A TEMPLATE FOR ARXIV STYLE *

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ABSTRACT

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1 Introduction

Planning for complex surgical procedures presents numerous challenges and difficulties, primarily due to the intricate and variable nature of human anatomy. The success of such interventions heavily relies on the surgeon's ability to anticipate and navigate these complexities, underscoring the importance of integration of advanced imaging and planning tools that can provide a detailed and accurate representation of the patient-specific anatomy [1]. Virtual reality (VR) offers a promising solution to the challenges inherent in complex surgery planning [2, 3, 4, 5]. By providing immersive, three-dimensional (3D) visualizations of patient-specific anatomy, VR enables surgeons to interact with and manipulate anatomical models in a immersive nature. This interactive capability allows for a more thorough visuospatial conversion from two-dimensional (2D) images, optimizing strategic planning. Supported by advancements in computing power and hardware [6], applications of VR in preoperative planning have demonstrated clinical benefits for both patients and physicians, including changes in preoperative planning [7, 8, 9, 10, 11, 12], improvements in surgical decision-making [13], and reductions in operative times [14, 15] across multiple surgical subspecialties [16, 4]. Integration with communication technologies can further enhance the convenience and accessibility of preoperative planning. The flexibility provided by enabling real-time interaction between multidisciplinary teams ensures that critical insights and decisions can be made without the need for all team members to be physically present in the same location [17, 18]. The combination of virtual reality with network communication can facilitate mutual understanding and collaboration among surgical team members, which is crucial for both patient outcomes and physician efficiency [19, 20]. In this work, we develop a VR surgical planning system, ColabSurgVR. This system allows multiple users to examine the patient organ model reconstructed from computed tomography (CT) dataset and collaborate on forming a preoperative plan in real time. Also we describe a protocol to process patient-specific image datas into 3D models for immersive interaction in virtual environment. To test the use case and performance, we have conducted a pilot user study involving 10 physicians to examine real world patient data present the preliminary qualitative result.
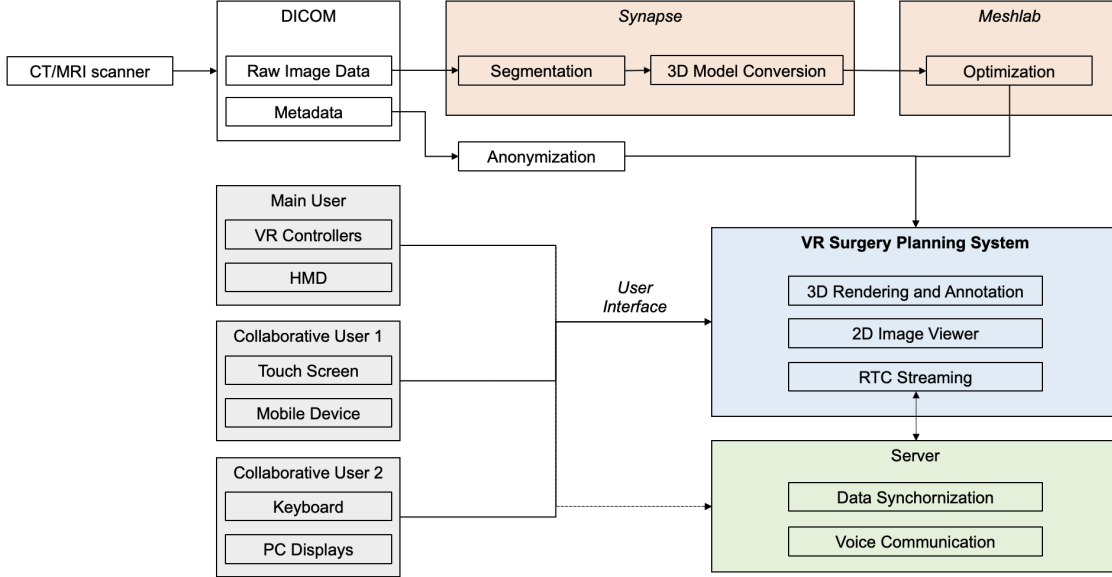

Figure 1: System architecture of ColabSurgVR.

2 System Design and Implementation

Our proposed pipeline takes the imaging data from CT and generates a 3D model for viewing in virtual reality. It involves processing steps to segment the content of the images and reconstrct the anatomy for the patient. The resultant 3D models will be further modified and then imported into our VR surgical planning system supporting immersive visulization and intuitive interaction. The user can assess the system either by extended reality or conventional devices. See Figure 1 for schematic representation of our workflow and system architecture.

2.1 Medical Image Acquisition

Volumetric data acquired from computer tomography (CT) scanners was output in the Digital Imaging and Communication (DICOM) format. The slice thickness was set to 1 mm for acquisition protocol, and all images were reconstructed into 3 mm slices for subsequent interpretation and analysis.

2.2 Segmentation and Virtual Reality Object Generation

The DICOM images were anonymized and then imported into a commercially available medical imaging workstation, Synapse 3D (Fujifilm, Tokyo, Japan), for 3D visualization, segmentation, and 3D model generation. Skin, bones, vascular structures, bronchi, bronchopulmonary segments, and tumors (if present) were segmented from the CT datasets semiautomatically using built-in extraction functions in Synapse 3D Viewer and Lung Analysis Resection applications. Additional segmentation of small branches and border modification were performed manually by assigning or deleting pixels in the image dataset to the corresponding desired anatomic structures. Isolation of submodels (e.g., isolating a rib from the bone models) was also conducted by manually dividing the segmented data. During manual refinement, the CT image data with adjustable window settings and a 3D volumetric rendering of the segmented region were both available to the operator for optimal evaluation and stereoscopic visualization. After segmentation, texture mapping was applied to define surface texture and color information of the segmented data. The resulting data were then exported into a standard tessellation language (STL) file format.

