

## Peer Review File

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### Review Comments

#### Reviewer A:

**Comment 1:** Dear Authors, Thank you for the opportunity to review the following article, entitled "Virtual Reality Simulation Training & Surgical Planning in Cardiothoracic Surgery: Preparing for the Future". The authors conduct a narrative review of the literature on VR simulations and preoperative planning tools in cardiothoracic surgery. Overall the review is comprehensive and well-written. It provides a good overview of this rapidly developing field.

**Reply 1:** We thank this reviewer for their review and kind words.

**Changes in the text:** Not applicable

#### Reviewer B:

**Comment 1:** The authors present a comprehensive non-systematic narrative review of virtual reality simulations and preoperative planning tools in cardiothoracic surgery, as well as the current state of the art and future prospects. This review is well structured and thoroughly illustrated. The key findings and conclusions of this manuscript will be very helpful for cardiothoracic surgeons, residents, and scrub nurses. Before this manuscript is accepted, could the authors explain the following minor concerns:

1. How should VR planning be set up in general preoperatively?

**Reply 1:** We thank this reviewer for their review, and their insightful comments. We see VR preoperative planning as a central feature of preparing an operation. Just as someone would not contemplate performing a lung resection without CT imaging, we foresee a change in the near future where VR becomes equally unmissable. VR planning will be set up in general by using a computer or a laptop with the VR hardware, which can directly load the imaging modality of interest, to plan the operation by the surgeon and to show the procedural steps to residents/scrub nurses/anesthesiologists etc.

**Changes in the text 1:** We added "The surgeon can immediately review the anatomy of the patient behind their computer in their office with VR hardware and software. These images can be automatically produced locally without the need for transfer of data to external sources." to the second paragraph of the Key Findings section.

**Comment 2:** The authors mentioned pulmonary segmentectomies and lobectomies as representative examples of adult thoracic surgeries. If the authors can add some information about the thymectomy and surgeries for mediastinal tumors (which are

also common surgeries in the adult thoracic department), that will be more interesting for the readers.

**Reply 2:** Unfortunately, we have not found any references about thymectomies or mediastinal tumor resection/planning. We found a publication that discussed the utility of a 3D reconstruction of a CT scan in the case of a persistent left superior vena cava, but there was no involvement of VR in visualising this recreation, precluding it from this review. (DOI: 10.1016/j.ijscr.2022.107503). Similarly, a presentation describing the advantages of advanced 3D imaging in RATS cases, which does not include VR visualisation. We agree that VR could form a central part of planning for adult thoracic surgical procedures, and as such we are in the planning stages of a paper regarding our experience of using VR-guided planning of mediastinal tumor resection via VATS/RATS.

**Changes in the text 2:** No changes.

**Comment 3:** The authors base their predictions on the year 2040. Before 2040, do the authors have any ideas about combining VR simulation or VR technology with 5G technology to proceed with some remote cardiothoracic surgeries, multidisciplinary team discussions, and/or peri-operative discussions with the patients and their families?

**Reply 3:** Interesting thought. We did not specifically think about the use of remote VR technology. In our center, we did tryouts with remote heart team discussions in a way that different specialities in different hospitals could login to the same VR environment to discuss a case. However, no publications were found that describe using VR planning and/or VR simulation software over 5G. We still think currently it is too early to use this kind of technology over 5G, but that it would be possible to do multidisciplinary team discussions and especially wet-lab simulation sessions over the internet.

**Changes in the text 3:** We added “This VR simulator is an online environment in which various surgeons from different part of the world can participate, to help and train the performing surgeon with the procedure.” to the section.

**Reviewer C:**

**Comment 1:** Thank you for the opportunity to review this narrative review with an overview of VR simulations and preoperative planning tools in cardiothoracic surgery. The review provides a nice overview of the current simulators and studies in the field. In general, I have the following comments:

- Language could be more concise in places. Language should be revised/proofread as several sentences are hard to understand or not precise enough. See also specific comments in the attached document. Furthermore, I find that in some places in the

manuscript there is a lack of references to back up specific statements. See specific comments below.

