Taylor & Francis
Taylor & Francis Group

Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tciv20

Augmenting the training space of an epidural needle insertion simulator with HoloLens

Daniel da Silva, Cátia Botelho Costa, Nuno André da Silva, Isabel Ventura, Francisca Pais Leite & Daniel Simões Lopes

To cite this article: Daniel da Silva, Cátia Botelho Costa, Nuno André da Silva, Isabel Ventura, Francisca Pais Leite & Daniel Simões Lopes (2021): Augmenting the training space of an epidural needle insertion simulator with HoloLens, Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, DOI: 10.1080/21681163.2021.2012833

To link to this article: https://doi.org/10.1080/21681163.2021.2012833

Published online: 21 Dec 2021.

https://doi.org/10.1080/21681163.2021.2012833

Taylor & Francis
Taylor & Francis Group

Augmenting the training space of an epidural needle insertion simulator with HoloLens

Daniel da Silva[a], Cátia Botelho Costa[b], Nuno André da Silva[b], Isabel Ventura[b], Francisca Pais Leite[b] and Daniel Simões Lopes[a,c]

[a]Instituto Superior Técnico, Universidade de Lisboa, Portugal; [b]Hospital Da Luz Learning Health, Luz Saúde, Lisboa, Portugal; [c]INESC ID, Lisboa, Portugal

ABSTRACT

The goal of this study is to explore the potential of the Optical See-Through Augmented Reality (OST-AR) in the training of median and paramedian epidural anaesthesia administration. To this end, we propose EpiduralLens, an epidural needle insertion simulator that augments the training space by resorting to a dummy, a HoloLens, an AR target, 3D sound feedback, and voice commands. The proposed system projects relevant 3D anatomical information and visual guides that are placed on and around the dummy, which are complemented with aural feedback that guides the instruction process. EpiduralLens was evaluated by 6 anaesthesiologists. The results of the formal evaluation sessions indicate that our prototype had high acceptability by the experts, verifying that combining an aural interface with 3D visual interface is a useful way to aid immersion and improve the learnability of trainees. Moreover, the participants showed interest in using the application in future sessions as a training aid for median and paramedian epidural anaesthesia administration.

ARTICLE HISTORY
Received 16 October 2021
Accepted 27 November 2021

KEYWORDS
Epidural needle insertion training; Hololens; expert assessment

Introduction

Two of the most common anaesthesia procedures are the median and paramedian epidural administrations (McLeod et al. 2015), which consists of local anaesthesia techniques to deliver anaesthetic to the surroundings of the dura mater, causing its diffusion inside the epidural space and inducing a reversible and controlled blockade of the sensory and motor roots of the spinal nerves (Sanchez and Riveros Perez 2020). If the needle punctures a little deeper, about 2 to 3 mm, we will enter the space of the spinal cord, and this is the procedure that is performed when the goal is to perform a spinal anaesthesia (Warriner 2018). Proper training is necessary to ensure safe and correct insertion of a needle. Improper administration of an epidural needle could hit a nerve (e.g. lumbar spine nerves and cauda equina) leaving the patient to lose lower body sensation either temporarily or forever, may also cause internal bleeding at the spinal cord level, which can lead to irreversible nerve damage as well. That is why epidural needle insertion requires a high degree of dexterity to insert the needle at the right place, inclination and depth.

Traditional epidural needle insertion training is based on the trainee observing real procedures to then train directly on patients. However, sometimes errors are committed due to lack of experience which could be easily avoided if the trainee could have trained with simulators beforehand, without putting real patients at risk. One of the greatest benefits of simulators is that they allow trainees to perform several repetitions that can be evaluated over time without the supervision of an instructor (Hammoud et al. 2008; Viglialoro et al. 2018). Several studies have explored the augmentation of the simulator space for training needle insertion, which demonstrated that AR increases not only the skills of the trainees but flattens the learning curve (Agten et al. 2018; Bottino et al. 2018; Mendes et al. 2020).

Many epidural simulators exist, and their complexity and degree of realism has improved over the years (Ferrari et al. 2016). However, epidural simulators have a high cost and lack visual-audio-haptic realism. One approach to overcome these limitations is to add layers of information (e.g. textual, visual, haptic, aural) through Augmented Reality (AR) technology, which is a relatively cost-effective way to add more functionalities and realism to a dummy (Agten et al. 2018; Mendes et al. 2020; Privorotskiy et al. 2021). However, none of these studies considers a HoloLens for training epidural needle insertion (Park et al. 2021; Barteit et al. 2021).