2.3 Model Optimization

To optimize the mesh representation of the 3D models, an open-source 3D mesh processing software, MeshLab (version 2023.12), was utilized [21]. The STL files were imported into MeshLab and first underwent a series of cleaning operations, including the removal of duplicated vertices, unreferenced vertices, and zero-area faces to enhance the mesh integrity. Then, quadric edge collapse decimation targeting a 50% reduction in face count was applied to reduce the polygon count while preserving essential geometric features [22]. Laplacian smoothing was applied to ensure balanced

surface smoothness. Normals were recomputed to correct any lighting and shading inconsistencies using weighted normal calculation. Finally, isolated mesh components were removed, with the minimum component size set to 10% of the overall model diameter. The optimized meshes were then exported in OBJ format for integration into our VR surgery planning system.

2.4 VR Environment Development

For the presentation and interaction with the 3D models, we developed our software using the Unity 3D engine (Unity Technologies, San Francisco, CA, version 2020.3) and integrated it with the Meta XR All-in-One SDK (version 60). We employed the Universal Rendering Pipeline (URP) from Unity, which facilitated optimized graphics performance across various platforms, including mobile devices, PCs, and head-mounted displays (HMDs) utilized in our study. The software was deployed on an Omen 16 laptop (HP Inc., Palo Alto, California) featuring an Intel® Core™ i7-12700H CPU at 2.30 GHz, 16 GB of RAM, and an NVIDIA® GeForce™ RTX 3070 graphics card. For an immersive virtual reality experience, we used the Meta Quest Pro and Meta Quest 3 HMDs (Meta, Menlo Park, California), along with their corresponding controllers. The Meta Quest Pro offers a resolution of 1800 x 1920 pixels per eye, a refresh rate of 72/90 Hz, and a field of view of 106 degrees. The Meta Quest 3 enhances these specifications with a resolution of 2064 x 2208 pixels per eye, a refresh rate of up to 120 Hz, and a field of view of 110 degrees. These devices provided stereoscopic visualization and interaction, dynamically adjusting the medical image data according to the user's movements and positional changes. During software operation, the HMD was connected to the computer via the built-in link functionality of the Meta Quest models.

2.5 User Interaction and Interfaces

As handheld controllers provide a more intuitive approach for interaction within a 3D virtual reality setting compared to conventional 2D controls, we implemented several interaction functions using the Meta Quest Touch Pro Controllers and Meta Quest 3 Touch Plus Controllers. Additionally, we developed an intuitive Graphical User Interface (GUI) to serve as a menu for segmented regions of the 3D models, anonymized patient profiles, and quick access to certain functions (Figure 2). The core interactions implemented in our system included:

- Continuous translation in all six degrees of freedom (6DoF)
- Continuous rotation in all three degrees of rotational freedom (3DoF)
- Selective visibility and transparency of individual segmented regions of the model
- Measurements of omnidirectional linear distance on the volume by placing start and end points
- Marking and drawing on the volume freely

A concurrent 2D slice image viewer was developed for comparison and correlation between 3D models and conventional medical images, including CT and MRI. A virtual cutting plane on the 3D models represented the corresponding level of the slice (Figure 3) and translated accordingly when the user scrolled through the images.

2.6 Synchronous Sharing

To enable real-time collaboration, education, and general communication, we develop a streaming feature that allows users without HMDs to join the preoperative planning system using conventional input devices and built-in browsers. Leveraging web real-time communication (WebRTC), we establish an extended reality (XR) cloud streaming service and a server. When the main user interacts with the system, updates are sent to the server, which then multicasts these updates to other clients [23]. Additionally, audio from the main user can be broadcasted to remote audiences.

