Virtual Reality Simulator for Training on Surgery Ergonomics Skills

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Abstract

This work focuses on ergonomics skills based on Virtual Reality (VR) training simulator for spine surgery. The proposed system used the Head Mounted Display (HMD) device for monitoring and data collection. The aim of the project was to provide a training approach for residents that would enable them to acquire the proper ergonomic skills needed while performing spine surgery. A VR training simulator has been designed and implemented to measure two ergonomic skills required that need to be maintained during any surgery. The two components were neck's angle and table's height. The experiments showed that the users are usually focused on their work and tend to pay less attention to their body's position and movements. This can result in a wrong ergonomics setup, which leads to musculoskeletal pain. Thus, the users (residents) need to be trained to have good ergonomics positions. The proposed system measured this using a specific metric that collected head positions, angles, elbow height, and other parameters. The designed model was a VR simulator for neurosurgical education in particular; however, it might be good for some other similar surgeries. The study concluded that incorporating simulations into residents' training and simulated surgeries can strengthen the surgeons' skills and outcomes. As a result, both residents and expert surgeons can benefit from the use of the developed model.

Keywords: simulation, training, ergonomics, skills

1. Introduction

Healthcare providers are exposed to numerous and varying workplace hazards, both emotionally and physically. The daily workload of surgeons exerts a physical strain on their body by assuming uncomfortable postures during long operations as mentioned by Soueid et al. [1]. Virtual reality (VR) has recently emerged as one of the technologies embraced in the simulation and training industries. The applications of VR include security, design and production, education, health care, and many others, as mentioned in Jayaram et al. [2]. The implementation of VR allows the simulated workplace prototype to be viewed in its actual operating environment while minimizing the need for a real operating room (OR) to be used, along with the consequences on surgeons and patients. Therefore, VR allows a large number of experiments to be performed in a controlled environment. This paper introduced a VR model to train neurosurgery residents on the basic ergonomics skills that need to be learned and executed during surgery.

There is a considerable demand for surgical training outside the OR. Nowadays, the residents' work-hours restrictions demand that new surgeons become professionals in a shorter period of time. Also, the high cost of the OR space, the need for supervision from highly trained professionals, and the risk involved when working on sick people limit the operating room-based training. As a result, there have been pressures to develop more efficient surgical training models other than the traditional apprenticeship design of surgical residency programs. In addition, greater focus has been put on patients' safety. Novice surgeon-training experience is minimal in the operating room. As such, the imperative necessity for novel training applications within a virtual context (without actual patients) is demanded. According to Badash et al. [3], due to these pressures, simulators have increased use in modern surgical training.

Earlier studies by Byrne [4], Helsel [5], and Alhalabi [6] concluded that VR technology could be beneficial in education. The hardware and software required for VR simulation are rapidly enhanced, and the costs of such systems are not as high as they used to be. Djukic et al. [7] have specified some indications that VR may become an important tool for medical personnel in the near future.

Wilson et al. [8] mentioned that over the last two decades, a virtual environment is seen as a three-dimensional 3D computer modeling, where a participant interacts intuitively with the environment or objects in real-time, and to some degree has a sensation of immenseness. The interaction of the participant is by point of view control, using controls or moving or re-orienting objects in the model, or through virtual controls (switches, handles, buttons, etc.).

A simulator is a model used for training by imitating real-life scenarios. In an environment where an error can result in the expendability or possible annulment of human life, surgical simulation empowers the practitioner with proficiency and expertise through repeated practice of trials and errors in an environment absolutely devoid of any risk or harm to a real patient. Repeated use of surgical simulations can decrease operating times and complication rates and increase successful patient outcomes as discussed in a study by Badash et al. [3] study. Ahlberg et al. [9] stated that there are many advantages of using simulation technology in surgical education; The output can be measured and immediate feedback is given without the need for an experienced instructor at each phase of the training. Also, the simulators can be accessed by students at any given time.

A growing number of surgical simulators have been introduced over the past three decades to serve various surgical specialties. Neurosurgery is one of the most demanding medical professions that necessitate a high level of expertise and precision. It is a very challenging surgical specialty where techniques and technologies are constantly emerging. There is a wide range of surgical operations ranging from minor to major. Common types of neurosurgical procedures include spinal procedures such as micro-discectomy, spinal fusion, laminectomy and cranial procedures such as burr hole, ventriculostomy, ventriculoperitoneal shunting, and craniotomy for various indications such as brain tumor surgery, epilepsy surgery, etc. [10].

As the field of neurosurgery continues to evolve, it has become obvious that neurosurgical training must also evolve in order to have young trainees ready for the operating room. If failure occurs, the sequence of actions in clinical training can't often be repeated. Learning and acquiring initial surgical skills especially for complex and high-risk procedures in the operating theater may cause some safety issues for patients and trainees. According to Aggarwal et al. [11], simulation offers surgeons and trainees the opportunity to rehearse the procedure in advance and practice skills before actually touching the patient.

Neurosurgical simulation presents real opportunities to enhance the safety and effectiveness of both classical and complex operative procedures.