In this work, we explore the benefits and limitations of OST-AR with 3D sound and voice commands to overcome the above mentioned limitations. By augmenting the training space with both anatomical and instructional information, we aim to answer if OST-AR can complement conventional training practices of median and paramedian epidural needle insertions. The contributions of our work consist of the following points: (i) we propose EpiduralLens as a HoloLens application that augments an epidural simulator with visual and aural augmentations; and (ii) we conduct a preliminary user study

CONTACT Daniel Simões Lopes daniel.lopes@inesc-id.pt INESC-ID taguspark, Avenida Professor Cavaco Silva, Edifício IST, Room 2N-9.19, 2744-016, Porto Salvo, Portugal

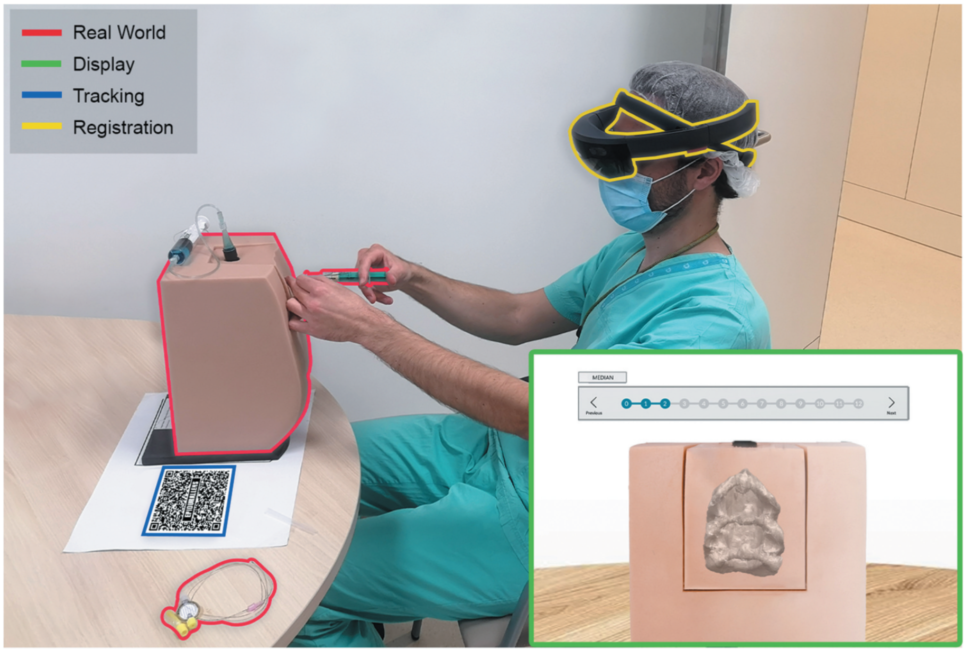

Figure 1. Overview of EpiduralLens: real world components (red), virtual component in the field of view of the user in right lower corner (green), tracking component (blue) and registration component (yellow).

with 6 experts to verify if EpiduralLens can assist the training of median and paramedian epidural needle insertions and administration of epidural anaesthesia.

EpiduralLens

The proposed training system included a mannequin of the lower back region, a set of needles, and a HoloLens (Figure 1). All code was developed in Unity3D (version 2019.4.18f1) with built-in support for Vuforia Engine (version 9.7.4), which is an AR software development kit for mobile devices and HMDs that uses computer vision to recognise and track AR targets and 3D objects in real time. We also made use of several interactive components from the Mixed Reality Toolkit (version 2.5.3).

Dummy and 3D reconstruction

The mannequin consisted of the GENESIS Epidural-Spinal Injection Simulator. This simulator represents the lumbar part of the patient and consists of a simple plastic mannequin with internal and external anatomical landmarks such as the spinous processes and the iliac crests. We reconstructed the 3D models of the dummy's surface and the inner lumbar spine piece. A CT scan of the whole simulator was acquired. The reconstruction of the 3D models was achieved following the steps described by (Ribeiro et al. 2009). The CT images clearly defined the skin surface and lumbar spine material. To 3D reconstruct the dummy's surface and vertebrae, we used a desktop app *ITK-SNAP* that allows user to browse through three-dimensional medical images, to perform manual or semi-automatic image segmentation by global thresholding, and to export boundary meshes extruded from the images. Since the exported meshes from *ITK-SNAP* contained mesh segmentation artefacts, we then relied on *Paraview* and *MeshLab*, two desktop apps commonly used for scientific visualisation with geometric processing features, to smooth mesh segmentation artefacts in *Paraview* and to decimate excessive or redundant vertices in *MeshLab*. The last step was to export the meshes to *.obj, a format that is easily imported into Unity3D.