3 Methods

We design a pilot study with 10 participants, including 3 attending surgeons and 7 residents. The purpose of the study is to perform an initial validation of the system and the recorded data rather than to characterize the performance of the participants. Written informed consent is obtained from all patients included for VR collaborative surgical planning with the system described above. After an introduction and familiarization session with the system, all participating physicians evaluate the patient-specific models as the main user, with no time limitations. Each participant also joins an additional session using smartphones to participate online. This study is approved by Research Ethics Committee of our institutional review board under 202305019RINC (approval date 2023/10/23). Informed consent is obtained from all participants, including physicians and patients.
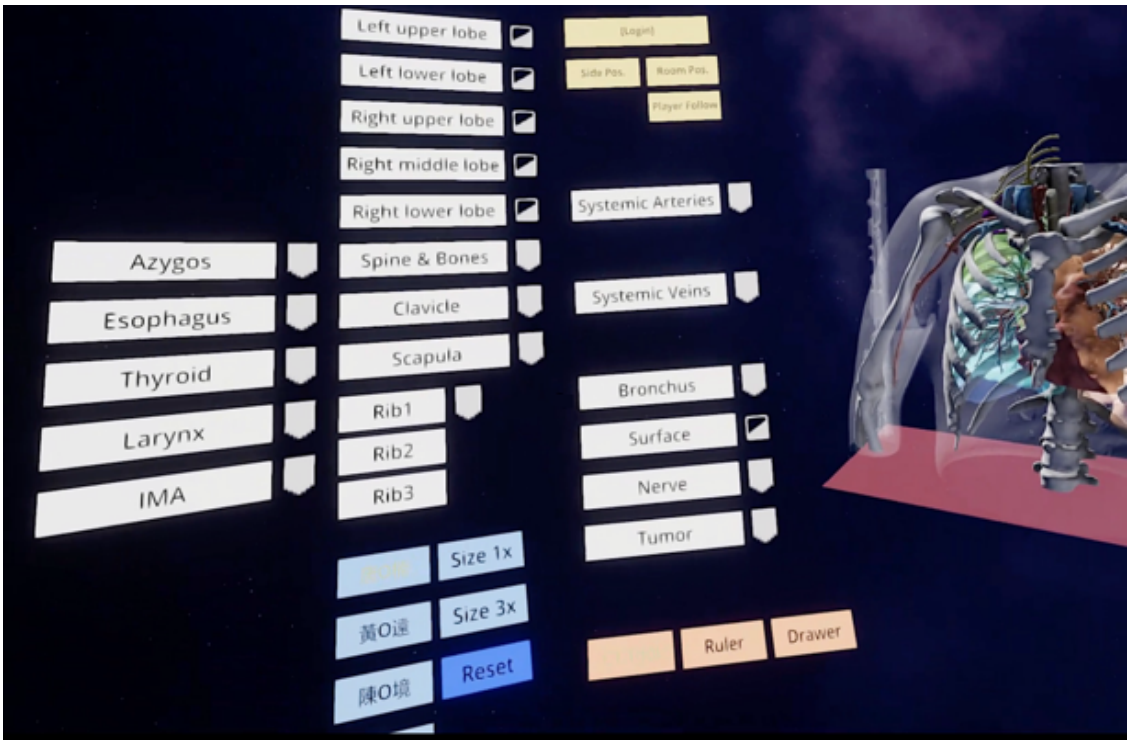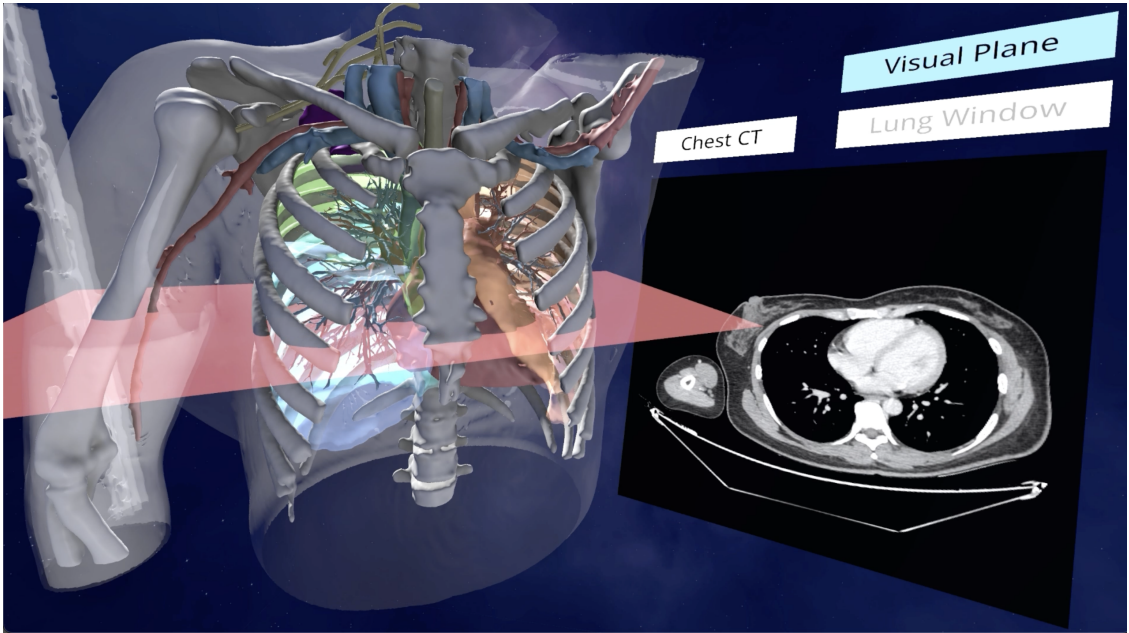
Figure 2: Graphical User Interface.

Figure 3: Virtual cutting plane of 3D model and corresponding CT slice.

4 Results

The presented pipeline requires approximately an hour from importing raw data to presentation of 3D models in the VR system. This time estimate comes from running the program on the aforementioned computing resources and device. The segmentation and visual fidelity of the end product was verified in both conventional 2D displays and HMDs, which are rated functionally accurate by all partcipants. The results for one patient are shown in Figure 2, 3 and video in Supplementary data.

5 Discussion

Surgical interventions for complex pathologies are highly intricate, requiring precise planning to optimize outcomes while preserving critical structures. These challenges necessitate advanced preoperative planning solutions that enable detailed visualization and interaction with patient-specific anatomy. Our virtual reality collaborative preoperative planning system addresses these needs by providing a workflow for reconstructing patient-specific 3D anatomic models from 2D image data. This VR system facilitates collaborative interaction and annotation of these virtual models in an immersive environment.

