

Novel virtual nasal endoscopy system based on computed tomography scans

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Abstract: Background Currently, many simulator systems for medical procedures are under development. These systems can provide new solutions for training, planning, and testing medical practices, improve performance, and optimize the time of the exams. However, to achieve the best results, certain premises must be followed and applied to the model under development, such as usability, control, graphics realism, and interactive and dynamic gamification. **Methods** This study presents a system for simulating a medical examination procedure in the nasal cavity for training and research purposes, using a patient's accurate computed tomography (CT) as a reference. The pathologies that are used as a guide for the development of the system are highlighted. Furthermore, an overview of current studies covering bench medical mannequins, 3D printing, animals, hardware, software, and software that use hardware to boost user interaction, is given. Finally, a comparison with similar state-of-the-art studies is made. **Results** The main result of this work is interactive gamification techniques to propose an experience of simulation of an immersive exam by identifying pathologies present in the nasal cavity such as hypertrophy of turbinates, septal deviation adenoid hypertrophy, nasal polyposis, and tumor.

Keywords: Virtual nasal endoscopy; Computed tomography; Gamification; Endoscopy teaching

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1 Introduction

The learning curve for techniques in a medical procedure is steep^[1,2]; however, a large part of these skills can be acquired by cadaveric dissections in both humans and animals. However, ethical, religious, and legal considerations can interfere with this paradigm in various regions of the world. Such barriers have led the

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medical and scientific community to seek technological solutions. There are many projects aimed at maximizing the ideal medical procedure. These include the Surgical Education Platform (SEP; SimSurgery, Oslo, Norway)^[3], the dV-Trainer (Mimic, Seattle, WA, USA)^[4], the Da Vinci Skills Simulator (dVSS; Intuitive Surgical)^[5], and the RobotiX Mentor (3D systems, Symbionix Products, Cleveland, OH, USA)^[6]. Projects like the ones above become references for similar platforms capable of integrating the qualification and training of students in the health area^[7].

This form of proactive learning has been around for some time now in several areas, including health^[8], education^[9,10], and aviation^[11]. Studies [12] and [13] describe the advantages of using virtual reality in various industries. Carrying out training using virtual reality or other simulator systems in medicine [14] has made it possible to maximize agility, efficiency, and effectiveness in managing medical emergencies and minimizing risks in operative procedures^[15]. These benefits are due to the simulators that provide sensory immersion, navigation, and manipulation training^[16]. Notably, there are few studies in the literature that provide a comprehensive explanation on the subject despite the significant benefits provided by these simulator systems^[17,18]. In this study, we systematically analyze and synthesize the work that is being carried out these days with simulators for various medical procedures. An overview of simulators for medical procedures operating in the market is given, and a nasal endoscopy simulator system is proposed to be an integral part of these scientific innovations.

The contributions of the present study are as follows. We focus on realistic simulation using promising technologies such as Unity 3D, which, through a set of tools, tries to approach the real-life situation through advanced graphical resources. In addition, the fact that the proposed system is designed for desktop computers enhances the general accessibility of the system as its control actions were developed for standard computer peripherals such as keyboard and mouse. Furthermore, we simulate the presence of pathologies, after which their diagnosis can be made by simulating the exam.

Another contribution of this study is that it proposes a virtual simulator for otolaryngology exams capable of training physicians to perform this exam. A review of state-of-the-art methods is also presented. Therefore, this study may serve as a basis for other studies focused on the simulation of exams and surgery in otolaryngology.

2 Theoretical basis and state of the art

Control and realism are fundamental premises to guarantee user immersion in virtual reality. However, certain barriers need to be overcome before these two principles can be applied together in harmony. Thus, references that can transmit crucial knowledge are needed to obtain a greater degree of realism in such projects. Software such as Unity and Blender can provide satisfactory results when combined with good prior knowledge on the subject to be developed.

Systems and equipment for simulating medical procedures for treating various diseases are being increasingly used as an adjunct to improve the efficiency and effectiveness of such procedures. Because of satisfactory results, various alternative procedures have been developed to decrease complications and increase both the adequacy and the similarity between the virtual and the real^[19].

