Chapter 3
A Tool for Collaborative Anatomical Dissection

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Abstract 3D reconstruction from anatomical slices permits anatomists to create three-dimensional depictions of real structures by tracing organs from sequences of cryosections. A wide variety of tools for 3D reconstruction from anatomical slices are becoming available for use in training and study. In this chapter, we present Anatomy Studio, a collaborative Mixed Reality tool for virtual dissection that combines tablets with styli and see-through head-mounted displays to assist anatomists by easing manual tracing and exploring cryosection images. By using mid-air interactions and interactive surfaces, anatomists can easily access any cryosection and edit contours, while following other user's contributions. A user study including experienced anatomists and medical professionals, conducted in real working sessions, demonstrates that Anatomy Studio is appropriate and useful for 3D reconstruction. Results indicate that Anatomy Studio encourages closely coupled collaborations and group discussion, to achieve deeper insights.

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3.1 Introduction

The traditional methods for anatomy education involve lectures, text books, atlases, and cadaveric dissections Preim and Saalfeld (2018). Cadaveric dissection plays an essential role for the training of manual dexterity and communication skills (Brenton et al. 2007; Preim and Saalfeld 2018). Also, according to Shaikh et al. (2015), the practice of cadaveric dissection helps students to grasp the three-dimensional anatomy and concept of innumerable variations.

Cadaveric dissection is considered a tool for studying the structural details of the body and the source of teaching material for anatomical education. However, the cadaveric dissection for teaching and training purposes is surrounded by ethical uncertainties (McLachlan et al. 2004; Shaikh et al. 2015). Also, once dissected, the results become irreversible since the surrounding structures are damaged for underlining the target structure. Furthermore, there is a global shortage of cadavers in medical schools for training students and surgeons. According to Shaikh et al. (2015), because of problems related to the use of cadavers, many curricula in anatomy have introduced a shift toward greater use of alternative modalities of teaching involving cadaveric plastination, non-cadaveric models, and computer-based imaging Kerby et al. (2010). To alleviate these problems, innovative technologies, such as 3D printing, Virtual Reality (VR) and Mixed Reality (MR), are becoming available for use. According to Burdea et al. (1996), VR is a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. Rather than compositing virtual objects and a real scene, VR technology creates a virtual environment presented to our senses in such a way that we experience it as if we were really there. On the other hand, MR refers to the incorporation of virtual objects into a real three-dimensional scene, or alternatively the inclusion of real-world real objects into a virtual environment. VR and MR have been proposed as a technological advance that holds the power to facilitate learning Pan et al. (2006). Also, anatomists and students rely on a wide variety of tools for 3D Reconstruction from Anatomical Slices (3DRAS) from these technologies. These tools suit several purposes: promote novel educational methods (Papa and Vaccarezza 2013; Chung et al. 2016; Zilverschoon et al. 2017), allow statistical analysis of anatomical variability Shepherd et al. (2012), and support clinical practice to optimize decisions Malmberg et al. (2017). It should be noted that 3DRAS tools are a complementary medium to live dissection, not their replacement (Ackerman 1999; Park et al. 2005; Pflesser et al. 2001; Uhl et al. 2006).

3DRAS make possible the virtual dissection resulting in accurate and interactive 3D anatomical models. Due to its digital nature, 3DRAS promote new ways to share anatomical knowledge and, more importantly, produces accurate subject-specific models that can be used to analyze a specific structure, its functionality, and relationships with neighboring structures Uhl et al. (2006).

By default, 3DRAS tools are designed for laborious manual segmentation forcing an expert to trace contours around anatomical structures throughout many sections. Once a set of segmented curves is assembled, it is then possible to reconstruct a

3D organ. Again, we remark that current 3DRAS tools promote single-user slice navigation and manual segmentation. These tasks are often performed using single flat display and mouse-based systems, forcing multiple scrolling and pinpointing mouse clicks. Such limited deployment is the foundation for the work presented in this chapter.

Clearly, this specific application domain presents a situation of limited deployment and underdeveloped usage of mature technologies, namely interactive surfaces and MR that bring high potential benefits. Therefore, we hypothesize that group interaction conveyed through spatial input and interactive surfaces can boost 3DRAS related tasks and attenuate dissection workload. According to Xiang Cao et al. (2008), interactive surfaces allow users to manipulate information by directly touching them, thus enabling natural interaction styles and applications. The ability to interact directly with virtual objects presented on an interactive surface suggests models of interaction based on how we interact with objects in the real world.