Limbrick et al. [12] mentioned that currently, about 70 % of medical schools have already incorporated some simulation types in their curricula, especially in operating-based specialties, such as general surgery, urology, and neurosurgery. Ganju et al. [13] concluded a recent survey of neurosurgery programs that simulation is considered an important tool to complement classical operative training. Therefore, modern and effective methods have gained interest and allow the trainees to perform complex tasks as shown in Durkin et al. [14] study. Cohen et al. [15] stated that neurosurgical trainees encounter significant challenges when planning and performing increasingly complex and critical procedures. Referring to Coelho et al. [16] , the educator's task becomes more complex and challenging as the number and complexity of neurosurgical operations continue to increase in parallel with technological developments, such s, minimally invasive spine surgery and instrumentation, interventional neuro angiography, image-guided navigation, and endoscopic surgery. Moreover, due to their workhour limitations, residents are unable to meet the demands to maximize training before being allowed to work on patients. Therefore Zanello et al. [17] concluded that this two-fold need is the main reason for reconsidering residents' training in all specialties.

According to the definition of the World Health Organization (WHO), Work-Related Musculoskeletal Disorders (WMSDs) comprise of all health concerns of locomotive equipment (skeleton plus muscles, tendons, cartilage, ligaments and nerves) and all related types of ill health, ranging from mild or transitory to permanent and disabling injuries. Lave et al. [18]. mentioned that in particular, spine neurosurgeons are subjected to WMSDs by taking on continuous non-neutral roles, with prolonged neck flexion and coronal misalignment as they work in a standing posture, often leaning over the operating table. Thus, there has been a major prevalence of back and neck pain among spine surgeons that is indicated by Auerbach et al.[19] who surveyed 561 surgeon members of the Scoliosis Research Society about the types and incidence of musculoskeletal diseases. The most common complaints were low back pain (62%), neck pain (59%), and shoulder discomfort (49%).

A study by Auerbach et al. [19] that spine surgeons have a higher prevalence of WMSDs relative to disease estimates in the general population. At rates far above disease estimates in the general population, their sample had surgical intervention for lumbar (7.1 %) and cervical disc disease (4.6 %). A number of studies were mentioned in Albayrak et al. [20] paper that emphasized the importance of postural ergonomics to reduce musculoskeletal fatigue among neurosurgeons. Sustained neck flexion is seen as an important risk factor for WMSDs among spine surgeons, as reported by different studies by Gadjradj et al., Park et al. 2012, and Park et al. 2014 [21-23]. Lave et al. [18] mentioned that such posture is often required during most procedures, for example, during cervical spine approaches. An additional contributing factor could be that surgeons tend to neglect their posture during surgery, as the procedure itself requires full attention.

According to Berguer [24], trainees and young neurosurgeons need to be aware of the substantial risk of suffering from WMSDs, learn good practice early on, and gain knowledge of the danger to which they are exposed. There has been an increased understanding of the importance of ergonomics and the application of system analysis in the field of medicine. In relation to intensive care units, gastrointestinal endoscopy, back injuries in health care personnel, and job difficulties in medical-surgical staff nurses, ergonomic issues were examined. Perhaps more than any other medical specialty, anesthesiologists have discussed the significant information display and equipment design factors that influence their work.

Previous research by Janki et al. [25] has shown that neutral body position is the most effective way to prevent ergonomic issues. Several modifications have led to this, such as the table’s height adjustability and the monitor 's optimum positioning. However, in their studies, Van Veelen et al. and Van Det et al. [26, 27] concluded that an adequate education in ergonomics is essential to maintain surgeon posture. Different methods have been used to test ergonomics during surgery, such as evaluating postures, determining muscle strain by means of electromyography, reporting on the (Visual Analog Scale) VAS score associated with certain positions, or measuring the angles of certain parts of the body

Ergonomics is characterized as the empirical study of people and their working conditions, particularly to demonstrate efficacy. Neurosurgical ergonomics has been ignored for several years and remains under-reported as mentioned by Lave et al. [18]. Stone et al. [28] re-referred that early awareness of human deficiencies in medical device production can minimize errors and prevent deficient performance deficiency issues compounded by stress and fatigue. Utilizing ergonomics in a designed phase may reduce the cost of product procurement and maintenance. An overview of the ergonomics challenge may help define key elements of surgical competence, ensuring that students have accessible and reliable training.

Virtual reality simulation is emerging as a powerful teaching method that can facilitate learning and eventually assessing skills. One of these skills is applying ergonomic knowledge during procedures, and this eventually should lead to reduced WMSDs as referred by Khan et al. [29]. Thus, this study aims is to describe the extent to which a newly developed VR simulation scenario of open spin-surgery can be effective in measuring and training for proper ergonomic performance of neurosurgery residents. The main goal is to increase the working practices of health care staff to minimize injuries, improve quality, and avoid potential adverse health effects of medical personnel (such as doctors, surgeons, scrub technicians, nurses, anesthesiologists, transporters, etc.).

2. Methodology

2.1. Part1: Build the VR simulator

An open spine surgery VR simulation scenario was created focusing primarily on the ergonomics of neck’s angle and elbow’s height, as these are the most commonly injured sites of residents and surgeons. The guidelines for proper ergonomics was based on Ronstrom et al. [30], which included the following: the appropriate neck’s angle is to be in flexion of 15–25° (Figure 1), and the table’s height must be adjusted so the patient is at the elbow’s level of the surgeon (Figure 2). Other guidelines by Alaqeel and Tanzer [31] suggested a table height of 5-10 cm above the elbow when requiring fine motor skills. However, we elected to follow the guidelines Ronstrom et al. [30] recommended as it was directed for open surgery. Furthermore, to create a surgical ergonomic scenario, the study aimed to be realistic enough to instill the user with a sense of comfortability and simultaneously be challenging enough in surgical tasks. Therefore, the Sabbagh et al. [32] roadmap for developing a VR simulation scenario (Figure 3) was used to include these principles in the proposed model.