The quality of the input data directly affects the fidelity of the 3D reconstructions in the virtual environment [24, 25]. To avoid loss of detail in the 3D models, acquisition and processing parameters of CT/MRI data need to be calibrated and standardized. Slice thickness of CT has been shown to be one of the primary factors affecting 3D model resolution and quality, with multiple studies proposing a maximum threshold of 1.25 mm [24, 26]. Consequently, we adopted a similar setting for input quality selection in our study.

The segmentation process is one of the most time- and resource-critical steps in generating anatomically accurate models. Manual segmentation by trained physicians or technicians has been extensively adopted in previous studies, achieving acceptable accuracy [7, 27, 28]. However, the workload of manual tracing limits its efficiency, cost-effectiveness, and reproducibility. Semi-automatic or automatic segmentation aims to replace manual labor with computational processes. Methodologies including thresholding, neural networks, and other machine learning algorithms have been reported for segmenting normal tissues [29] or pathologies [30, 31, 32] across different regions. Semi-automatic segmentation alleviates the manual workload by efficiently producing segments of different organs while preserving the flexibility of manual editing for rare anatomical variations or complex pathologies. As demonstrated in our study, integrating semi-automatic segmentation into the generation of 3D-VR models has proven feasible and clinically useful for preoperative planning [10, 33]. A fully automatic process to segment multiple structures within a region of interest could potentially further improve efficiency and facilitate streamlining the process into an executable pipeline [34, 35, 36]. However, there is still limited evidence on the feasibility of incorporating such a strategy into clinical planning [37].

Mesh optimization is essential in virtual reality (VR) to ensure smooth and immersive user experiences [38]. Optimization techniques like polygon reduction and smoothing are crucial for managing the high computational demands of VR applications [38, 39]. Several open-source computer-aided design software packages are available and validated for generating and editing 3D medical models [40, 13]. In our study, we adopted MeshLab, which provides a wide range of advanced tools and functionalities and is supported by some of the largest online communities at present times [41].

Implementing multi-user collaboration in a virtual environment provides an innovative way for communication in medical settings. The benefits extend beyond preoperative planning into surgical simulation, personnel training, and education purposes [42, 17, 43]. To maximize the advantages of collaborative features while addressing the cost of current HMDs, our system allows users to join via conventional devices with network connection and browsers. This approach not only ensures convenience and accessibility but also offers a comparable user experience for those using non-HMD devices, facilitating spectating and interaction without compromising the overall quality [44].

6 Conclusion and Future Work

We present the system architecture and technical setup of ColabSurgVR, a virtual reality collaborative system for preoperative planning. Our workflow involves creating detailed, patient-specific anatomical models from 2D image data and presenting them in an immersive, three-dimensional visualization platform. This interactive environment enhances the accuracy of surgical planning and enables real-time collaboration among multidisciplinary teams. Initial validation through a prospective pilot study with clinical participants demonstrated the system's accuracy and potential clinical benefits. Future research will focus on enhancing the capabilities and usability of our VR system. One area of focus is optimizing computational processes to achieve rapid turnaround times suitable for emergent surgeries. Additionally, expanding and validating the VR system's application in clinical practice through comparative trials with

more participants and patients will help assess its clinical impact on both surgeon-specific and patient outcomes. The proposed system could also be beneficial for a wide range of clinical applications beyond surgical planning, including physician training, student teaching, case collection, and patient communication.

Acknowledgments

References

[1] M. Yiasemidou, D. Glassman, D. Jayne, and D. Miskovic. Is patient-specific pre-operative preparation feasible in a clinical environment? a systematic review and meta-analysis. *Comput Assist Surg (Abingdon)*, 23(1):57–68, 2018. 2469-9322 Yiasemidou, Marina Glassman, Daniel Jayne, David Miskovic, Danilo Journal Article Meta-Analysis Research Support, Non-U.S. Gov't Systematic Review England 2018/12/01 Comput Assist Surg (Abingdon). 2018 Dec;23(1):57-68. doi: 10.1080/24699322.2018.1495266.

[2] A. Arjomandi Rad, R. Vardanyan, S. G. Thavarajasingam, A. Zubarevich, J. Van den Eynde, Mpbo Sá, K. Zhigalov, P. Sardiari Nia, A. Ruhparwar, and A. Weymann. Extended, virtual and augmented reality in thoracic surgery: a systematic review. *Interact Cardiovasc Thorac Surg*, 34(2):201–211, 2022. 1569-9285 Arjomandi Rad, Arian Orcid: 0000-0002-4931-4049 Vardanyan, Robert Orcid: 0000-0002-8111-2084 Thavarajasingam, Santhosh G Zubarevich, Alina Orcid: 0000-0002-2444-5747 Van den Eynde, Jef Orcid: 0000-0002-5606-376x Sá, Michel Pompeu B O Zhigalov, Konstantin Orcid: 0000-0002-6440-3736 Sardiari Nia, Peyman Ruhparwar, Arjang Orcid: 0000-0003-2725-9912 Weymann, Alexander Orcid: 0000-0003-2966-6159 Journal Article Systematic Review England 2021/09/21 Interact Cardiovasc Thorac Surg. 2022 Jan 18;34(2):201-211. doi: 10.1093/icvts/ivab241.