In this chapter, we present Anatomy Studio Zorzal et al. (2019), a collaborative MR dissection table approach where one or more anatomists can explore a whole anatomical data set and carry out manual 3D reconstructions. As stated in Mahlasela et al. (2016) and Zamanzadeh et al. (2014), collaboration is essential of work relationships in any profession, as it is through this continuous process that a common vision, common goals, and realities are developed and maintained. Collaboration in the workplace has become a popular research topic since it allows users to get

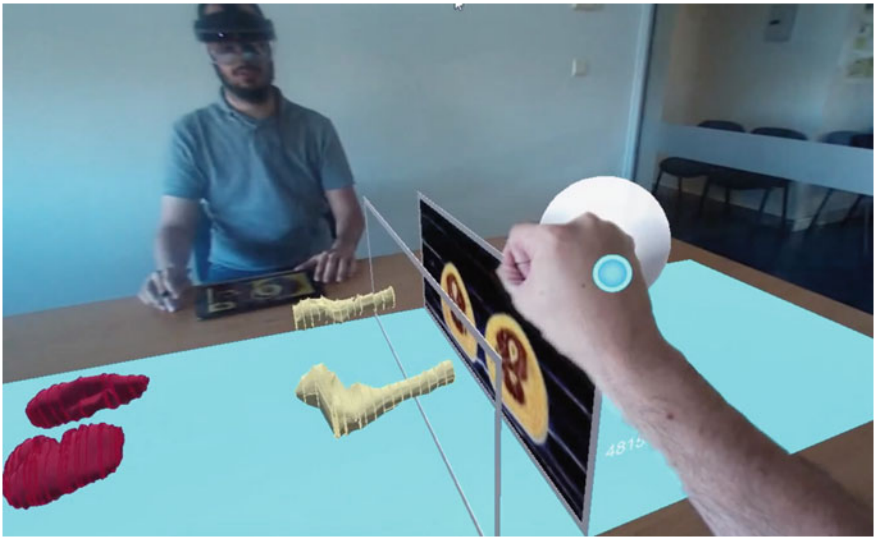

Fig. 3.1 Overview of Anatomy Studio, a collaborative MR dissection table approach where one or more anatomists can explore anatomical data sets and carry out manual 3D reconstructions using tablets and styli

involved in group activities that not only increase learning, but also produce other benefits, such as the development of relationships and social skills Garcia-Sanjuan et al. (2018).

Anatomy Studio mirrors a drafting table, where users are seated and equipped with head-mounted see-through displays, tablets, and styli. Our approach adopts a familiar drawing board metaphor since tablets are used as sketch-based interfaces to trace anatomical structures, while simple hand gestures are employed for 3D navigation on top of a table, as shown in Fig. 3.1. By using hand gestures combined with mobile touchscreens, the anatomists can easily access any cryosection or 2D contour and follow each user's contribution toward the overall 3D reconstructed model.

3.2 Related Work

Since Höhne and Hanson (1992) presented a pioneering work on computer-assisted anatomy education and the advent of the Visible Human Project Ackerman (1999), interactive solutions have been proposed for virtual dissection, yet still the Windows, Icons, Menus and Pointer (WIMP) paradigm prevails ecumenical for image segmentation within the 3DRAS community (Wu et al. 2013; Fang et al. 2017; Asensio Romero et al. 2018; Chung et al. 2018). More effective approaches are sorely needed as conventional WIMP interfaces are known to hamper 3D reconstruction tasks because they rely on mouse-based input and 2D displays (Olsen et al. 2009; Meyer-Spradow et al. 2009). Besides lacking direct spatial input and affording limited navigation control, WIMP approaches for 3DRAS also promote single-user interaction, even though several studies refer to the importance of collaborative drawing (Lyon et al. 2013; Alsaid 2016) such has not been performed for a strictly 3D reconstruction purpose.

Another serious limitation of WIMP is that they prescribe timely slice-by-slice segmentation. For instance, the Korean Visible Human took 8 years to segment using mouse input (Park et al. 2005; Chung et al. 2015). Clearly, there is a need to speedup the segmentation process without discarding manual operability, as anatomists feel more in control to produce meticulous and informed contours manually (Igarashi et al. 2016; Sanandaji et al. 2016). Another restriction consists of the limited 3D perception offered by WIMP interfaces, as this induces a greater cognitive load by forcing anatomists to build a 3D mental image from a set of 2D cryosections.