2.1 Current medical procedure simulation methods

Currently, the needs for medical procedure simulations can be divided into six basic categories: human cadavers, humanoid mannequins that can be subdivided into specific parts to create bench mannequins, 3D-printed body parts, use of animals considering some organs between humans and animals are similar, hardware, and software. Some equipment are dedicated to advanced technologies to transmit maximum immersion

and virtual reality of navigation simultaneously. Mimic dV-Trainer^[4], dVSS (daVinci skills simulator)^[5], and Symbionix Robotix Mentor^[6] are equipment that have fully developed hardware and software with manual controls and images and maximum rendering and resolution. In graphic representation studies of human tissues^[20,21], efforts have been made to improve the visual aspects. In this case, the visual quality of the virtual scenes has a direct benefit on the development of relevant skills according to the concept of simulation PSVR (patient-specific virtual reality). Therefore, techniques for good graphic representation of human or animal body tissues are fundamental for the realism of such simulations^[22]. Computer graphics have resources that can simulate the interaction between the brightness of the simulated environment and the virtual texture of the organic material developed. These characteristics are highlighted when realism is preserved in the cutting actions of virtual organic material with 3D internal structures. These systems allow the user to cut anatomical structures arbitrarily, reconstruct the texture on the surfaces of the cutting zone to respect the internal structures, and adapt the mesh in the cutting regions appropriately^[23]. The basic equipment for medical procedure simulation systems can be divided into: bench mannequins; 3D printing; animals; hardware; software; and hardware and software.

Each type of equipment is described in this section, with examples from the most traditional to the most advanced in terms of technology, realism, gameplay, and immersion. Subsequently, the most recent studies of each area are discussed, which reflects the level of interest of researchers and developers in each field.

2.1.1 *Bench Mannequins*

This type of simulation is one of the most common methods used today due to its easy access, and because it resembles human corpses or human parts, in size as well as internal cavities^[24]. A chest surgery simulation course held in Rwanda in East Africa made it possible to accelerate the acquisition of general thoracic surgery skills by general surgery residents in a practical, fast, and accessible way in an environment that offers few training opportunities^[25]. Following the same theme [26] developed a training model for the insertion of a suprapubic catheter that uses a scaled reproduction of an adult male pelvis with bone landmarks.

2.1.2 *3D printing*

3D printing is a technology used to create prototypes for technical products, such as medical implants and even artificial organs, using layers of human cells^[27]. They are characterized as printed bio models that physically reproduce, in three dimensions, body structures using software and a 3D printer^[28,29]. The authors of [30] report on the use of 3D printed parts of structures in surgical simulations for preoperative planning and patient education in cases of correction of deformities in foot and ankle surgeries. In [31] the authors show the paradigm shift in surgical planning through the use of a 3Dgraphy simulator, highlighting the experience of the first 50 surgeries performed by doctors using 3D printed bio models. In another example, a model derived from a patient was developed for neurovascular surgical simulation, where medical students could practice aneurysmal clipping procedures on a geometrically accurate skull and vascular tree^[32]. Similarly, the authors in [33] propose an endoscopic simulation of endonasal skull-based surgery using an artificial skull-based model developed by laser sintering.

2.1.3 *Animals*

In certain cases, procedures are performed on dead animals or organs extracted from them due to their similarity to human organs^[34]. An example of this type of method is the Sinus Model Oto-Rhino Neuro Trainer (SIMONT, Prodelphus, Brazil) that simulates the endoscopic environment so that carotid lesions can be treated within the anatomical limitations seen in the human nasal vestibule, nasal cavity, and nasal cavity—sphenoid sinus^[35]. Another simulation-based training in cardiac surgery has been applied to training modules for

cardiopulmonary bypass, myocardial revascularization, aortic valve replacement, massive gas embolism, acute intraoperative aortic dissection, and sudden deterioration of cardiac function^[36]. Following the same theme, the authors of [37] propose simulation-based learning to improve the acquisition of skills in mitral valve surgery. In this system, the authors submitted an instructional video of porcine mitral annuloplasty.

2.1.4 Hardware

Applications seek better integration between hardware and software to deliver a more realistic user experience. Therefore it would provide the user with an immersive state, which involves introducing them to a specific simulator environment and then performing iteration activities that link what is simulated and what they will find in real situations.