[3] R. Q. Mao, L. Lan, J. Kay, R. Lohre, O. R. Ayeni, D. P. Goel, and D. Sa. Immersive virtual reality for surgical training: A systematic review. *J Surg Res*, 268:40–58, 2021. 1095-8673 Mao, Randi Q Lan, Lucy Kay, Jeffrey Lohre, Ryan Ayeni, Olufemi R Goel, Danny P Sa, Darren de Journal Article Review Systematic Review United States 2021/07/21 J Surg Res. 2021 Dec;268:40-58. doi: 10.1016/j.jss.2021.06.045. Epub 2021 Jul 17.

[4] M. Queisner and K. Eisenträger. Surgical planning in virtual reality: a systematic review. *J Med Imaging (Bellingham)*, 11(6):062603, 2024. 2329-4310 Queisner, Moritz Orcid: 0000-0001-7917-9231 Eisenträger, Karl Orcid: 0000-0001-8090-9246 Journal Article Review United States 2024/04/29 J Med Imaging (Bellingham). 2024 Nov;11(6):062603. doi: 10.1117/1.JMI.11.6.062603. Epub 2024 Apr 25.

[5] A. H. Sadeghi, S. E. Mathari, D. Abjigitova, Apwm Maat, Yjhj Taverne, Ajjc Bogers, and E. A. F. Mahtab. Current and future applications of virtual, augmented, and mixed reality in cardiothoracic surgery. *Ann Thorac Surg*, 113(2):681–691, 2022. 1552-6259 Sadeghi, Amir H Mathari, Sulayman El Abjigitova, Djamila Maat, Alexander P W M Taverne, Yannick J H J Bogers, Ad J J C Mahtab, Edris A F Journal Article Review Netherlands 2020/12/22 Ann Thorac Surg. 2022 Feb;113(2):681-691. doi: 10.1016/j.athoracsur.2020.11.030. Epub 2020 Dec 19.

[6] R. Rahman, M. E. Wood, L. Qian, C. L. Price, A. A. Johnson, and G. M. Osgood. Head-mounted display use in surgery: A systematic review. *Surg Innov*, 27(1):88–100, 2020. 1553-3514 Rahman, Rafa Wood, Matthew E Qian, Long Price, Carrie L Johnson, Alex A Osgood, Greg M Orcid: 0000-0001-6271-4971 Journal Article Systematic Review United States 2019/09/14 Surg Innov. 2020 Feb;27(1):88-100. doi: 10.1177/1553350619871787. Epub 2019 Sep 12.

[7] D. Abjigitova, A. H. Sadeghi, J. J. Peek, J. A. Bekkers, Ajjc Bogers, and E. A. F. Mahtab. Virtual reality in the preoperative planning of adult aortic surgery: A feasibility study. *J Cardiovasc Dev Dis*, 9(2), 2022. 2308-3425 Abjigitova, Djamila Sadeghi, Amir H Peek, Jette J Orcid: 0000-0002-8412-2851 Bekkers, Jos A Bogers, Ad J J C Mahtab, Edris A F Orcid: 0000-0003-2647-5509 Journal Article Switzerland 2022/02/25 J Cardiovasc Dev Dis. 2022 Jan 18;9(2):31. doi: 10.3390/jcdd9020031.

[8] W. Bakhuis, A. H. Sadeghi, I. Moes, Apwm Maat, S. Siregar, Ajjc Bogers, and E. A. F. Mahtab. Essential surgical plan modifications after virtual reality planning in 50 consecutive segmentectomies. *Ann Thorac Surg*, 115(5):1247–1255, 2023. 1552-6259 Bakhuis, Wouter Sadeghi, Amir H Moes, Iris Maat, Alexander P W M Siregar, Sabrina Bogers, Ad J J C Mahtab, Edris A F Journal Article Netherlands 2022/09/10 Ann Thorac Surg. 2023 May;115(5):1247-1255. doi: 10.1016/j.athoracsur.2022.08.037. Epub 2022 Sep 6.

[9] A. H. Sadeghi, W. Bakhuis, F. Van Schaagen, F. B. S. Oei, J. A. Bekkers, Apwm Maat, E. A. F. Mahtab, Ajjc Bogers, and Yjhj Taverne. Immersive 3d virtual reality imaging in planning minimally invasive and complex adult cardiac surgery. *Eur Heart J Digit Health*, 1(1):62–70, 2020. 2634-3916 Sadeghi, Amir H Orcid: 0000-0002-6118-2341 Bakhuis, Wouter Van Schaagen, Frank Oei, Frans B S Bekkers, Jos A Maat, Alexander P W M

Mahtab, Edris A F Bogers, Ad J J C Taverne, Yannick J H J Journal Article England 2020/11/23 Eur Heart J Digit Health. 2020 Nov 23;1(1):62-70. doi: 10.1093/ehjdh/ztaa011. eCollection 2020 Nov.

[10] A. H. Sadeghi, Apwm Maat, Yjhj Taverne, R. Cornelissen, A. C. Dingemans, Ajjc Bogers, and E. A. F. Mahtab. Virtual reality and artificial intelligence for 3-dimensional planning of lung segmentectomies. *JTCVS Tech*, 7:309–321, 2021. 2666-2507 Sadeghi, Amir H Maat, Alexander P W M Taverne, Yannick J H J Cornelissen, Robin Dingemans, Anne-Marie C Bogers, Ad J J C Mahtab, Edris A F Journal Article United States 2021/07/29 JTCVS Tech. 2021 Mar 16;7:309-321. doi: 10.1016/j.xjtc.2021.03.016. eCollection 2021 Jun.