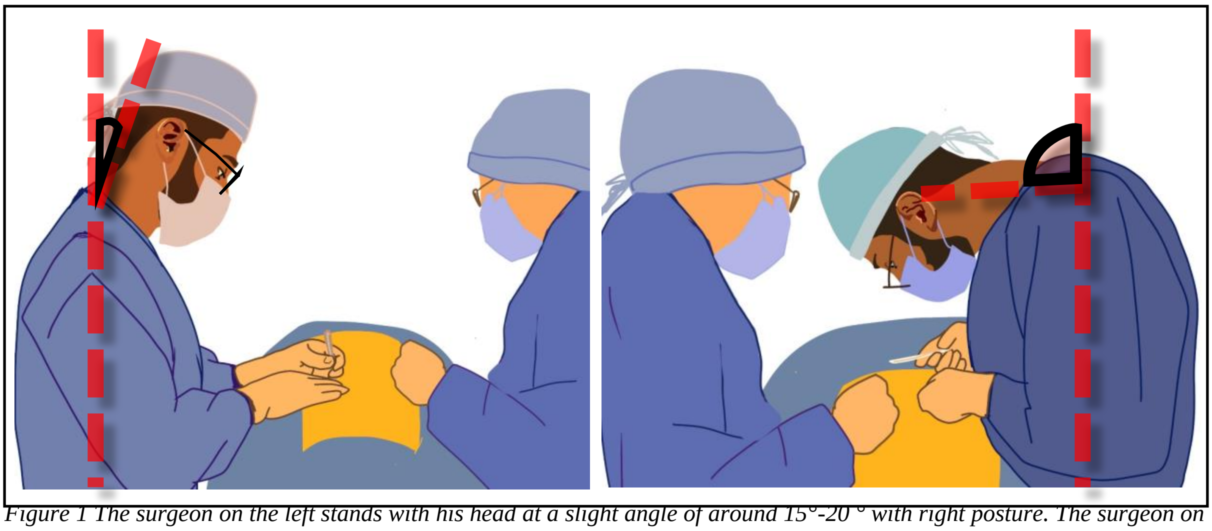


Figure 1 The surgeon on the left stands with his head at a slight angle of around 15°-20 ° with right posture. The surgeon on the right has an inappropriate posture with highly flexed neck.

Figure 2 The appropriate operating table height indicated by operating surface at elbow level

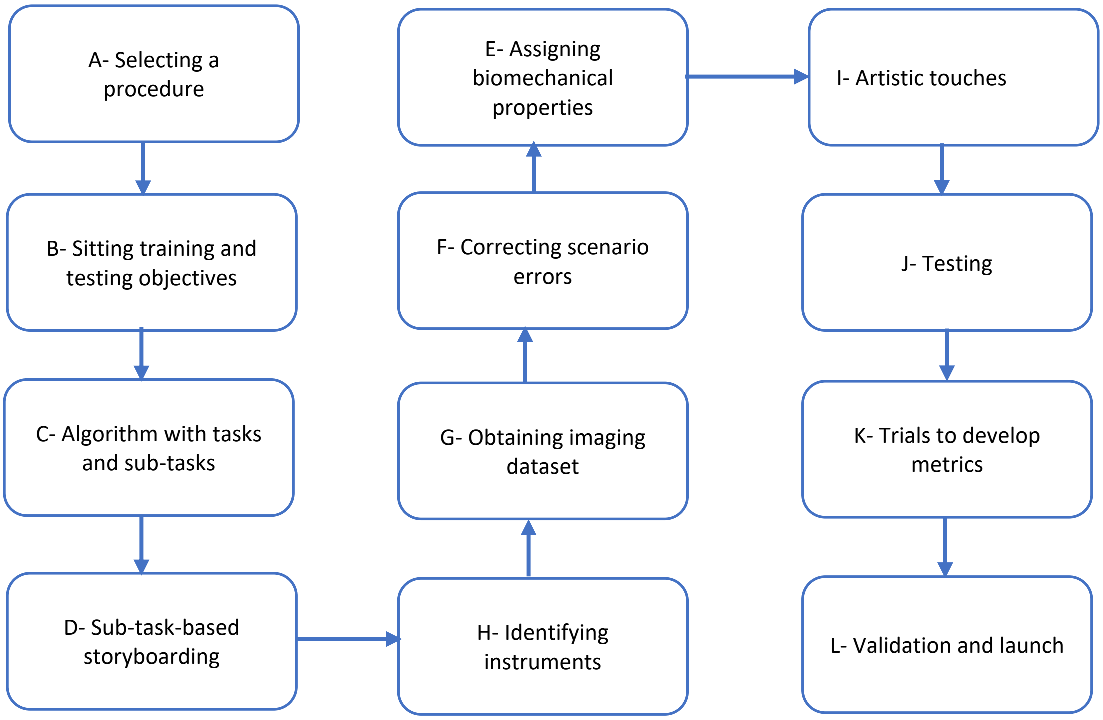


Figure 3 Proposed prototype scenario-building roadmap

The proposed prototype scenario-building roadmap is explained in detail in the following section:

A. Selecting a procedure (Figure 3.A). In this step, one of the most common procedures in neurosurgery, as well as, one commonly associated with WMSDs were selected: spinal-cord surgery.
B. Setting training and testing objectives (Figure 3.B). In accordance with the study's main aim, the ergonomics skills were identified: neck's angle and elbow's height. The neck angle is measured using the built-in gyroscope in the headset, while the elbow height is defined from the floor to the elbow. The training objectives included neurosurgery medical practitioners (consultants, specialists, residents, and interns).
C. Algorithm for the task and sub-tasks (Figure 3.C). The task here was to perform a skin incision for a lumbar disc procedure. The sub-task is defined by moving the surgeon close to the patient's table and sitting their elbow's height.

The calculation of the elbow's height is defined mathematically using the relation below, where the center and the radius of a sphere are calculated using 3 points on the surface of the sphere as explained by Guo et al. [33]. This can be determined with a simple linear system of 2 equations and 2 unknowns, where the input points are p_1

(x_1, y_1, z_1), p_2 (x_2, y_2, z_2), and p_3 (x_3, y_3, z_3) and the unknown is the circle radius and the center of the c (x_0, y_0, z_0).

The idea is based on the assumption that the 3 points (p_1, p_2,p_3) must belong to a (circle with maximum radius) of a sphere with center c. Thus, the following conditions must be fulfilled:

- The 3 points (p_1, p_2 and p_3) ϵ to a sphere with center c.

  $(px_1\text{-}c_x)^2 + (py_1\text{-}c_y)^2 + (pz_1\text{-}c_z)^2 - r^2 = 0$ (1)

  $(px_2\text{-}c_x)^2 + (py_2\text{-}c_y)^2 + (pz_2\text{-}c_z)^2 - r^2 = 0$ (2)

  $(px_3\text{-}c_x)^2 + (py_3\text{-}c_y)^2 + (pz_3\text{-}c_z)^2 - r^2 = 0$ (3)

- The 3 points and the center (p_1, p_2, p_3 and c) ϵ to the same plane, either $x - y$, $x - z$, or $y - z$ plane.

- Now, the vectors can be defined as:

  $v_1 = p_2\text{-}p_1 = (v_{1x}, v_{1y}, v_{1z})^T$

  v2 = $p_3\text{-}p_1 = (v_{2x}, v_{2y}, v_{2z})^T$

  - The direct expressions for k_1 and k_2 can be derived obtaining:

  $k_1 = 0.5\cdot(v_2^T \cdot v_2)\cdot[(v_1^T \cdot v_1) - (v_1^T \cdot v_2)]/[(v_1^T \cdot v_1)\cdot(v_2^T \cdot v_2)\text{-}(v_1^T \cdot v_2)^2]$

  $k_2 = 0.5\cdot(v_1^T \cdot v_1)\cdot[(v_2^T \cdot v_2) - (v_1^T \cdot v_2)]/[(v_1^T \cdot v_1)\cdot(v_2^T \cdot v_2)\text{-}(v_1^T \cdot v_2)^2]$

  for more information on how k_1 and k_2 are calculated, please refer to the refence by Guoet al. [33].

  - After determining k_1 and k_2, the center of the circle is:

    $c_x = p_{1x} + k_1 v_{1x} + k_2 v_{2x}$ (4)

    $c_y = p_{1y} + k_1 v_{1y} + k_2 v_{2y}$ (5)

    $c_z = p_{1z} + k_1 v_{1z} + k_2 v_{2z}$ (6)

D. Sub-task-based story boarding step (Figure 3.D). The operator opens the skin and the muscle around the spinal processes and suctions the blood exposing the spinal processes in the lumbar spine.

E. Assigning biomechanical properties (Figure 3.E) includes adding the haptic feedback and suction and monopolar sounds and effect according to their movements within the wound helps to make the environment close to reality.

F. Correcting scenario errors (Figure 3.F) includes modifying the instrument's design errors to meet reality as close as possible.

G. Obtaining the image dataset (Figure 3.G) used in creating the 3D environment and the interaction between the operator and the tissues.
H. Identifying the instruments (Figure 3.H), the needed instruments are: suction, retractors, 15 blade scalpels, and monopolar.
I. Artistic touches (Figure 3.I) include the imported models to the environment. The models such as the anesthetic operator and the monitoring assistant were carefully designed.
J. Testing step (Figure 3.J), we have conducted several meetings with the subject matter experts including (biomedical engineers, computer scientists, and surgeons) in order to build and test the created environment.
K. Trials to develop metrics (Figure 3.K) include the data analysis according to each operator with a relationship to the ergonomics skills measured.
L. The validation and launch process (Figure 3.L). The validation approach applied to the prototype includes face and content validity, which are mainly based on qualitative data. In addition, the study should examine the discriminative validity distinguishing different performance levels of neurosurgeons at different levels of experience. The design and implementation of the simulator have taken all possible measures to build the environment in full congruency to the reality and to achieve the complete training expectation in terms of reality of the scenes, the tasks, impact, and the reaction.