An example of this is a simulator developed to simulate transluminal endoscopic surgery through a natural orifice that manages to provide the feedback with 2 degrees of freedom, and translational and rotational force to the user through the endoscope, yielding 5.62N and 190.05N•mm of continuous force and torque, respectively^[38]. These forces are found in the simulated patient's abdomen. This same level of realism can be seen in the simulation laboratory for pulsatile, tissue, and vascular surgeries for resident training. In this case, three different vascular surgery simulation stations were developed: carotid endarterectomy with angioplasty of shunt and patch, by-pass, and formation of arteriovenous grafts^[39]. Another example of a similar concept is the development and validation of the neonatal endotrainer with reduced space. This model was developed to train residents in pediatric procedures that have difficulty being performed in reduced spaces^[40].

2.1.5 Software

This type of simulation is based on system applications developed for computers that allow professionals to experiment with different medical procedures in an artificial environment. These simulators avoid the use of tools generally used for medical procedures. This type of system was proposed by the authors of [41] who developed a system to simulate maxillo-facial surgery using 3D CT images. Their approach for elastic modeling of human tissue is based on embedded boundary condition techniques that allow simulating craniofacial surgery directly on the patient's tomography image grid. Since then, other studies following the same methodology have been carried out, as well as a hybrid computational simulation of SPECT (single photon emission computed tomography) with preoperative 3D MSCT (multi-slice computer tomography) in breast cancer surgery^[42]. It is relevant in cases where there is a need for greater precision in using actuation tools during the simulator's execution. This factor is linked to the effectiveness of the actions of the surgical procedure during the simulation. A similar methodology was used to set up a computer-assisted surgical simulation for the concomitant reconstruction of the temporomandibular joint and orthognathic surgery^[15]. The authors of [43] present a realistic plastic surgery simulation structure automatically guided by golden ratio data.

2.1.6 Hardware and software

While some studies follow separate hardware and software strands, others try to add greater interactivity by applying the two strands in a single simulation model. Using this theme, an immersive haptic-virtual training can be simulated for eye cataract surgery. The study presents a telesurgery simulation implemented on three display platforms: conventional 2D desktop screen, the Reach in Display, and then on the customized DIVINE (Desktop-Immersive Virtual and Interactive Networked Environment)^[44]. A similar simulation (training) has been set up for enucleation of the prostate by a Holmium Laser^[45]. The study of photorealism in sinus surgery endoscopic simulation had a similar objective of showing how a virtual simulation can obtain satisfactory photorealism and surgical verisimilitude^[21]. On the same theme, the authors of [46] developed a simulation

model for a sinus endoscopy exam. In their prospective, controlled, and multi-institutional study, the effectiveness of a training device called the Endoscopic Sinus Surgery Simulator (ES3) was evaluated^[46]. Another study, based on the virtual reality of basic laparoscopic skills using the Leap Motion device, investigated the potential of a virtual reality simulator to assess basic skills^[47]. Using the same technology, a cataract surgery simulator based on interactive gestures also proposes a realistic medical procedure simulation developed using the game development software^[48]. Similarly, the authors of [49], a mixed reality study, developed a surgical simulator by segmenting critical anatomical structures present in 3D models using a 3D-printed endoscope.

Other examples include a study based on the practice and improvement of endovascular techniques, especially carotid artery angioplasty, angiograms, and angioplasties of other peripheral arteries using an Endovascular Simulator (Mentice VIST G5)^[50].

2.2 Watershed segmentation technique

Assuming that objects in a grayscale image are regions formed by connected pixels owing to their similar grayscale values, it is possible to extract one of these objects or regions using its neighborhood properties. Thus, it is acceptable to assume that if there is a visible difference in grayscale levels between two neighboring pixels, it can be interpreted that they belong to two distinct objects in the image^[51].

To highlight one of these objects in the image, segmentation techniques must be used. Among the most used, there are two segmentation approaches: edge detection and region growth. In the case of region growth, homogeneous regions are located. The growth of these regions is based on similarity measures combining spatial or spectral attributes and is carried out until all image pixels are associated with a region^[52]. In contrast, in edge detection techniques, an object in an image usually has a slight variation in grayscale and a sharp gray level variation in the vicinity of a pixel characterizes these edges. Therefore, we conclude that the task of an edge detector is to find these variations. Among the main tools of mathematical morphology that use segmentation techniques is *Watershed*, which consists of a combination of the previously mentioned techniques^[53].