[11] M. Thumerel, Y. Belaroussi, E. Prisciandaro, A. Chermat, S. Zarrouki, B. Chevalier, A. Rodriguez, R. Hustache-Castaing, and J. Jougon. Immersive three-dimensional computed tomography to plan chest wall resection for lung cancer. *Ann Thorac Surg*, 114(6):2379–2382, 2022. 1552-6259 Thumerel, Matthieu Belaroussi, Yaniss Prisciandaro, Elena Chermat, Anaelle Zarrouki, Sarah Chevalier, Benjamin Rodriguez, Arnaud Hustache-Castaing, Romain Jougon, Jacques Journal Article Netherlands 2022/08/14 Ann Thorac Surg. 2022 Dec;114(6):2379-2382. doi: 10.1016/j.athoracsur.2022.06.059. Epub 2022 Aug 10.

[12] S. Zawy Alsofy, I. Sakellaropoulou, and R. Stroop. Evaluation of surgical approaches for tumor resection in the deep infratentorial region and impact of virtual reality technique for the surgical planning and strategy. *J Craniofac Surg*, 31(7):1865–1869, 2020. 1536-3732 Zawy Alsofy, Samer Sakellaropoulou, Ioanna Stroop, Ralf Evaluation Study Journal Article United States 2020/05/21 J Craniofac Surg. 2020 Oct;31(7):1865-1869. doi: 10.1097/SCS.0000000000006525.

[13] A. A. Preukschas, P. A. Wise, L. Bettscheider, M. Pfeiffer, M. Wagner, M. Huber, M. Golriz, L. Fischer, A. Mehrabi, F. Rössler, S. Speidel, T. Hackert, B. P. Müller-Stich, F. Nickel, and H. G. Kenngott. Comparing a virtual reality head-mounted display to on-screen three-dimensional visualization and two-dimensional computed tomography data for training in decision making in hepatic surgery: a randomized controlled study. *Surg Endosc*, 38(5):2483–2496, 2024. 1432-2218 Preukschas, Anas Amin Wise, Philipp Anthony Bettscheider, Lisa Pfeiffer, Micha Wagner, Martin Huber, Matthias Golriz, Mohammad Fischer, Lars Mehrabi, Arianeb Rössler, Fabian Speidel, Stefanie Hackert, Thilo Müller-Stich, Beat Peter Nickel, Felix Kenngott, Hannes Götz SFB 125/Deutsche Forschungsgemeinschaft/ Comparative Study Journal Article Randomized Controlled Trial Germany 2024/03/08 Surg Endosc. 2024 May;38(5):2483-2496. doi: 10.1007/s00464-023-10615-8. Epub 2024 Mar 8.

[14] J. D. Shirk, D. D. Thiel, E. M. Wallen, J. M. Linehan, W. M. White, K. K. Badani, and J. R. Porter. Effect of 3-dimensional virtual reality models for surgical planning of robotic-assisted partial nephrectomy on surgical outcomes: A randomized clinical trial. *JAMA Netw Open*, 2(9):e1911598, 2019. 2574-3805 Shirk, Joseph D Thiel, David D Wallen, Eric M Linehan, Jennifer M White, Wesley M Badani, Ketan K Porter, James R Journal Article Randomized Controlled Trial Research Support, Non-U.S. Gov't United States 2019/09/19 JAMA Netw Open. 2019 Sep 4;2(9):e1911598. doi: 10.1001/jamanetworkopen.2019.11598.

[15] T. C. Steineke and D. Barbery. Microsurgical clipping of middle cerebral artery aneurysms: preoperative planning using virtual reality to reduce procedure time. *Neurosurg Focus*, 51(2):E12, 2021. 1092-0684 Steineke, Thomas C Barbery, Daniela Journal Article United States 2021/08/02 Neurosurg Focus. 2021 Aug;51(2):E12. doi: 10.3171/2021.5.FOCUS21238.

[16] L. Lan, R. Q. Mao, R. Y. Qiu, J. Kay, and D. de Sa. Immersive virtual reality for patient-specific preoperative planning: A systematic review. *Surg Innov*, 30(1):109–122, 2023. 1553-3514 Lan, Lucy Orcid: 0000-0003-4474-6018 Mao, Randi Q Qiu, Reva Y Kay, Jeffrey de Sa, Darren Journal Article Systematic Review United States 2022/12/01 Surg Innov. 2023 Feb;30(1):109-122. doi: 10.1177/15533506221143235. Epub 2022 Nov 30.

[17] V. Chheang, P. Saalfeld, T. Huber, F. Huettl, W. Kneist, B. Preim, and C. Hansen. Collaborative virtual reality for laparoscopic liver surgery training. In *2019 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*, pages 1–17.

[18] Vuthea Chheang, Patrick Saalfeld, Fabian Joeres, Christian Boedecker, Tobias Huber, Florentine Huettl, Hauke Lang, Bernhard Preim, and Christian Hansen. A collaborative virtual reality environment for liver surgery planning. *Computers and Graphics*, 99:234–246, 2021.

[19] Yael Einav, Daniel Gopher, Itzik Kara, Orna Ben-Yosef, Margaret Lawn, Neri Laufer, Meir Liebergall, and Yoel Donchin. Preoperative briefing in the operating room: Shared cognition, teamwork, and patient safety. *Chest*, 137(2):443–449, 2010.