**Reply 1:** We thank the reviewer for their feedback, and helpful comments in improving this manuscript. We have adapted the manuscript to simplify and shorten sentences to improve readability.

**Changes in Text 1:** Please see changes below where specific examples were raised.

**Comment 2:** As many abbreviations are used in the text it could be beneficial with a list of abbreviations.

**Reply 2:** We have included a list of abbreviations at the beginning of the manuscript.

**Changes in Text 2: Line 65:** “CPR: Cardiopulmonary Resuscitation, ECC: Extracorporeal Circulation, OR: Operation Room, MRI: Magnetic Resonance Imaging; CT: Computed Tomography, HMD: Head Mounted Display, CSU-ALS: Cardiac Surgery Unit Advanced Life Support, LVAD: Left Ventricular Assist Device, VATS: Video Assisted Thoracoscopic Surgery, VR: Virtual Reality, VSD: Ventricular Septal Defect”

**Comment 3:** Especially in the background but also in the main body of the text some paragraphs are too long and overall, the manuscript could be abbreviated.

**Reply 3:** We have made changes including making the background more succinct and reduced the paragraph sizes in the results section.

**Changes in Text 3:** Please see the comments below referring to specific instances where language has been simplified and shortened.

## **Abstract**

**Comment 4:** In general, a nice and precise abstract with overall clear language.

**Reply 4:** Thank you.

**Changes in Text 4:** No changes.

**Comment 5:** Lines 30-31: Sentence could be changed, a bit unclear.

**Reply 5:** Changed.

**Changes in Text 5: Line 110:** “The relative lack of patient cases, such as was seen at the height of the COVID-19 pandemic, also makes a strong case for competency-based simulation to be able to become proficient despite relatively low exposure.”

## **Background:**

**Comment 6:** In general: There are many long sentences and longer sections that could be abbreviated or even omitted. Language should be proofread and ameliorated. There are several phrases in the text where there is not subject-verb agreement.

**Reply 6:** Various language changes have been implanted to simplify sentence constructions, and improve readability.

**Changes in Text 6:**

Lines 101-103 “Improved preoperative preparation through VR has the potential to improve the flow of the surgery plausibly resulting in shortening the procedure. It may also result in less perioperative surprises followed by necessary improvisations, thereby reducing intraoperative patient risk.”

Line 131- 133 “Despite almost 30 years passing since this prediction, we are still grappling with the issue that the computational power and miniaturisation required to create flexible, responsive, and realistic scenarios in stand-alone VR may only just be arriving.”

**Comment 7:** Line 64-67: I recommend rephrasing. I recommend the phrase of a “specialism that performed blind procedures” should be put in other words.

**Reply 7:** This sentence has been rephrased and divided to improve readability.

**Changes in Text 7:** Line 71-74 “Cardiothoracic surgery began a specialism that performed procedures with no direction visualisation such as a valve commissurotomy without extracorporeal circulation during the 1950s. It has since evolved to include elaborate preoperative planning via echocardiography, coronary angiography, and CT/MRI imaging modalities.<sup>1,2</sup>”

**Comment 8:** Line 77: I recommend rephrasing. The use of “however” and “thus” is not correct in this phrase.

**Reply 8:** This sentence has been rephrased

**Changes in Text 8:** The range of interventions that cardiothoracic surgeons routinely perform is well defined, thereby further facilitating the creation of procedural simulations.

**Comment 9:** Line 84: the word “competency” is used, it could be an idea to briefly introduce Messick’s framework, as this is also mentioned later on in the article as i.e. “construct validity” is mentioned.

**Reply 9: Good idea to introduce Messick’s framework at this point. We added it to the paragraph.**

**Changes in Text 9:** “This (simulation-based) competency assessment needs to be validated using a framework, for which Messick’s validity framework (based on five pillars of evidence: content, internal structure, relationship with other variables, response process and consequence) is the current standard.” was added.

**Comment 10: Line 98-100: citations for the statements?**

**Reply 10:** We have included a citation to a paper Urology where preoperative planning for robotic procedures reduced both the operative duration and the intraoperative blood loss, as well as the post operative length of stay.