Registration and tracking

We resorted on the Microsoft HoloLens (1st Generation) that runs a built-in Windows 10 operating system. Marker-based tracking relied on Vuforia software (version 9.7.4) and a single AR target (QR code-based pattern, 12 × 12 cm) (Figure 1). Target detection is achieved by comparing a previously uploaded image of the target with what the HoloLens' front camera is capturing.

Augmented virtual content

Regarding visual content, we included an initial menu, a progress bar and glyphs to represent needle placement and needle inclination. Figure 2(a) displays the opening menu that allows users to get acquainted with the AR environment, besides asking the user which epidural needle administration s/he wants to train (i.e. median or paramedian). Figure 2(b) shows the 3D model of the lumbar spine overlaid on the mannequin as well as a progress bar placed above the dummy, which consists of a timeline with the temporal location relative to all training stages. During the procedure session, relevant anatomical information is rendered namely the lumbar spine (Figure 2(b)) and the locations of the spinous processes of L3, L4 and L5 (Figure 3).

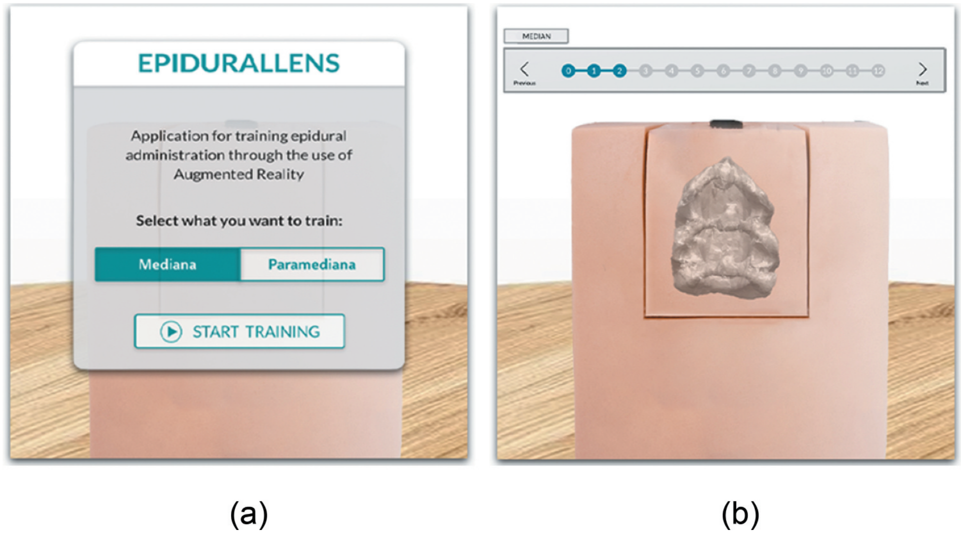

Figure 2. Overview of EpiduralLens' **(a)** opening menu and **(b)** procedure environment.

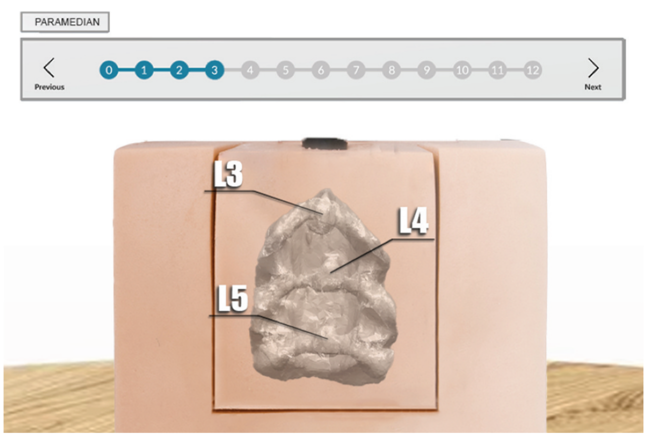

Figure 3. Identification of the spinous processes of lumbar vertebrae L3, L4 and L5.