[20] L. Morley and A. Cashell. Collaboration in health care. *J Med Imaging Radiat Sci*, 48(2):207–216, 2017. 1876-7982 Morley, Lyndon Cashell, Angela Journal Article United States 2017/06/01 J Med Imaging Radiat Sci. 2017 Jun;48(2):207-216. doi: 10.1016/j.jmir.2017.02.071. Epub 2017 May 31.

[21] Paolo Cignoni, Marco Callieri, Massimiliano Corsini, Matteo Dellepiane, Fabio Ganovelli, and Guido Ranzuglia. *MeshLab: an Open-Source Mesh Processing Tool*, volume 1. 2008.

[22] Michael Garland and Paul S. Heckbert. Surface simplification using quadric error metrics, 1997.

[23] Kenji Leibnitz, Tobias Hoßfeld, Naoki Wakamiya, and Masayuki Murata. Peer-to-peer vs. client/server: Reliability and efficiency of a content distribution service. In Lorne Mason, Tadeusz Drwiega, and James Yan, editors, *Managing Traffic Performance in Converged Networks*, pages 1161–1172. Springer Berlin Heidelberg.

[24] Jonathan M. Ford and Summer J. Decker. Computed tomography slice thickness and its effects on three-dimensional reconstruction of anatomical structures. *Journal of Forensic Radiology and Imaging*, 4:43–46, 2016.

[25] G. Sampogna, R. Pugliese, M. Elli, A. Vanzulli, and A. Forgione. Routine clinical application of virtual reality in abdominal surgery. *Minim Invasive Ther Allied Technol*, 26(3):135–143, 2017. 1365-2931 Sampogna, Gianluca Pugliese, Raffaele Elli, Marco Vanzulli, Angelo Forgione, Antonello Journal Article England 2017/01/14 Minim Invasive Ther Allied Technol. 2017 Jun;26(3):135-143. doi: 10.1080/13645706.2016.1275016. Epub 2017 Jan 13.

[26] B. J. Whyms, H. K. Vorperian, L. R. Gentry, E. M. Schimek, E. T. Bersu, and M. K. Chung. The effect of computed tomographic scanner parameters and 3-dimensional volume rendering techniques on the accuracy of linear, angular, and volumetric measurements of the mandible. *Oral Surg Oral Med Oral Pathol Oral Radiol*, 115(5):682–91, 2013. 2212-4411 Whyms, Brian J Vorperian, Houri K Gentry, Lindell R Schimek, Eugene M Bersu, Edward T Chung, Moo K P30 HD003352/HD/NICHD NIH HHS/United States R01 DC006282/DC/NIDCD NIH HHS/United States P30 HD03352/HD/NICHD NIH HHS/United States R01 DC6282/DC/NIDCD NIH HHS/United States Comparative Study Journal Article Research Support, N.I.H., Extramural United States 2013/04/23 Oral Surg Oral Med Oral Pathol Oral Radiol. 2013 May;115(5):682-91. doi: 10.1016/j.oooo.2013.02.008.

[27] J. Le Moal, C. Peillon, J. N. Dacher, and J. M. Baste. Three-dimensional computed tomography reconstruction for operative planning in robotic segmentectomy: a pilot study. *J Thorac Dis*, 10(1):196–201, 2018. 2077-6624 Le Moal, Julien Peillon, Christophe Dacher, Jean-Nicolas Baste, Jean-Marc Journal Article China 2018/03/31 J Thorac Dis. 2018 Jan;10(1):196-201. doi: 10.21037/jtd.2017.11.144.

[28] R. G. Louis, G. K. Steinberg, C. Duma, G. Britz, V. Mehta, J. Pace, W. Selman, and W. C. Jean. Early experience with virtual and synchronized augmented reality platform for preoperative planning and intraoperative navigation: A case series. *Oper Neurosurg (Hagerstown)*, 21(4):189–196, 2021. 2332-4260 Louis, Robert G Steinberg, Gary K Duma, Christopher Britz, Gavin Mehta, Vivek Pace, Jonathan Selman, Warren Jean, Walter C Orcid: 0000-0001-6774-2066 Journal Article United States 2021/06/26 Oper Neurosurg (Hagerstown). 2021 Sep 15;21(4):189-196. doi: 10.1093/ons/opab188.

[29] L. Lenchik, L. Heacock, A. A. Weaver, R. D. Boutin, T. S. Cook, J. Itri, C. G. Filippi, R. P. Gullapalli, J. Lee, M. Zagurovskaya, T. Retson, K. Godwin, J. Nicholson, and P. A. Narayana. Automated segmentation of tissues using ct and mri: A systematic review. *Acad Radiol*, 26(12):1695–1706, 2019. 1878-4046 Lenchik, Leon Heacock, Laura Weaver, Ashley A Boutin, Robert D Cook, Tessa S Itri, Jason Filippi, Christopher G Gullapalli, Rao P Lee, James Zagurovskaya, Marianna Retson, Tara Godwin, Kendra Nicholson, Joey Narayana, Ponnada A K25 AG058804/AG/NIA NIH HHS/United States P30 AG021332/AG/NIA NIH HHS/United States Journal Article Research Support, N.I.H., Extramural Systematic Review United States 2019/08/14 Acad Radiol. 2019 Dec;26(12):1695-1706. doi: 10.1016/j.acra.2019.07.006. Epub 2019 Aug 10.

[30] Fausto Milletari, Nassir Navab, and Seyed-Ahmad Ahmadi. *V-Net: Fully Convolutional Neural Networks for Volumetric Medical Image Segmentation*. 2016.