**Changes in Text 10: Line 146:** Citation “8” referring to paper with DOI: /10.1016/j.urology.2018.12.026.

**Comment 11: - Line 113-115: long and a bit clumsy sentence.**

**Reply 11:** Simplified and divided the sentence.

**Changes in Text 11:** Line 137: “Surgery is a logical application for VR simulations, as this field has for a long time struggled with the issue of how to train its junior members without exposing patients to undue risk. This is especially true in the context of an ever busier and more complex operating schedule.”

**Comment 12: Line 123-130: The link to simulation in aviation is relevant, but this section could be abbreviated, as an in-depth description of the aviation simulations is not necessary.**

**Reply 12:** This paragraph has been shortened.

**Changes in Text 12:** Line 146: “As with many safety-related paradigms that have been inherited by the surgical field, aviation continues to drive innovation on this front. Junior pilots who face similar training challenges to their surgical colleagues have enjoyed the benefits of VR for decades. Simulator based training, with or without VR, forms a central part of their education, and has helped to build experience whilst saving on both training costs and reducing the risk of fatal accidents.”

## **Objective**

**Comment 13: Line 162: Objective. Gets mixed with background/introduction. Should be abbreviated and stated more clearly. I recommend that the De Visser**

criteria should be introduced in the background section and not under objective. Line 168-172 is the actual objective of the article.

**Reply 13:** The following paragraph has been moved to the background section:

**Changes in Text 13:** Line 237 – 241 “In order to properly assess the merits of the surgical simulators, De Visser et al. stated in 2011 that “..physical realism, case complexity, and performance assessment..” would be the primary parameters by which surgical simulators of the future should be judged.<sup>19</sup> We will apply these criteria to the simulators considered below.”

## **Methods**

**Comment 14:** It Could be discussed whether excluding bronchoscopy is justified. In many other countries bronchoscopy is performed by cardiothoracic surgeons (Line 182-184).

**Reply 14:** Due to the fact that bronchoscopy is not routinely performed by cardiothoracic surgeons in the Netherlands, we are not able to evaluate its usefulness in daily practice, and hence have excluded it from our review.

**Changes in Text 14:** Not applicable.

**Comment 15:** You should reference to table 1 in the text.

**Reply 15:** An in-text reference has been added into the methods section.

**Changes in Text 15:** Line 278-279: “A summary of the search strategy can be found in table 1.”

## **Main body**

**Comment 16:** Vats lobectomy: Clear and concise language in this section.

**Reply 16:** We appreciate this feedback.

**Changes in Text 16:** Not applicable.

**Comment 17:** Line 246-248: language could be clarified

**Reply 17:** Language has been rephrased.

**Changes in Text 17:** Line 354 “The number of surgical robots that are being introduced into surgical practice is rapidly increasing. To make optimal use of these new tools, training programmes are required to help surgeons become accustomed to their use.”

**Comment 18:** Conclusion of study line 258: I don't know if a learning curve conclusion can be made based on time of procedure. Novices might as well be fast because they are not careful/ do not have knowledge about the procedure?

**Reply 18:** Some of the original learning curve surgical studies propose that surgical time is a good proxy for learning (<https://pubmed.ncbi.nlm.nih.gov/11155830/>). The best learning curve studies indeed include complications as an additional factor in producing cumulative summation charts (CUMSUM). Where complications are less relevant or not available such as in the case of a wetlab simulation, time is an acceptable proxy for competency in our view.

**Changes in Text 18:** Not applicable.

**Comment 19:** Line 278-281: hard to understand, rephrase.

**Reply 19:** Language has been rephrased.

**Changes in Text 19:** Line 392-396: "This study demonstrates that high quality robotic surgery simulators, and potentially other generic VR simulators do not necessarily have to simulate an entire procedure in order for them to be of use for trainee cardiothoracic surgeons. This is also true for more senior surgeons who are familiarising themselves with the robotic surgery environment."