During the needle insertion step, visual aids for the point of insertion and needle inclination are represented using two trapezoidal shapes. The visual aid of the median approach represents the point of insertion as the centre of the vertical line between the L3-L4 spinous processes, with an angle perpendicular to the puncture surface (Figure 4(a)). As for the visual aid of the paramedian approach, it represents the point of insertion placed 1 cm to the right and 1 cm downwards relative to the point of insertion of the median approach, with a cephalic angle relative to the perpendicular of the puncture surface, about 10% (Figure 4(b)). In par with the rendering of visual content, aural content was introduced. During the initial menu, where a synthesised voice explains the goal of the training session and how it is possible to navigate throughout the AR application. During the procedure environment, the aural interface explains what needs to be done in each step, creating the perception of having an instructor nearby. Note that, users can control 3D buttons for 'Start', 'Previous', 'Next', 'Median' or 'Paramedian' through hand-gestures or by verbalising these commands.

Expert evaluation

Participants

We evaluated EpiduralLens next to six medical professionals (2 female), 5 were medical doctors in the specialities of anaesthesiology with 6, 8, 9, 10 and 36 years of clinical experience. The remaining participant was an intern. Three participants reported no previous experience with OST-AR, but all were highly familiarised with Mobile AR, while 3 participants never dealt with Augmented Reality applications. All reported that they perform epidural blockage on a daily basis.

Tasks

Firstly, participants performed a habituation task that consisted of interacting with all available features, including voice, so that the participant could get used to the interface and its mechanics. Participants took up to 5 minutes for the habituation task. Secondly, participants were asked to place an epidural needle at a specific location of the lower back. In particular, participants were requested to administer a needle injection by, firstly, placing the needle tip as close as possible to the predetermined location and then to adjust the inclination of the needle.

Procedure

All tests were conducted in an office/room at the Simulation Centre of the Hospital da Luz (Lisbon Portugal). The expected duration of each evaluation session was about 20–30 minutes and comprised six phases: (i) informed consent and demographics, (ii) introduction, (iii) free experimentation, (iv) task execution, (v) questionnaires, and (vi) guided interview. Before testing our system, participants were prompted to fill in an informed consent form then a small demographic profile form. At the beginning of each session, we asked participants to stand up in front of the simulator, to place the AR headset and to hold the needle firmly. After a thorough demonstration

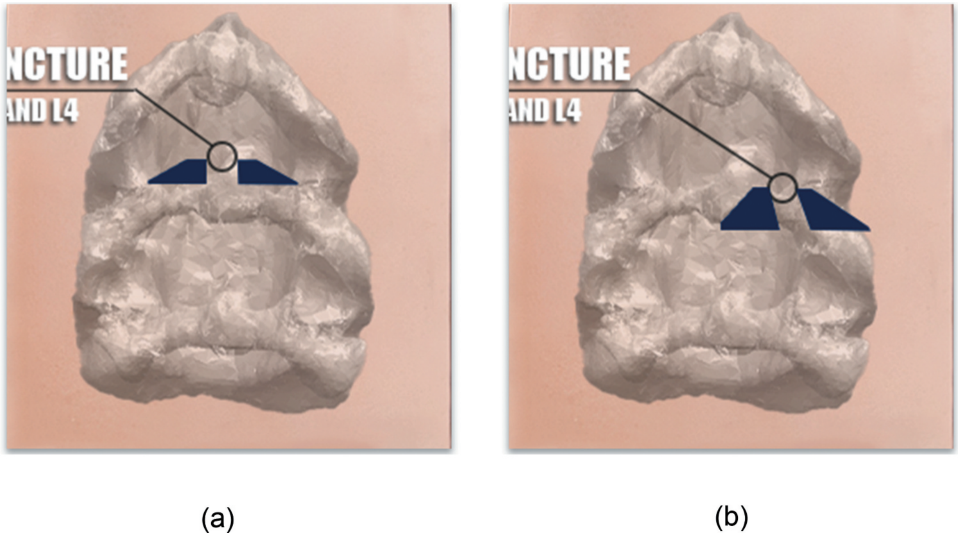

Figure 4. Needle insertion visual aids for **(a)** median and **(b)** paramedian approaches.

Table 1. Median (Mdn) and Inter-Quartile Range (IQR) of the responses to the Likert items.