[31] Ramin Ranjbarzadeh, Abbas Bagherian Kasgari, Saeid Jafarzadeh Ghoushchi, Shokofeh Anari, Maryam Naseri, and Malika Bendechache. Brain tumor segmentation based on deep learning and an attention mechanism using mri multi-modalities brain images. *Scientific Reports*, 11(1):10930, 2021.

[32] P. Sarker, M. M. H. Shuvo, Z. Hossain, and S. Hasan. Segmentation and classification of lung tumor from 3d ct image using k-means clustering algorithm. In *2017 4th International Conference on Advances in Electrical Engineering (ICAEE)*, pages 731–736.

[33] H. Ujiie, A. Yamaguchi, A. Gregor, H. Chan, T. Kato, Y. Hida, K. Kaga, S. Wakasa, C. Eitel, T. R. Clapp, and K. Yasufuku. Developing a virtual reality simulation system for preoperative planning of thoracoscopic thoracic surgery. *J Thorac Dis*, 13(2):778–783, 2021. 2077-6624 Ujiie, Hideki Yamaguchi, Aogu Gregor, Alexander Chan, Harley Kato, Tatsuya Hida, Yasuhiro Kaga, Kichizo Wakasa, Satoru Eitel, Chad Clapp, Tod R Yasufuku, Kazuhiro Journal Article China 2021/03/16 J Thorac Dis. 2021 Feb;13(2):778-783. doi: 10.21037/jtd-20-2197.

[34] Edgars Edelmers, Dzintra Kazoka, Katrina Bolocko, Kaspars Sudars, and Mara Pilmane. Automatization of ct annotation: Combining ai efficiency with expert precision. *Diagnostics*, 14(2):185, 2024.

[35] S. Hanaoka, Y. Masutani, M. Nemoto, Y. Nomura, S. Miki, T. Yoshikawa, N. Hayashi, K. Ohtomo, and A. Shimizu. Landmark-guided diffeomorphic demons algorithm and its application to automatic segmentation of the whole spine and pelvis in ct images. *Int J Comput Assist Radiol Surg*, 12(3):413–430, 2017. 1861-6429 Hanaoka,

Shouhei Orcid: 0000-0002-7496-1651 Masutani, Yoshitaka Nemoto, Mitsutaka Nomura, Yukihiro Miki, Soichiro Yoshikawa, Takeharu Hayashi, Naoto Ohtomo, Kuni Shimizu, Akinobu Journal Article Germany 2016/12/03 Int J Comput Assist Radiol Surg. 2017 Mar;12(3):413-430. doi: 10.1007/s11548-016-1507-z. Epub 2016 Nov 30.

[36] R. M. Summers. Progress in fully automated abdominal ct interpretation. *AJR Am J Roentgenol*, 207(1):67–79, 2016. 1546-3141 Summers, Ronald M Z01 CL040003-06/Intramural NIH HHS/United States Z01 CL040004-05/Intramural NIH HHS/United States Journal Article Review United States 2016/04/22 AJR Am J Roentgenol. 2016 Jul;207(1):67-79. doi: 10.2214/AJR.15.15996. Epub 2016 Apr 21.

[37] N. Tucker, B. P. Sutton, C. Duncan, C. Lu, S. Koyejo, A. J. Tsung, J. Maksimovic, T. Ralph, S. M. Pieta, and M. T. Bramlet. Fully automated conversion of glioma clinical mri scans into a 3d virtual reality model for presurgical planning. In *2022 Annual Modeling and Simulation Conference (ANNSIM)*, pages 392–403.

[38] Kanchan Bahirat, Chengyuan Lai, Ryan P. Mcmahan, and Balakrishnan Prabhakaran. Designing and evaluating a mesh simplification algorithm for virtual reality. *ACM Trans. Multimedia Comput. Commun. Appl.*, 14(3s):Article 63, 2018.

[39] D. P. Luebke. A developer's survey of polygonal simplification algorithms. *IEEE Computer Graphics and Applications*, 21(3):24–35, 2001.

[40] Taseef Hasan Farook, Aparna Barman, Johari Yap Abdullah, and Nafij Bin Jamayet. Optimization of prosthodontic computer-aided designed models: A virtual evaluation of mesh quality reduction using open source software. *Journal of Prosthodontics*, 30(5):420–429, 2021.

[41] O Blender. Blender—a 3d modelling and rendering package. *Retrieved. represents the sequence of Constructs1 to*, 4, 2018.

[42] T. Butnaru and F. Girbacia. Collaborative pre-surgery planning in a tele-immersive environment using vr technology. In Simona Vlad, Radu V. Ciupa, and Anca I. Nicu, editors, *International Conference on Advancements of Medicine and Health Care through Technology*, pages 9–14. Springer Berlin Heidelberg.

[43] Vuthea Chheang, Virve Fischer, Holger Buggenhagen, Tobias Huber, Florentine Huettl, Werner Kneist, Bernhard Preim, Patrick Saalfeld, and Christian Hansen. Toward interprofessional team training for surgeons and anesthesiologists using virtual reality. *International Journal of Computer Assisted Radiology and Surgery*, 15(12):2109–2118, 2020.

[44] J. Gugenheimer, E. Stemasov, J. Frommel, and E. Rukzio. A demonstration of sharevr: Co-located experiences for virtual reality between hmd and non-hmd users. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 755–756.