**Comment 20:** Lines 296-299: reference to back up this statement?

**Reply 20:** We have added two references to this section. 1) Regarding the evidence that an excessive cognitive load inhibits learning (DOI: 10.1097/ACM.0000000000003524), and 2) that resuscitation situations can result in high cognitive load and poor decision making and/or failure to recall protocols accurately. (DOI: 10.1186/s12960-019-0441-x)

**Changes in Text 20:** Lines 616/617: Added citations as specified above.

**Comment 21:** Line 399: you should not start a sentence with an abbreviation

**Reply 21:** We changes this sentence in a way it does not start with MAPCA, but with an explanation of the two studies that are performed.

**Changes in Text 21:** "Two pilot studies of patients with major aortopulmonary collateral arteries (MAPCAs) were conducted to assess added value of VR over conventional CT scan visualization."

**Comment 22:** Line 403: Sentence is unclear, rephrase. Do you mean they are heterogenous?

**Reply 22:** We have updated the language to reflect the meaning of this sentence.

**Changes in Text 22: Line 523:** “Major aortopulmonary collateral arteries (MAPCAs) are very variable: the number of MAPCAs, the offspring and the anatomical course varies significantly between patients.”

**Comment 23: Line 448:** Is this study published? If so, reference?

**Reply 23:** It has since been published, and we have added a citation in text.

**Changes in Text 23: Line 828:** Citation added.

## **Discussion**

**Comment 24: Line 512-515:** Reminds a lot of the introduction and is not really a key finding. I think this part should be rephrased and more precisely state the actual findings of this article.

**Reply 24:** We agree, and have shortened this sentence to better reflect the findings of the study.

**Changes in Text 24: Line 642:** “We are now witnessing the arrival of virtual reality in cardiothoracic surgery, and are learning how to use the technology to our advantage and finding where it is not as applicable as previously thought.”

**Comment 25: Line 523-524,** I do not understand the meaning of this sentence, rephrasing is advisable.

**Reply 25:** We have rephrased this sentence to clarify the meaning.

**Changes in Text 25: Line 613:** “VR is starting to make a significant contribution to pre-surgical planning, where flexible visualisation of complex and/or aberrant anatomy is relatively more straightforward using VR.”

**Comment 26: Strengths and limitations:** a limitation is also the mentioning of several studies not published and not in peer-review.

**Reply 26:** We agree, and we added a sentence to the strengths and limitations section.

**Changes in Text 26:** Added “A limitation of this narrative review is that some studies are included that have not been published yet. However, to provide an overview as complete as possible, we included the preliminary results of those studies.”



**Comment 27:** Line 552: Omit “however” in the end of the sentence

**Reply 27:** Changed.

**Changes in Text 27:** Deleted the word “however”.

**Comment 28:** Line 555: reference?

**Reply 28:** Added citations referring to 4 different software strategies for preoperative planning sub-lobar resection, illustrating that there are currently many different options in use.

**Changes in Text 28: Line 1072:** added citations as above.

**Comment 29:** Line 558: “in our opinion” – I don’t know if this is really necessary to write.

**Reply 29:** Agree since this is a narrative review.

**Changes in Text 29: Line 1075:** Deleted “in our opinion”.

## Tables

**Comment 30:** Would it be possible to put the De Visser criteria for the simulators in the tables? As you mention in the objective you are following the De Visser criteria.

**Reply 30:** We have included De Visser’s criteria in Table 2.

**Changes in Text 30:** Please see Table 2.

## Reviewer D

**Comment 1:** The list of abbreviations is normally in alphabetic order

**Reply 1:** Thank you for this comment. This has been addressed in the manuscript.

**Changes in the text:** Line 63-67 “CPR: Cardiopulmonary Resuscitation, CSU-ALS: Cardiac Surgery Unit Advanced Life Support, CT: Computed Tomography, ECC: Extracorporeal Circulation, HMD: Head Mounted Display, LVAD: Left Ventricular Assist Device, MRI: Magnetic Resonance Imaging; OR: Operation Room, VATS: Video Assisted Thoracoscopic Surgery, VR: Virtual Reality, VSD: Ventricular Septal Defect”

## Introduction:

**Comment 2:** Line 118-119: Improve/improved is used twice in the sentence.

**Reply 2:** Have rewritten this sentence.

**Changes in text:** Improved preoperative preparations using novel digital imaging techniques have the potential to accelerate the flow of the surgery by shortening the procedure.