Other interaction paradigms have been proposed for 3DRAS, namely, Augmented Reality (AR) and Virtual Reality (VR) have been explored for medical visualization, since immersion can improve the effectiveness when studying medical data Laha et al. (2013). For instance, Ni et al. (2011) developed AnatOnMe, a prototype AR projection-based handheld system for enhancing information exchange in the current practice of physical therapy. AnatOnMe combines projection, photo, and video capture along with a pointing device for input, while projection can be done directly on the patient's body. Another related study proposed the introduction of AR above the Tabletop for the analysis of multidimensional data sets, as their approach facilitated collaboration, immersion with the data, and promoted fluid analyses of the data Butscher et al. (2018). Furthermore, a collaborative learning intervention using AR has been proposed for learning clinical anatomy system Barmaki et al. (2019). The system uses the AR magic mirror paradigm to superimpose anatomical visualizations over the user's body in a large display, creating the impression that she sees the relevant anatomic illustrations inside her own body.

Another advantage of AR and VR paradigms is that they promote expeditious navigation of volumetric data along complex medical data sets. To this regard, Hinckley et al. (1994) adopted two-handed interactions on a tangible object to navigate multiple cutting planes on a volumetric medical data set. Coffey et al. (2012) proposed a VR approach for volumetric medical data sets navigation using an interactive multitouch table and a large-scale stereoscopic display. Sousa et al. (2017) introduced a VR visualization tool for diagnostic radiology. The authors employed a touch-sensitive surface to allow radiologists to navigate through volumetric data sets. Lopes et al. (2018) explored the potential of immersion and freedom of movement afforded by VR to perform CT Colonograpy reading, allowing users to freely walk within a work space to analyze 3D colon data.

Furthermore, the combination of immersive technologies and sketch-based interfaces have been proposed for 3DRAS education and training, but not for accurate 3D reconstruction (Lundström et al. 2011; Teistler et al. 2014; Lu et al. 2017; Saalfeld et al. 2016). Immersive solutions usually place anatomical representations within a 3D virtual space Lu et al. (2017), similarly to plaster models used in the anatomical theater, or consider virtual representations of the dissection table (Lundström et al. 2011; Teistler et al. 2014) but often require dedicated and expensive hardware. Only recently have 3D or VR approaches been considered to assist the medical segmentation process (Heckel et al. 2011; Johnson et al. 2016; Jackson and Keefe 2016) but the resulting models continue to be rough representations of subject-specific anatomy. In turn, sketch-based interfaces have been reported to complement or even finish off automatic segmentation issues that rise during anatomical modeling (Olabarriaga and Smeulders 2001; Malmberg et al. 2017). Although tracing can be guided by simple edge-seeking algorithms or adjustable intensity thresholds, these often fail to produce sufficiently accurate results (Shepherd et al. 2012; van Heeswijk et al. 2016).

Given the size and complexity of the data set, coordinating 3D reconstruction with navigation can be difficult as such tasks demand users to maintain 3D context, by choosing different points of view toward the 3D content, while focusing on a subset of data materialized on a 2D medium. To assist the visualization task, head-tracked stereoscopic displays have proven to be useful due to the increased spatial understanding (Coffey et al. 2012; Hwaryoung Seo et al. Hwaryoung Seo et al.; Lopes et al. 2018). However, prior work has been primarily conducted within navigation scenarios and not for 3D reconstruction from medical images; thus, it is not clear if there are benefits of complementing 3D displays with 2D displays Tory et al. (2006).

Despite the many advancements in medical image segmentation, most semi- and automatic algorithms fail to deliver infallible contour tracing. That is why clinical practice in medical departments is still manual slice-by-slice segmentation, as users feel more in control and produce a more informed, meticulous 3D reconstruction (Igarashi et al. 2016; Sanandaji et al. 2016). Note that, segmentation of cryosections is a labeling problem in which a unique label that represents a tissue or organ is assigned to each pixel in an input image.

Tailored solutions for 3D reconstruction that rely on easily accessible, interactive, and ubiquitous hardware, besides guaranteeing qualified peer-reviewing, are welcomed by the Anatomy community. While using HMDs or tablets to interact with 2D and 3D data is not new, combining them for 3DRAS has not been studied. Much research focuses on VR-based navigation for surgical planning and radiodiagnosis. However, our approach addresses 3D reconstruction. Moreover, we specifically worked with anatomists and our interaction was purposely designed to combine a 2D sketch-based interface for expedite segmentation with spatial gestures for augmented visualization.