2.2. Part 2: Scenario

The resident (the user of the simulator) can adjust the table height using red (lower)/green(higher) buttons. In the simulator (Figure 4), the VR headset works as a device to measure the neck angle using a built-in gyroscope. This data (1. neck angle- the pitch, 2. elbow height,3. table height, and 4. scalpel position [patient’s body height + table height]), is captured every second and saved in a .csv file for later analysis. Figure 5 explains this process.

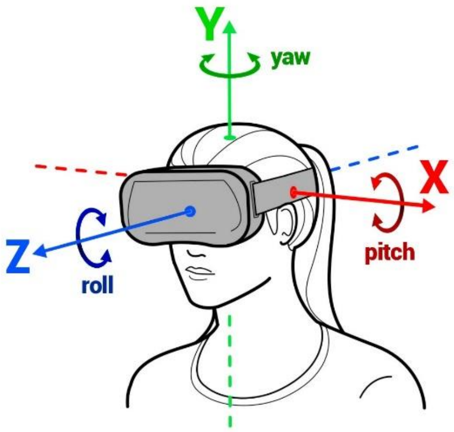


Figure 4 Neck angles [34]

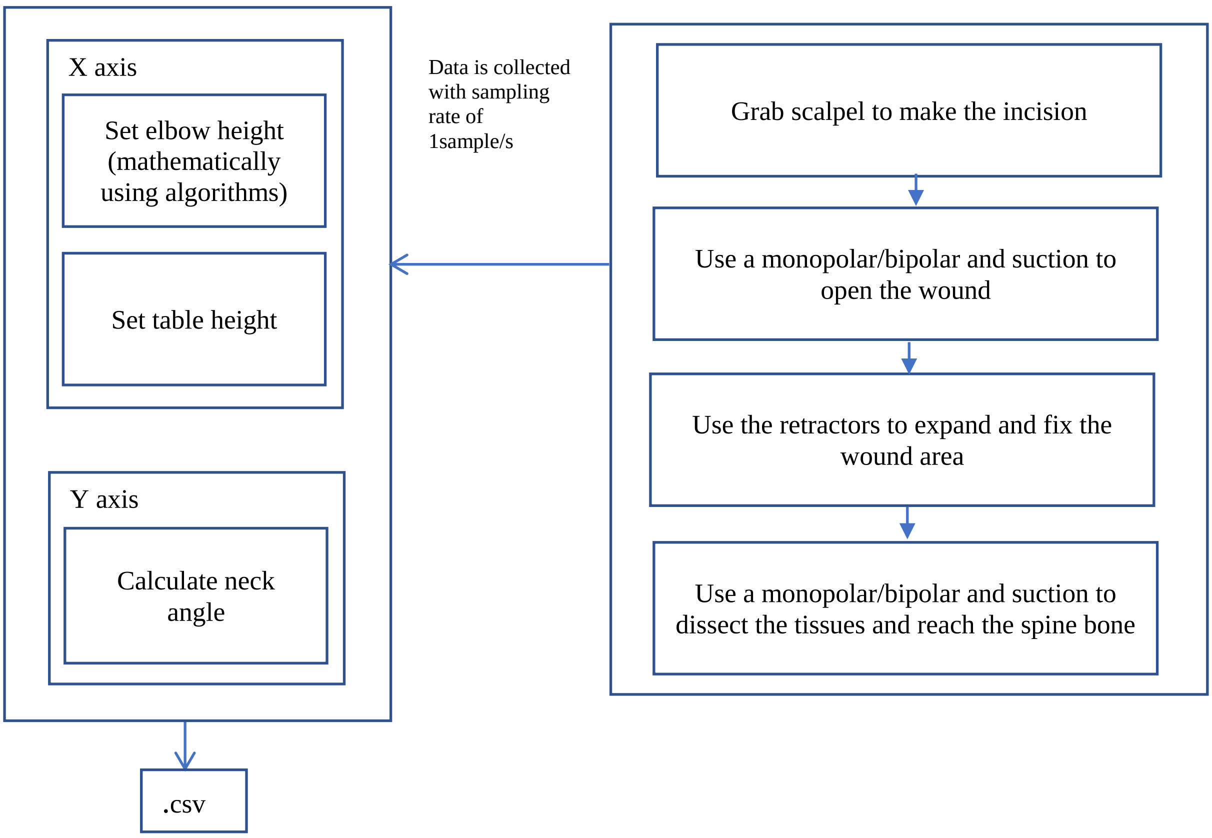


Figure 5 System Block Diagram

The data is collected (the elbow's height (c_x, c_y, c_z)) and compared with the scalpel's position. The surgical operation requires the resident to do the following

1- Make the incision cut using a 15-blade scalpel, as shown in Figure 6.

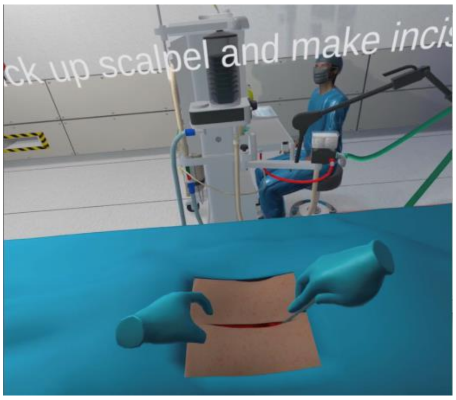


Figure 6 The operator making the incision

2- Using a monopolar/bipolar and suction, the user opens the wound (Figure 7).