Statement	Mdn (IQR)
The anatomy of the mannequin is realistic	4.0 (3)
The anatomy of the projected lumbar spine is realistic	5.0 (0)
Easiness to identify the anatomical landmarks	6.0 (1)
Usefulness of visualising the internal lumbar anatomy	6.0 (0)
Usefulness of graphic elements shown to indicate the insertion point of the needle.	5.0 (1)
Usefulness of graphic elements shown to indicate the orientation of the needle.	5.0 (0)
Easiness to use	6.0 (1)
Learnability	6.0 (0)
Usefulness for needle insertion training	7.0 (1)
Interactivity promotes focus and learning	6.0 (0)

of all the interactive system features and functions, we asked participants to test EpiduralLens by themselves, but with the restriction that they had to experiment each available function at least once. After task execution, we provided a questionnaire regarding the quality of their experience and assessed user preferences with a list of statements scored on a 6-point Likert Scale (6 indicates full agreement). Perceived usability and perceived task load were collected by filling out the System Usability Scale (SUS) and the Raw NASA Task Load Index (NASA-TLX) questionnaires, respectively. Lastly, we conducted a guided interview to record participants' impressions about the interface, the interaction techniques, the potential application in training (i.e. benefits and limitations), and the adequacy of EpiduralLens to assist epidural training. Participants were invited to elaborate as much as possible on the issues they found to be the most relevant from their experience. We also requested their thoughts and opinions regarding improvements to the system. Complementary to the questionnaires and guided interviews, we also gathered observational notes taken during test evaluation sessions.

Results and discussion

The data collected for the system evaluation includes the responses to satisfaction questionnaires and detailed answers of the semi-structured interview conducted after the questionnaires.

User satisfaction and perceived usability

The responses to the satisfaction questionnaire show good feedback of EpiduralLens for medical training. All the medians are above 3,5 (the central value of the scale). The median and IQR of the responses are illustrated in Table 1.

Analysing the responses obtained we realise that one of the most positive aspects of the application is the visualisation of the projection of the lumbar spine on the dummy (Mdn = 6.0; IQR = 0), promoting overall focus and learning. However, the statement with the greatest disagreement was related to the realism of the mannequin (Mdn = 4.0; IQR = 3). Users said that the composition of the mannequin did not reliably depict the ligaments that exist in real patients. The SUS score of EpiduralLens provided the expert's level of perceived usability, which scored 80.41 (the average score for the SUS scale is 68 (between 0 and 100)), which indicates that the system was considered as a good user experience.

Perceived workload

To measure the perceived workload we used the raw NASA-TLX, that is a way to measure the subjective mental workload. The values can range from 1 to 21. EpiduralLens presented the following parameter scores (Mdn(IQR)): mental demand – 6.0(7); physical demand – 3.5(2); temporal demand 1(0); overall performance – 1.5(3); effort – 4.5(5); and frustration level – 1(0). It is visible that the average of the medians of almost all parameters is found where the system workload is considered small or medium. The parameters with highest median and IQR are 'mental demand' and 'effort', verified by the small effort made to get used to the HoloLens and their projections.

Participant Feedback

The semi-structured interview provided more feedback of the experts regarding the advantages and disadvantages of EpiduralLens.

Complement to conventional training

All participants considered that EpiduralLens could complement the training of epidural administration, and one participant mentioned that 'these types of systems are a good way for students to have initial contact with these procedures'. It was generally agreed that this type of augmented training system is intended only for training and for people who are just beginning to learn these procedures.

Limitations

Regarding the limitations, 4 participants referred to the small field of view of the HoloLens. However, this limitation can be easily surpassed by more modern OST-AR devices such as the HoloLens 2. When asked about discomfort felt while using the system, the participants reported that they just had to get used to the system for the discomfort to disappear or they did not experience discomfort at all. Just 1 participant reported discomfort during the procedure, saying that it would be valuable to have lighter and more natural OST-AR headset. It was also mentioned by 2 participants that 'it would be interesting to be able to see the small movements of the needle inside the dummy'.

Aural content

Regarding the aural interface, all 6 participants agreed that it is important for immersion and promotes the learning of the trainees. It was also said by a user that 'different audios with different patient stories could be added, to make the aural interface even more realistic for the trainees who will be using it'.

Visual content

When asked about the visual elements, all agreed that the most important visual element was the projection of the lumbar spine. Regarding the visual buttons, none were used, with all users deciding to use the voice commands to interact with the system.

Acceptability

All participants mentioned that they would like to have access to the app as a tool to help training in epidural administration. As one anaesthesiologist with 36 years of experience said 'There is no question that this kind of technology has to be adopted in medical training'.