3.3 Anatomy Studio

Our approach, Anatomy Studio, combines sketching on a tablet with MR based visualization to perform 3D reconstruction of anatomic structures through contour drawing on 2D images of real cross-sections (i.e., cryosections). While the tablet's interactive surface offers a natural sketching experience, the 3D visualization provides an improved perception of the resulting reconstructed content over traditional desktop approaches. It is also possible to interact with Anatomy Studio using mid-air gestures in the MR visualization to browse throughout the slices. The combination of mid-air input with interactive surfaces allows us to exploit the advantages of each interaction paradigm, as most likely their synergistic combination should overcome the limitations of either modality in isolation, a result well-known from multi-modal interface research. Additionally, Anatomy Studio enables two or more experts to collaborate, showing in real time the modifications made to the contours by each other, and easing communication.

The main metaphor used in Anatomy Studio is the dissection table. Using MR, collaborators can visualize 3D reconstructed structures in real size above the table, as depicted in Fig. 3.1. The content becomes visible to all people around the virtual dissection table who are wearing MR glasses. Also, users can select slices from the common MR visualization to be displayed on their tablet device in order to perform tracing tasks.

In order to support tablet and MR glasses for each user and the collaboration between all participants, Anatomy Studio uses the distributed architecture illustrated in Fig. 3.2. Anatomy Studio was developed using Unity 3D (version 2018.3.8f1), C# programming language for scripting and Meta SDK 2.8. Two applications were developed to run on both device types: Windows-based ASUS T100HA tablets and Meta 2 headsets. The whole data set, comprised 12.2 gigabytes in high-resolution images, as well existing contours already traced, are stored in a Web Server, accessible

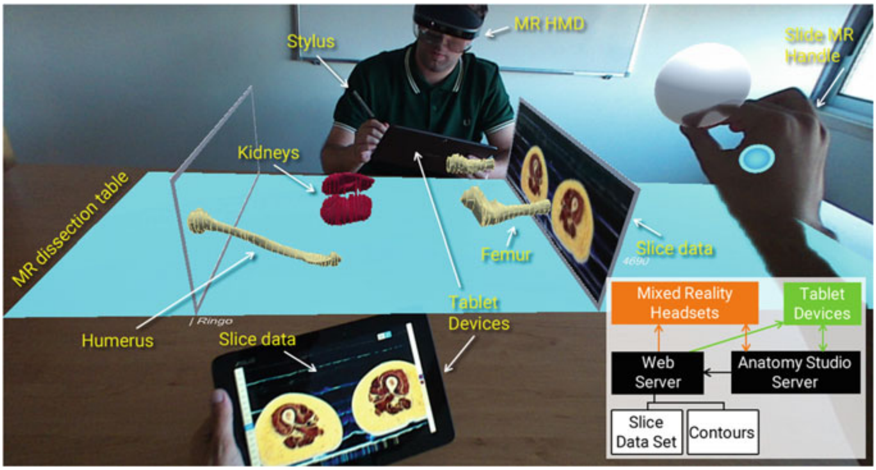

Fig. 3.2 Anatomy Studio's distributed architecture

by all devices in the session. However, to show immediate previews during slice navigation, each device displays thumbnails as slice previews, which consist in low-resolution images. All together, these thumbnails require only 36 megabytes.

Located on the same machine as the Web Server, is the Anatomy Studio server to which all devices connect. While only this server can make changes to the files in the Web Server, such as storing contours, all clients can read from it. The clients, both MR glasses and tablet devices, have an associated user ID so that they can be properly paired between each other. Every time a user changes his active slice or modifies a contour, the client device immediately notifies the server and all other clients through UDP messages.

Existing digitizations of sectioned bodies consist of thousands of slices, each of which with a thickness that can be less than 1mm. As such, Anatomy Studio offers two possible ways to browse the collection of slices: one fast and coarse, useful for going swiftly to a region of the body, and another that allows specific slice selection.

To perform a quick selection of a slice in a region of the body, Anatomy Studio resorts to mid-air gestures. Attached to the frame representing the current slice in the MR visualization, there is a sphere-shaped handle, as depicted in Fig. 3.1, which can be grabbed and dragged to access the desired slice. This allows to switch the current slice for a distant one efficiently. Slices selected by other collaborators are also represented by a similar frame, without the handle, with the corresponding name displayed next to it. To ease collaboration, when dragging the handle and approaching a collaborator's slice, it snaps to the same slice.