Figure 7 Use a monopolar/bipolar and suction

3- Using the retractors to expand the wound area and set the opening to a specific dimension as shown in Figure 8.

Figure 8 Use retractors to expand the wound area

4- Using a monopolar/bipolar and suction to dissect the tissues and reach the spine where the main operation will be conducted.

In these experiments, we used the Oculus Quest [35]. It is an all-in-one gaming system built for VR and no personal computer is required during the run. It has a built-in gyroscope and a built-in accelerometer and the hardware provides room-scale tracking. It comes with touch controllers where the user's hands and gestures will appear in the VR environment. The gaming engine used to operate with the VR headset is called Unity.

The 3D wound and surgical instruments shown in Figure 9 were designed using 'Blender' which is a free and open-source software toolkit for 3D computer graphics used to build animated movies, visual effects, graphics, 3D printed models, motion graphics, 3D interactive apps, virtual reality, and games [36]. With a strong foundation of modeling capabilities, there's also robust texturing, rigging, animation, lighting, and a host of other tools for complete 3D creation.

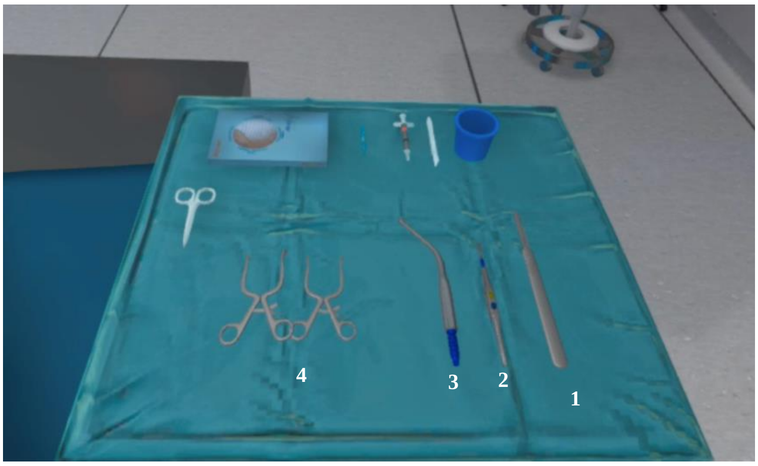


Figure 9 Designed surgical instrument, 1- scalpel, 2- suction, 3- monopolar/bipolar, 4- retractors.

Once the wound and instruments were modeled, they were imported to the VR 3D environment in Unity platform as shown in Figure 10. The animation of the residents and their interaction with the instruments is controlled by C# script.

In order to proceed with the experiments and evaluation survey, we have applied for ethical approval from the unit of biomedical ethics research committee (IRB reference no. 613-20).

Figure 10 3D virtual environment

3.3 Part 3: Statistical analysis:

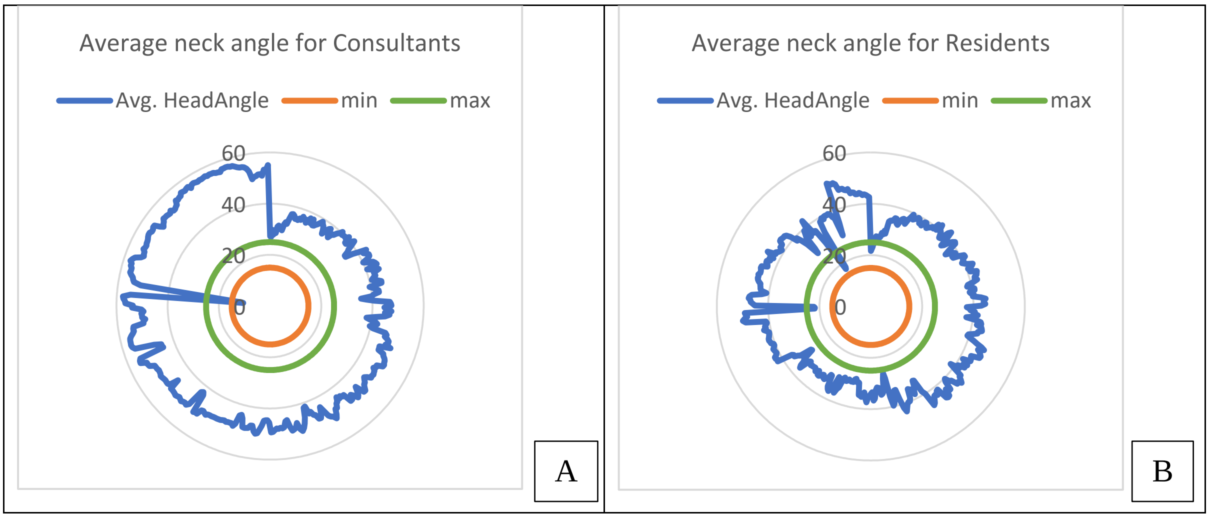
The statistical variables that have been examined in this study are the user's neck's angle and the elbow's height related to the table's height. Many statistical equations have been applied to the collected data including, Mean, Standard Error, Median, Mode, Standard Deviation, Kurtosis, ...etc. To compare the performance across consultants, specialists, residents and interns, t-test was also applied to determine if there were significant statistical differences between the results obtained for each level of proficiency.