More complex cases

One of the main suggestions that users mentioned was the need to provide trainees with more complex case studies. Three participants said that the dummy used is a 'perfect' and 'unrealistic' case, which is good for a first interaction with the procedure but does not yet illustrate the real day to day cases. For this it would be necessary to create an application that worked on different dummies or a system that makes use of CT images of real patients, as one participant pointed out.

Conclusion

In this work, we designed a HoloLens application with visual and aural interfaces to assist the training of epidural anaesthesia administration. A preliminary user study was conducted with 6 experts. The results indicate that the designed interfaces meet the criteria required for training epidural needle insertion and have the potential to reduce the dependence on an instructor without affecting the performance of the procedure.

Funding

This work was supported by the Fundação para a Ciência e a Tecnologia [UIDB/50021/2020].

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Nuno André da Silva http://orcid.org/0000-0003-4216-2107
Francisca Pais Leite http://orcid.org/0000-0003-2550-2616
Daniel Simões Lopes http://orcid.org/0000-0003-0917-9396

References

Agten C, Dennler C, Rosskopf A, Jaberg L, Pfirrmann C, Farshad M. 2018. Augmented reality–guided lumbar facet joint injections. Invest Radiol. 53:1. doi:10.1097/RLI.0000000000000478.

Barteit S, Lanfermann L, Bärnighausen T, Neuhann F, Beiersmann C. 2021. Augmented, mixed, and virtual reality-based head-mounted devices for medical education: systematic review. JMIR Serious Games. 9(3):e29080. doi:10.2196/29080.

Bottino AG, Ingrassia PL, Lamberti F, Sal- Vetti F, Strada F, Vitillo A. "Holo-BLSD: an augmented reality self-directed learning and evaluation system for effective basic life support defibrillation training." (2018).

Ferrari V, Viglialoro RM, Nicoli P, Cutolo F, Condino S, Carbone M, Siesto M, Ferrari M. 2016. Augmented reality visualization of deformable tubular structures for surgical simulation. Int J Med Robot Comput Assist Surg. 12(2):231–240. doi:10.1002/rcs.1681.

Hammoud MM, Nuthalapaty FS, Alice R, Casey PM, Emmons S, Espey EL, Kaczmarczyk JM, Katz NT, Neutens JJ, Peskin EG, et al. 2008. To the point: medical education review of the role of simulators in surgical training. Am J Obstet Gynecol. 199:338–343. doi:10.1016/j.ajog.2008.05.002.

McLeod A, Baxter JSH, Ameri G, Ganapathy S, Peters TM, Chen ECS . 2015. Detection and visualization of dural pulsation for spine needle interventions. Int J CARS. 10:947–958. doi:10.1007/s11548-015-1192-3.

Mendes H, Costa C, Silva N, Leite F, Esteves A, Lopes D. 2020. PIÑATA: pinpoint insertion of intravenous needles via augmented reality training assistance. Comput Med Imaging Graph. 82:101731. doi:10.1016/j.compmedimag.2020.101731.

Park S, Bokijonov S, Choi Y. 2021. Review of microsoft hololens applications over the past five years. Appl Sci. 11:7259. doi:10.3390/app11167259.

Privorotskiy A, Garcia VA, Babbitt LE, Choi JE, Cata JP. 2021. Augmented reality in anesthesia, pain medicine and critical care: a narrative review. J Clin Monit Comput. doi:10.1007/s10877-021-00705-0.

Ribeiro N, Fernandes P, Lopes D, Folgado J, Fernandes P . 3-D solid and finite element modeling of biomechanical structures—a software pipeline. In: 7th EUROMECH Solid Mechanics Conference, Lisbon, Portugal. 2009.

Sanchez MG, Riveros Perez E. 2020 Epidural. In: StatPearls. Accessed 15th December 2021 https://www.ncbi.nlm.nih.gov/books/NBK554550/

Viglialoro R, Esposito N, Condino S, Cutolo F, Guadagni S, Gesi M, Ferrari M, Ferrari V, et al. 2018. Augmented reality to improve surgical simulation. lessons learned towards the design of a hybrid laparoscopic simulator for cholecystectomy. IEEE Trans Biomed Eng. 66:(7): 2091- 2104. doi:10.1109/TBME.2018.2883816 .

Warriner B. 2018. Anesthesia course. Accessed15th December 2021. https://www.youtube.com/watch?v=_Ko-m4kFOiI.