The very small thickness of each slice ($\leq$1 mm) together with inherent precision challenges of mid-air object manipulation Mendes et al. (2016) makes it difficult to place the MR handle in a specific position to exactly select a desired slice. Thus, Anatomy Studio also provides a scrollable list of slices in the tablet device (Fig. 3.3)

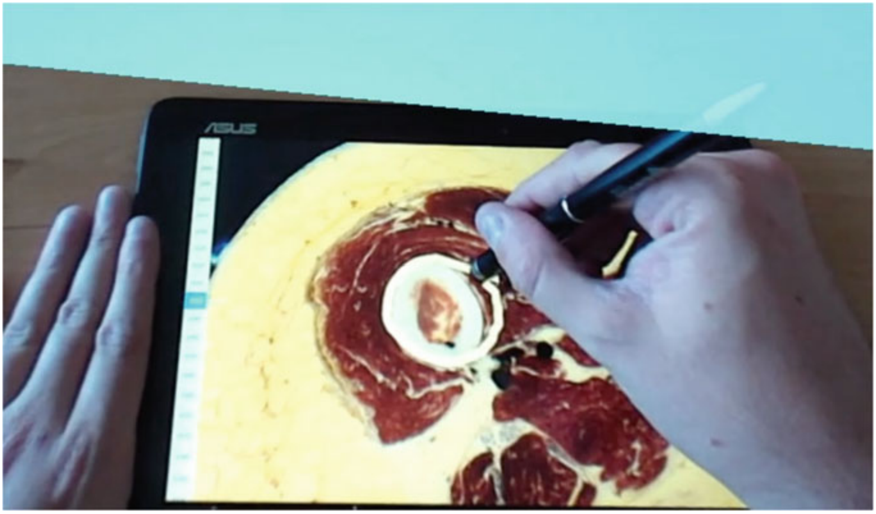

Fig. 3.3 Tracing the contour of a kidney with the stylus on the tablet. On the left pane there is a scrollable list of slices, and the right pane shows the available structures

that only shows a very small subset of 20 slices around the currently selected one. This list is constantly synced with the MR handle and, after defining a region, users are able to unequivocally select a specific slice. Of course, due to the high number of slices, this scroll alone was not feasible to browse the whole data set, and needs to be used in conjunction with our Fast Region Navigation approach. In addition, slices' numbers are accompanied with the name of the collaborators that have them currently selected, which makes them reachable by a single tap. In Anatomy Studio only coarse slice selection is done in mid-air, as more precise slice selection is performed through the tablet device.

To provide a natural experience that fashions sketching on paper with a pen, Anatomy Studio offers anatomists a tablet device and a stylus.

To ease the tracing process, the image can be zoomed in and out, to provide both overall and detailed views, as well as translated and rotated, using the now commonplace Two-Point Rotation and Translation with scale approach Hancock et al. (2006). After each stroke is performed, either to create or erase contours, Anatomy Studio promptly propagates the changes to the MR visualization making them available to all collaborators. It also re-computes the structure's corresponding 3D structure according to the new information, offering a real-time 3D visualization of the structure being reconstructed.

We implemented a custom 3D reconstruction algorithm that uses the strokes created by the users to recreate an estimated three-dimensional mesh of a closed 3D model. Each time a user changes the drawing made on a certain slice, a localized reconstruction process is initiated that comprises 3 steps: (1) Contouring can be performed by inputting smaller strokes; (2) The algorithm then iterates through the line to find the extreme points, which will help iterate through the line during reconstruction; and (3) A mesh is finally created by connecting two closed lines from neighboring slices.

Therefore, each individual triangle is created so the normal vectors are coherently oriented to the outside of the final 3D model. By applying this simple process to each pair of neighboring lines, we can create a complete closed 3D model in real time, so alterations can be immediately reflected on the 3D augmented space.

3.4 Evaluation

Our main goal was to assess whether collaborative tools such as Anatomy Studio can provide viable alternatives to current methods, and whether these would be well received by the medical community, focusing on qualitative valuations rather than basic performance metrics.

To assess whether Anatomy Studio can be used as a mean to enable collaboration and aid in the process of anatomical 3D reconstruction, we conducted a user study with experienced anatomists and medical professionals. To this end, we resorted to a data set that consists of serial cryosection images of the whole female body from the Visible Korean Project Seok Park et al. (2015).

For testing our prototype we used two Meta2 optical see-through head-mounted displays to view the augmented content above the table. We used this device mainly because of its augmented 90 degree field of view, which facilitates the visualization and interaction with the augmented body being reconstructed. We used the Meta2 headsets to perform the interaction in the environment, as they possess an embedded depth camera similar to the Microsoft Kinect or the Leap Motion that, besides tracking the headset position and orientation, also track users' hands and fingers, detecting their position, orientation, and pose. Each of the MR glasses was linked to a PC with dedicated graphics card. We also used one Windows-based ASUS T100HA tablet with a 10 inch touch screen and an Adonit Jot Pro stylus for each participant. An additional Microsoft Kinect DK2 was used recording video and audio of the test session for further evaluation.