The validation method is applied by a self-developed questionnaire (web-based) which contains questions on realism and the usefulness of the application. The training system has been evaluated in a questionnaire-based study. After completing the experiment, each participant had to fill in some answers regarding their level of expertise and their awareness of ergonomics skills. The participants needed to inform in the survey whether they had experienced any illnesses or discomfort related to their work conditions during any of the VR tasks scenarios such as back or neck discomfort. After the training, all users were asked to fill out a web-based form by rating statements about the training system. A Likert scale ranging from 1 (= very easy) to 5 (= very hard) was used to record their opinions. The users had the liberty to write text comments and suggestions via the web interface.

1. Results and discussion

The total number of participants was 38. Fifteen (39.47%) of them were consultants,15 (39.47%) were residents, 4 (10.52%) were interns, and 4 (10.52%) were specialists. They were from the following hospitals: King Abdulaziz University Hospital, King Abdulaziz University Hospital in Jeddah - Saudi Arabia, King Faisal Specialist Hospital and research center in Jeddah – Saudi Arabia, King Fahad Hospital in Jeddah – Saudi Arabia, AlNoor Specialist Hospital in Makkah – Saudi Arabia, and National Guard Hospital in Jeddah – Saudi Arabia. The users were asked to use the VR headset, and start conducting the spine surgery. Each user interacted with the system for 5 minutes following the scenario described in part 2.

All data related to the neck's angle, and table's height was analyzed. The differences in the neck's angle for the four level of proficiency of users that employed the system is presented in Figure 11. The averages of the descriptive statistics for the data measuring the neck's angle for the four level of proficiency of users are presented in Table 1.



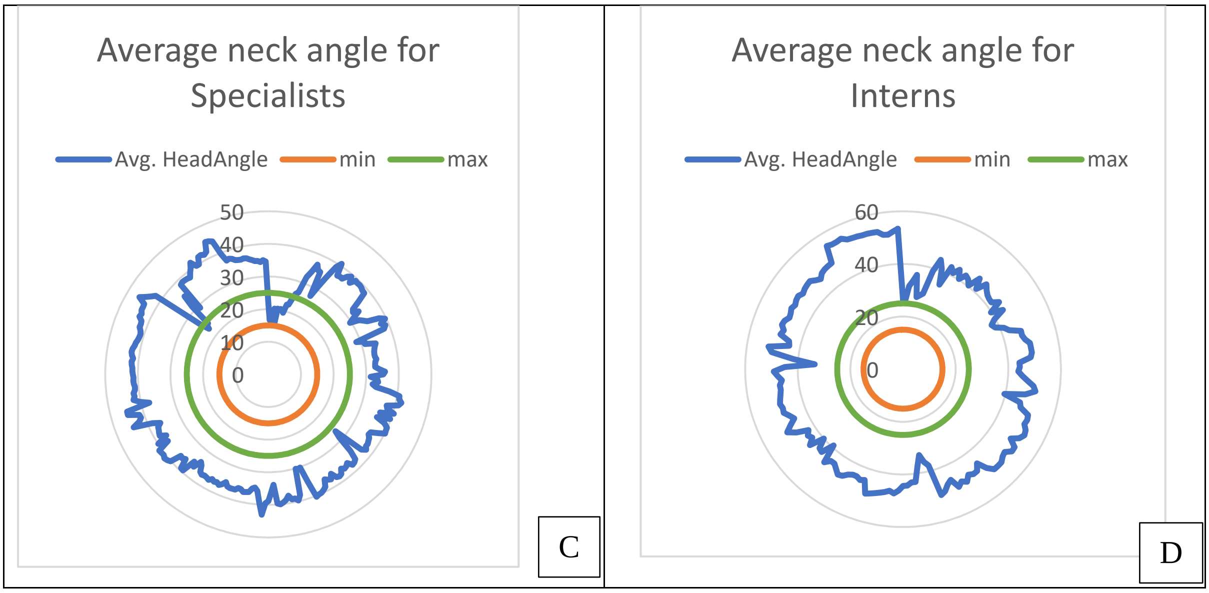


Figure 11. Neck angle of A. consultants; B. residents; C. specialists; D. interns

Table 1. Average of descriptive statistics for each level of proficiency of user

	Consultants	Interns	Residents	Specialists
Mean	40.97504	45.34816	39.94995	35.86153
Standard Error	0.671811	0.644863	0.690832	0.531334
Median	42.58667	47.15875	41.387	37.46
Mode	40.47267	44.2175	38.71467	38.535
Standard Deviation	9.188041	7.981203	9.921262	7.668814
Sample Variance	88.49642	66.00583	105.9429	72.206
Kurtosis	3.573529	5.167442	0.993583	1.465944
Skewness	-1.35883	-1.85369	-0.74854	-0.67188
Range	45.95933	46.9375	49.04333	39.5575
Minimum	10.22533	10.41	10.19133	13.0225
Maximum	56.18467	57.3475	59.23467	52.58
Confidence Level (95.0%)	1.326918	1.27416	1.362518	1.047708

An analysis of Table 1 indicates that, in terms of mean, median and mode, the specialists have the closest values to the ideal range (15-25 degrees), followed by the residents, consultants and interns. A high value for Kurtosis indicator points out that for interns there are more outliers than for the other level of proficiency of users. This can be explained by the fact that they are the least experienced and when performing the tasks, they are trying to find the right position through rapid large movements.