The *Watershed* segmentation technique is based on the gradient of the pixels. The method permits the image to be interpreted as topographic relief. Therefore, the intensities in the gray gradients are understood as altitude in this relief. The term basin is related to water, meaning that water is drained in a specific area. Dams are classified as *Watershed* and the entire segmented part is a *watershed*^[54]. In image processing, gradient values depend on pixel intensity. The gradient region of greatest intensity is *Watershed*, which is divided into the nearest local minima^[55].

In this case, the morphological gradient agent of an image can be used to obtain the contour in binary images or to highlight the contours in grayscale images, as can be seen in Equation 1^[56].

$$g(I) = (I \oplus B) - (I \ominus B) \quad (1)$$

where $g(I)$ represents the gradient function, (I) is the original image, $(I \oplus B)$ is the dilation of $(D_B(I))$ using the structuring element B , and $(I \ominus B)$ depict the erosion $(\in_B(I))$ of (I) using the structuring element B .

Through Equation 1, it is also possible to obtain the internal gradient, called g^- and which is defined by Equation 2, which expresses the difference between the original image and its erosion, highlighting the internal contours of the objects in the image. In contrast, external gradient g^+ is represented by Equation 3, which expresses the difference between the image dilated and the original, reinforcing the external contours of the objects.

$$g^-(I) = I - \in_B(I) \quad (2)$$

$$g^+(I) = D_B(I) - I \quad (3)$$

Thus, it is possible to conclude that *Watershed* is a morphological method, where the gradient values of the

image pixels are calculated, structuring a topographical relief with smaller gradients forming the valleys and the larger ones forming the mountains. The contours that form the edges are obtained from the convergence regions of the basins formed by the flood. The pixels of these basins are grouped based on the search for values close to each local minimum^[56].

2.3 Simulators for training medical procedures in the literature

A list of simulator systems is given in [Table 1](#) to demonstrate the types of simulators for training medical procedures. A literature search based on relevant words ("virtual reality", "surgery simulation", "medical procedure simulation", "surgery training", and "training systems") related to this study was carried out on Science Direct, Scopus, and Web of Science bibliographic bases. Articles considered relevant and current in their respective categories were included. Systems that involved the use of human corpses were excluded from the list because they do not use innovative technologies to carry out training and simulation.

Based on the cited keywords and development model, those articles were chosen that showed the development of technology, explaining the methodology used, and that were in agreement with the development assumptions that major technologies in medical studies use today: the display of data during simulation; display of results at the end of the simulation; texture fidelity; fidelity in lighting; topology deformation when touched; no loss of detail; use of hardware for control; and specialty and application. Articles that deal only with the validation of systems already presented in other works, case studies, or work studies were excluded.

Technologies and equipment used for teaching have become more expensive and inaccessible, and only a few educational institutions are able to buy them. Furthermore, surgical activities have been demanding a greater degree of assertiveness from professionals. Thus, the use of more accessible technologies allows the study and practice of surgical techniques in earlier semesters of medical courses.

During the selection of articles from the literature, those that presented the technologies used and the results obtained in improving medical-surgical skills were prioritized. In addition, articles were sought that presented results that could be compared with other works, quantitatively or even qualitatively, to serve as a reference for developing new technologies.

[Table 1](#) provides a list of studies involving the simulation of medical procedures as an instrument for training students and professionals in their respective fields. [Table 1](#) is classified by author, year of publication, reference course of the work, and institutions involved in developing the simulators. The model section shows the type of simulator applied and, thus, the technology used. Furthermore, [Table 1](#) displays the specialty of the simulator's area of expertise and the educational level for which it was developed (that is, students, teachers, or both). In addition, the table informs the educational context showing the location where the simulator can be used. The last column of the table gives the duration of instructions required to complete the training for each simulator. This parameter was not reported in some studies. The institutions were included in the analysis to help find other related works, thesis, and technical reports about this theme and identify the prominent institutions researching the subject. The target audience was analyzed to distinguish test environments, whether academic or professional. The duration of the instructions were helpful in determining whether the tests were fast or long, which can, in turn, determine longer or shorter immersion times.