Participants were grouped in pairs, seating at a table, facing each other as shown in Fig. 3.4. Each was equipped with an optical see-through head-mounted display, a tablet, and a stylus. Firstly, researchers outlined the goals of the session and provided an introduction to the prototype. Prior to start, participants were asked to fill a demographic questionnaire, regarding their profile information and previous experience with the tested technologies (MR glasses, virtual dissection applications, and multi-touch devices), as well as an informed consent. A calibration process was performed to enable each headset to locate the virtual objects in real space.

Then, both participants were instructed to perform a training task, individually, where they were free to interrupt and ask questions whenever they deemed necessary. This was followed by the test task, in which participants where asked to collaborate to achieve the final result. Both tasks were based on reconstructing different anatomical

Fig. 3.4 A pair of participants during a user evaluation session

structures using sketches. To prevent excessively long sessions, both the solo training task and the collaborative test task were limited to 15 min. Participants were then asked to fulfill a questionnaire about their user experience. Finally, we conducted a semi-structured interview in order to gather participants opinions, suggestions and to clarify the answers obtained from the questionnaires.

We conducted usability testing and evaluated our prototype with ten participants (one female), eight of which were medical professionals and two were medical students, recruited during an international congress on Digital Anatomy using a convenience sampling strategy. Participants' ages varied between 23 and 69 years old ($\overline{x}$ = 43.6, s = 19.5). Having this particular sample size also ensured that we met recommended minimum criteria for usability evaluation of the intervention. According to Faulkner (2003), in a group of ten people, 82–94,6% of usability problems will be found. Participants who have evaluated our prototype are domain experts, have worked for a long time and have many years of experience. Because of this expertise, the expert is a trusted source of valuable information about the topic and the domain (Costabile t al. 2003; Caine 2016; Sousa et al. 2017; Akram Hassan et al. 2019).

Among the professionals, four were radiologists (with an average of five years of experience), one neurologists, one surgeon, one dental surgeon, and one internist with 27 years of experience.

The majority (80%) were familiarized with touch screen devices, but 70% reported having no prior experience with optical see-through MR technology. Five participants stated to perform virtual dissections, four of them on a daily basis.

3.5 Results and Discussion

We reviewed the usability testing videos and observed that users behaved in three ways when they were focusing on the MR environment. Figure 3.5 shows the total time used in each session and the general percentage of interaction modes identified. We assign a tablet time for tablet interaction mode when a user focuses on device usage. MR interaction mode when a user focuses or explores in the MR environment. As well, when a user interacts with the MR environment using his hands. Finally, a collaboration time for collaboration when a user interacts with other participants through conversation.

Also, we assessed user preferences and experience through a questionnaire with a list of statements for participants to score on a 6-point Likert Scale (6 indicates full agreement). Our evaluation with medical experts suggests that MR combined with tablets can be a viable approach to overcome existing 3DRAS issues. This chapter presents the summarized evaluation results, more details are available in Zorzal et al. (2019).

Regarding the overall prototype, the participants found it easy to use and, in particular, considered the combination of MR and tablet sliders to function well together. They also considered that the tablet's dimensions were appropriate for the tasks performed, and that contouring using a stylus was an expedite operation. Participants that perform virtual dissections professionally found it easier to segment slices using Anatomy Studio when compared to the mouse-based interface they are acquainted to. All participants remarked that Anatomy Studio is a viable alternative to conventional virtual dissection systems. Using AR, we are able to show that a virtual surface on top of each body's reconstructed structures are rendered volumetrically in full size, as depicted in Fig. 3.6, visible for all collaborators around it, provided that they are properly equipped with AR glasses. Also, users can choose slices in the AR visualization, in order for them to be shown on the tablet device and to be sketched

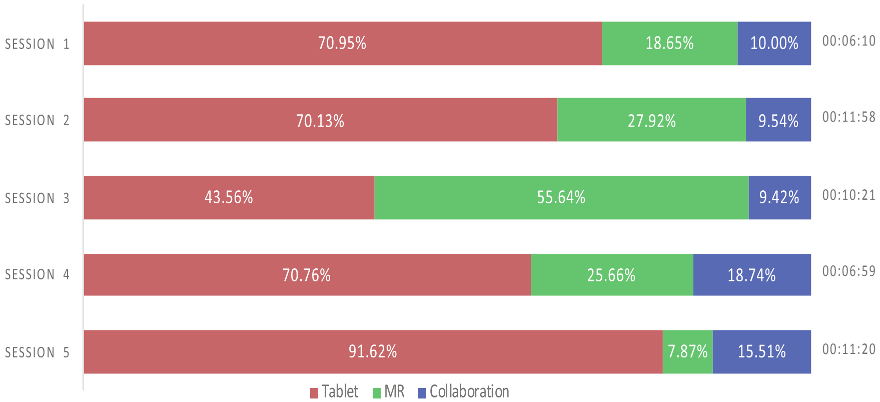

Fig. 3.5 Total time used in each session and the general percentage of interaction modes