**Comment 3:** Line 159-160: De Visser criteria is very briefly introduced. Can this be elaborated, as you state that you will use these criteria on the simulators.

**Reply 3:** Please see our response to comment 5.

**Changes in Text:** As below in comment 5.

**Comment 4:** Line 182: "investigate in how far" – I recommend rephrasing this sentence.

**Reply 4:** We have rephrased this sentence.

**Changes in Text:** Line 206: "Our objective was to gather relevant literature on VR simulators and preoperative planning tools alike, in order to create an overview of the field and investigate to what extent these tools are integrated into current cardiothoracic surgery practice, and where they are likely to contribute to in the coming years as VR technology matures."

**Comment 5:** Objective: is the objective also to evaluate the articles/simulators according to the de Visser criteria? Because now you introduce de Visser in the introduction, but then you don't mention it in the objective, and I find it hard to read how exactly you are gonna use the de Visser criteria.

**Reply 5:** We have added how we will apply these criteria in the objective, and in the introduction. In the results, and in Table 3, it is clear how these are applied, and how well each simulator meets the criteria.

**Changes in Text: Line 215:** "To conduct a comprehensive evaluation of the surgical simulators under consideration, we will utilize De Visser's criteria as the primary parameters for assessment.<sup>22</sup> As outlined by De Visser et al., these criteria encompass 3 areas: physical realism, case complexity, and performance assessment. These criteria can be further defined as follows. The physical realism construct includes visual quality, instrument realism, and haptic feedback. The case complexity construct includes case variability or the ability to approach the same case in multiple ways, and complication simulation or the ability to simulate mistakes and/or unexpected events during the procedure. Finally, performance assessment includes objective measures of performance, including instrument path length or blood loss for example. By applying these criteria, we can thoroughly examine the merits of the simulators discussed below, specifically in terms of their adherence to these fundamental aspects. To ensure a well-rounded evaluation, we will consider relevant literature pertaining to each simulator's compliance with the specified criteria."

**Line 254:** "When evaluating each VR simulator, we assess its adherence to De Visser's criteria concerning the levels of physical realism, case complexity, and its capability to effectively evaluate user performance. This assessment relies on a literature review dedicated to each simulator, enabling a determination of its adherence to the aforementioned criteria."

**Comment 6:** Line 334: "Setup up" – the word "up" should be removed.

**Reply 6:** Removed duplicate word.

**Changes in Text:** Line 358: "A randomised controlled trial was performed whereby cardiothoracic surgery residents were randomised to receive conventional classroom/manikin CSU-ALS training, or VR CPR-sim training, and their abilities subsequently tested using a moulage setup."

**Comment 7:** Line 422: You should not start a sentence with an abbreviation

**Reply 7:** Removed abbreviation

**Changes in Text:** Line 412: “Virtual reality affords a multitude of possibilities in visualising complex anatomy, including full 3-dimensional reconstructions, the option to visually remove structures that otherwise obscure the view of the target anatomy, being able to orient and zoom in an intuitive manner, and highlight relevant features.”

**Comment 8:** Line 479: “18 year” – the word “old” is missing.

**Reply 8:** Fixed.

**Changes in Text:** Our group produced a 3D-VR recreation of the coronary and thoracic anatomy of an 18-year-old patient who was undergoing minimally invasive coronary artery bypass grafting after suffering from Kawasaki disease.

**Comment 9:** Line 492-494: The sentence is hard to read, I recommend rephrasing.

**Reply 9:** Rephrased.

**Changes in Text:** In a review of VR visualization of the mitral valve, Nanchahal et al. reported that VR not only helps visualize the mitral valve more accurately but also demonstrates associated annular pathology compared to conventional echocardiography.