To determine if there are statistical differences between the results obtained for each user level of proficiency, for the neck angles, for each user, the mean of the head angle was computed (Table 2). Based on these results, a t-test for consultants versus residents (Table 3) and for interns versus specialists (Table 4) was performed using the data analysis module from Microsoft Excel. As can be observed from Table 3, -t-critical one tail t-Stat<t-critical one tail and $p>0.05$ where p-value = 0.785522, indicating that we cannot reject the null hypothesis (that the means of consultants and residents are statistically insignificant). Distinctively, in table 4, t-Stat>t-critical two tail and $p<0.05$ where p-value = 0.023702, indicating that we must reject the null hypothesis (that the means of interns and specialists are statistically significant). Thus, the differences between the residents and the consultants are statistically insignificant and there are statistical significant differences between specialists and inters, in terms of head angle. As a consequence, there is a need for advanced training for intern users to reach the necessary level of agronomy that ensures the reduction of injury.

Table 2. Mean of head angle obtained by each user

Criteria	Consultants	Interns	Residents	Specialists
1	29.69957	48.70036	35.01514	40.23226
2	34.41759	35.58516	26.91687	28.59651
3	43.02932	48.28938	27.55603	30.38732
4	37.42358	48.81775	45.58265	44.23004
5	55.819		37.69524	
6	48.44587		40.0125	
7	38.24797		31.09252	
8	18.54827		52.37396	
9	36.69255		50.91987	
10	40.28505		23.85101	
11	43.19073		40.43364	
12	44.47423		48.01839	
13	32.32693		40.17885	
14	60.77973		43.02844	
15	51.24521		56.57416	

Table 3. t-Test results for the comparison between Consultants and Residents

	Consultants	*Residents*
Mean	40.97504	39.94995
Variance	112.9989	96.2993
Observations	15	15
Pearson Correlation	0.021446	
Hypothesized Mean Difference	0	
df	14	
t Stat	0.277407	
P(T<=t) one-tail	0.392761	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.785522	
t Critical two-tail	2.144787	

Table 4. t-Test results for the comparison between Residents and Interns

	Residents	*Interns*
Mean	45.34816	35.86153
Variance	42.41406	57.29423
Observations	4	4
Pearson Correlation	0.666144	
Hypothesized Mean Difference	0	
df	3	
t Stat	3.252356	
P(T<=t) one-tail	0.023702	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.047405	
t Critical two-tail	3.182446	

It is worth noting that the close similarity in the results is due to the familiarity with the VR technology. During the experiment, most of the residents were familiar with dealing with the VR device, which led them to perform the required task smoothly and in a short time as compared to the consultants who had difficulties using the technology.

Regarding the realism of the simulated spine surgery, the majority of the users mentioned that it was midway between being completely realistic and completely unrealistic. This indicates that the system needs to be improved in terms of realism as shown in Figure 12.

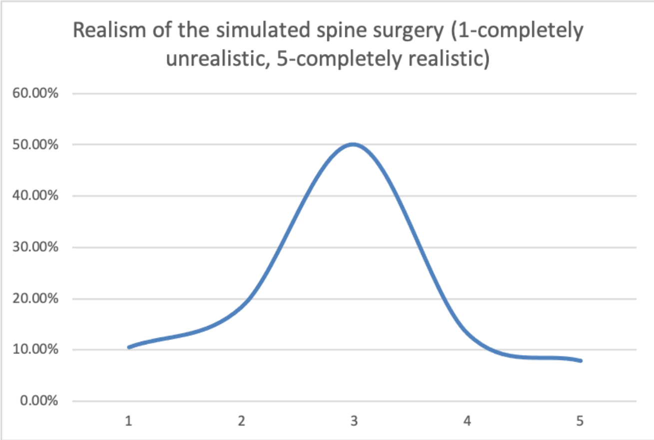


Figure 12 Realism of the simulated spine surgery (1-completely unrealistic, 5-completely realistic)

Regarding the usefulness of the VR device during the performed task, nearly 75% of the users agreed on the ease of the use of the device. The spine surgery scenario's difficulty was also evaluated. Seventy-six percent (76%) of the users agreed on the ease of the performed scenario.

Our findings correlate with results of previous research. In comparison to Park et al. [23] experiment , our study used a software tool (VR), while they used a hardware setup. As a result, we had the advantage of simplicity to use, low cost, portability, and distributability. Additionally, Park et al. [23] had a special hardware setup, where only a single user could have been in the experiment at any given time. Moreover, they were targeting the optimum table's height relative to the surgeon, while we were targeting the differences between the elbow's height relative to the table's height among various groups (consultants, residents, specialists, and interns).

2. Conclusions

In this work, a VR system for raising awareness regarding ergonomics and future training for current spine surgeons was designed, implemented and tested. The prototype was implemented based on a well-defined roadmap comprised of 8 steps. In order to test the VR simulator, 38 users from 4 categories (consultants, specialists, residents, and interns) were selected from 5 hospitals in Saudi Arabia. The analysis of the results showed that there is statistical difference regarding the head's angle between specialists and interns. Future works may include collecting different attributes such as hand movements and back's angle as well as creating higher tier metrics to further assess ergonomics of surgeons and trainees and find benchmarks that would hopefully aid train residents to attain better ergonomics and help prevent trainee WMSDs.

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