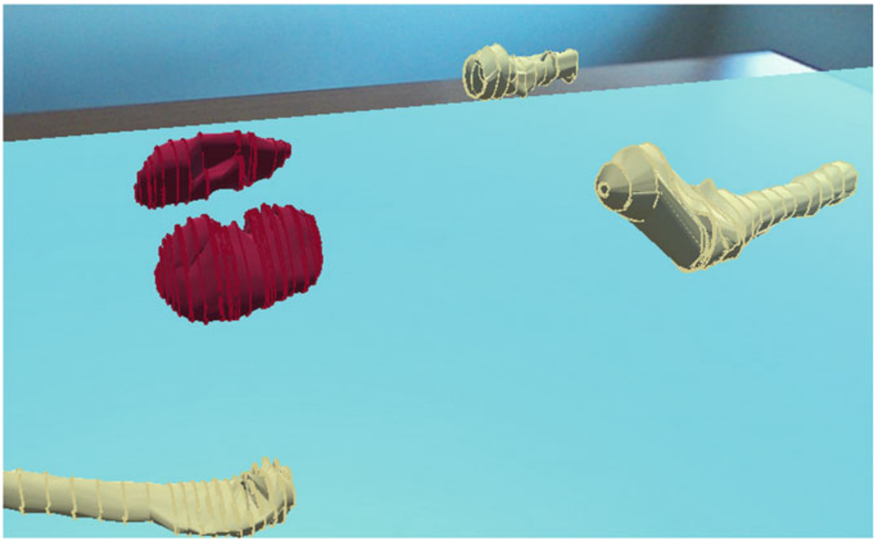

Fig. 3.6 Detail of the AR volumetric rendering above the table, showing lines and the corresponding reconstructed volumes of two kidneys (in burgundy) and three bones (in beige)

upon. They also noted that the visual representations of the 3D model and the slices above the virtual table are appropriate for anatomical study. The participants agreed that the 3D model overview allowed them to rapidly identify and reach anatomical locations. Furthermore, the augmented 3D space created a shared understanding of the dissection tasks and promoted closely coupled collaboration and face-to-face interactions.

We also gathered observational notes taken during evaluation sessions and transcripts of recorded semi-structured interviews, in order to obtain participants' opinions, suggestions, and to clarify the answers from the questionnaires. Participants stated that Anatomy Studio is adequate to "distinguish the several structures" and "understand the spatial relation between [them]". Therefore, "[with tools like Anatomy Studio] we do not need a corpse to learn anatomy". Notwithstanding, "virtual is different from cadaveric material, because we do not have the feeling of cutting tissue". Lastly, the collaborative capabilities of Anatomy Studio were praised, since "working in groups is more effective because, as medics, the experience counts a lot to do a better job, and there should be a mixture of experiences during these sections".

Overall, participants work daily alone and rarely collaborate. Participants said that collaboration offered an equal opportunity to share ideas. Assisted in understanding and respecting diversity better, make team-focused decisions leading the team to a swift achievement of a common goal. The most observed benefit of collaboration was of the less time spent to complete a task.

Also, the participants mentioned some challenges. Two participants said that the stylus contour was very thick and made it difficult for the task. Another mentioned that they had to adapt to the orientation of the drawing presented on the tablet, because the orientation in the computed tomography image is so that the anterior is on top, posterior is bottom, left of the patient is on the right side of the image and the right is on the left side of the image. One participant reported that initially, Anatomy Studio seemed complex because it has many gadgets. Another suggestion mentioned by two participants is the need for prior training to get accustomed to the environment of MR. Another participant mentioned with although the virtual does provide a good interaction, the experience is not identical to that of the real body. In a real body we can feel the difference through touch and cutting the tissues.

The advantage of using technological tools for teaching anatomy is that, in addition to the static figure, one can also understand and demonstrate the dynamics of movement. However, there are challenges to be explored. These challenges limit the actual use of these applications in the routine of health professionals and the transfer of this technology to the productive sector; on the other hand, these challenges create opportunities for research and development.

