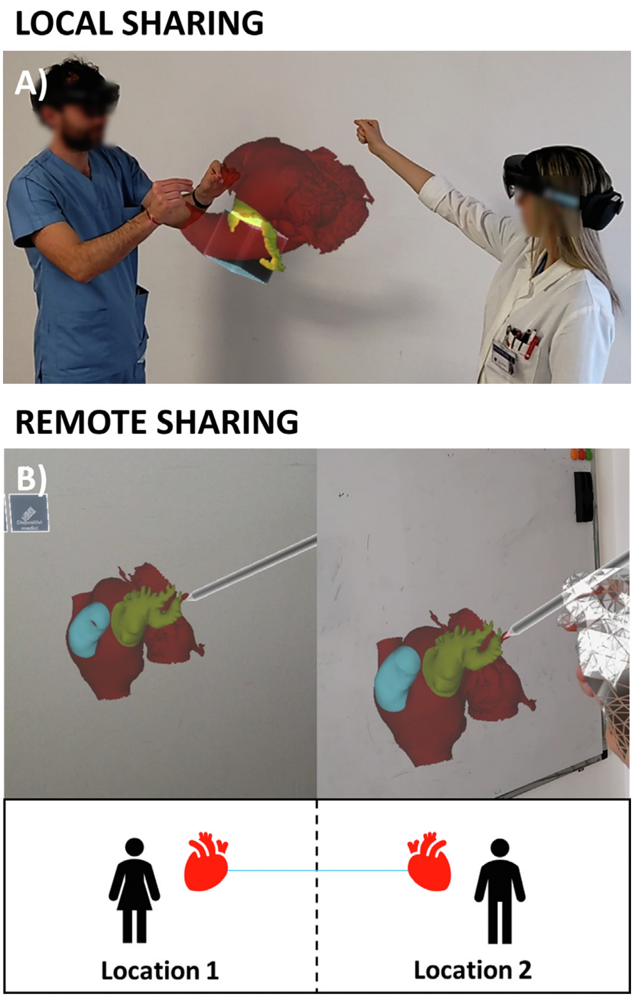

Fig. 3. Sharing of the Holographic model between clinicians. **(A)** Local sharing between clinicians in the same room interacting to perform 3D cropping of a patient-specific holographic model. **(B)** Remote sharing between clinicians located in different places. The 3D pointer (white transparent pencil-stick) controlled by the second operator (right panel) is shared with the clinician in the first location (left panel) preserving the same identical position in the scene relative to the 3D model.

real-time the holographic model and the interactions performed on it between two or more people wearing the MxR device. Our MxR platform proved able to perform the real-time sharing both between clinicians located in the same place (i.e., local sharing; Fig. 3A) and in different places (i.e., remote sharing; Fig. 3B).

Although only a small patient cohort was used, the preliminary results obtained suggest that it is feasible to perform a comprehensive 3D analysis of the LAA with our novel MxR platform. Our software provided an intuitive way to fully appreciate the complex LAA morphology and the spatial relationship with surrounding structures such as the LCx. This suggests that with further developments MxR could have the potential to become a pivotal tool in LAA occlusion planning thanks to the real-3D perception, which could possibly lead to a more accurate and faster planning phase.

Finally, the possibility offered by our MxR platform to share the holographic scene between different clinicians allowed for an effective and engaging collaboration between the Heart Team specialists; moreover, the remote sharing might improve the clinical case discussion between experts from different hospitals.

Declaration of competing interest

Matteo Pasquali is employed at Artiness s.r.l. that has developed the software used in the manuscript.

Omar Pappalardo and Alberto Redaelli are founders of Artiness s.r.l.

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