A significant challenge in the area is to make applications that offer realistic simulations of anatomical features. It is interesting to develop techniques that improve user perception, tactile sensitivity and spatial correlation between physical and virtual objects. Furthermore, Periya and Moro (2019) expressive finger-gestures may assist in identifying comparisons between scans, or unique anatomical variations and features when compared to using a mouse-and-keyboard approach. Also, introducing new teaching approaches in traditional culture is a current challenge for the applications that work in the area of health education.

3.6 Lessons Learned

The lessons learned serve as a valuable tool for use by other researchers and developers who are assigned related projects. These lessons may be used as part of new project planning in order to present what main guidelines for the development of tool for collaborative anatomy. The following lists the lessons learned for the Anatomy Studio.

- **Combined approaches**: Mobile devices such as tablets bring the potential of MR into every learning and collaborative environment Birt et al. (2018). The self-directed approach allowed by MR can enhance experiential learning, engagement, while tackling challenging content in both medical practice and health sciences. In addition, previous research Iannessi et al. (2018) reported that MR allows for better visualization of 3D volumes regarding the perception of depth, distances, and relations between different structures. Accordingly, we chose to follow these approaches, because when comparing MR through an HMD with a virtual window through a tablet, the first is more practical and natural, provides stereoscopic visualization, and can be easily combined with a tablet for 2D tasks, where these devices excel.

- **Transmission and display improvements**: Although medical applications require high-resolution images with realistic features, good practice in collaborative applications is to display instant thumbnails during slice navigation. Also, to avoid network congestion and even decrease throughput, shared virtual environments should change only when there is a change considered significant. We consider the UDP protocol a suitable choice for real-time data streams since no connection is created and only direct data is sent.
- **Slice browsing**: Due to the thickness of the slices and the precision challenges inherent in handling objects in the air, we consider two possible ways to browse the collection of slices: fast region navigation, useful forgoing swiftly to a region of the body, and another precise slice selection that allows specific slice selection.
- **Real-time 3D visualization**: After each stroke is performed, either to create or erase contours, Anatomy Studio promptly propagates the changes to the MR visualization making them available to all collaborators. It also re-computes the structure's corresponding 3D structure according to the new information, offering a real-time 3D visualization of the structure being reconstructed.
- **Interaction and collaboration**: Users behaved in three ways when they were focusing on the MR environment: (i) MR preview when the user raised his head and looked at the environment, (ii) MR exploration when the user analyzed the environment moving the head or body to different directions and kept a fixed eye on the environment of MR content, and (iii) MR interaction when the user interacted with the environment using his hands. Also, participants did use collaborative conversation to complete the task. This ability is an outcome-driven conversation aimed at building on each other's ideas and a solution to a shared problem.

3.7 Conclusions

In this chapter, we presented a collaborative MR dissection table where one or more anatomists can explore large data sets and perform expedite manual segmentation.

Collaborative MR systems are either visualization-based or systems in which users can create and modify a 3D model collaboratively in a 3D space. Our results show that collaborative virtual dissection is feasible supporting two tablets, and has the potential to scale to more simultaneous collaborators, whereby users that can choose the slice to trace on simultaneously, thus contributing to mitigating the reconstruction workload. Moreover, our approach provides for a portable and cost-effective 3DRAS tool to build anatomically accurate 3D reconstructions even for institutions that do not have the possibility to perform actual dissections on real cadavers. Our results illustrate the perceived potential of the approach, and its potential to motivate novel developments. Furthermore, all test sessions involved real drawing tasks, in a realistic setting, where participants were asked to build a 3D reconstruction of an anatomical structure as best as they (anatomists) could.

While the work presented in this chapter represents a first step toward MR for virtual dissection, as future work, we intend to conduct a comprehensive user evaluation with non-experienced students, to compare the learning curve and the ease of use of an iterated version of Anatomy Studio against the most common approaches to 3DRAS.

According to de Souza Cardoso et al. (2020), a crucial aspect to consider is that the selected visualization device should be ergonomic and should not limit or increase the necessary movement required to execute the main activity. Although fatigue, stress tests and cognitive load are important variables to understand the limitations of the proposed system, they were not considered in this chapter, as the focus of our work was to explore the potential of Anatomy Studio as an MR system to perform virtual dissection through sketches by enabling collaboration between multiple users. We intend to study such variables in the near future. While the work presented is exploratory, we see it as the precursor to a new generation of collaborative tools for anatomical applications.

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