In short, [Table 1](#) shows the contribution of simulator systems for training in medical procedures. Using such training tools is very promising and its application will undoubtedly increase in the coming years. Based on each study, one can highlight the main points of significance, focus, dedication, and interest and consider other research areas. Thus, observing the data for each study that has already been validated, it is possible to point out the more critical regions of interest to bring reality as close as possible to the virtual, using:

- Interactivity with feedback from actions taken;
- Approximation of the realism of the simulated procedure in accordance with what occurs in the field;

Table 1 Comparison between medical procedure simulator systems

Authors	Year	Course	Institution	Model type	Specialty/ Application	Target audience	Educational context	Duration of instruction
Valentine et al.	2016	Otorhinolaryngology	University of Adelaide	Bench model using sheep	Nasal endoscopic surgery	Students	Academic laboratory	Uninformed
Ramirez et al.	2018	Pneumatology	University of Virginia	Bench model	Thoracic surgery	Surgeons	Academic laboratory	2 hours
Singal et al.	2015	Urology	Feinberg School of Medicine	Bench model	Insertion of suprapubic catheters	Students	Academic laboratory	2 days
Jastifer et al.	2017	Pediatrics	American College of Foot and Ankle Surgeons	Software-aided 3D printing	Orthopedic surgery	Students and surgeons	Academic laboratory and Surgery room	Uninformed
Bagaria et al.	2017	Orthopedics	HN Resilience Mumbai Foundation Hospital	Software-aided 3D printing	Orthopedic surgery	Students and surgeons	Academic laboratory	Uninformed
Ryan et al.	2016	Neurosurgery	Schools of Biology and Health Systems Engineering	Software-aided 3D printing	Neurovascular surgery	Students	Academic laboratory	Uninformed
Oyama et al.	2014	Otorhinolaryngology	Ohio State University	Software-aided 3D printing	Nasal endoscopic surgery	Students	Academic laboratory	Uninformed
Feins et al.	2017	Cardiology	University of North Carolina, Johns Hopkins, West Indies, Stanford and Rochester	Bench model using unspecified animal	Cardiac surgery	Students and surgeons	Academic laboratory and Surgery room	3 to 4 hours
Joyce et al.	2011	Cardiology	Stanford University, North Carolina, New York, Yale, New Haven and Conn	Bench model using porcine	Cardiac surgery	Students and surgeons	Academic laboratory	3 weeks
Dargar et al.	2014	Gastroenterology	Rensselaer Polytechnic Institute of Troy	Hardware	Colonoscopy	Surgeons	Academic laboratory	Uninformed
Fletcher et al.	2017	Angiology	Virginia Tech School of Medicine	Hardware	Cardiac surgery	Students	Academic laboratory	Uninformed
Wang and Du	2007	Orthopedics	Harbin Institute of Robotics and Technology of China	Software	Orthopedic surgery	Students and surgeons	Academic laboratory and Surgery room	Uninformed
Nikolic et al.	2015	Oncology	Kragujevac Faculty of Medical Sciences e Universidadde de Kragujevac	Software	Breast tumor surgery	Students and surgeons	Academic laboratory	Uninformed
Wolford et al.	2016	Orthodontist	University of Texas Health Sciences Center	Software	Orthognathic surgery	Students and surgeons	Academic laboratory	Uninformed
Jianfeng et al.	2016	Facial Cosmetology	Jishou College of Information Science and Engineering	Software	Facial Plastic Surgery	Students and surgeons	Academic laboratory and Surgery room	Uninformed
Novelli et al.	2014	Oral and maxillofacial trauma	Milano University	Software with the possibility of 3D printing assistance	Orbital wall reconstruction surgery	Students and surgeons	Academic laboratory	Uninformed
Yada et al.	2018	Pediatrics	Tokushima University	Software	Minimally invasive pediatric surgery	Students and surgeons	Academic laboratory and Surgery room	Uninformed
Shen et al.	2007	Ophthalmology	School of Information Technology and Engineering and University of Ottawa	Software operating alongside hardware	Eye Cataract Surgery	Students	Academic laboratory	Uninformed
Kuronen-Stewart et al.	2015	Urology	King's College of London	Software operating alongside hardware	Enucleation of the Prostate	Students and surgeons	Academic laboratory	15 minutes
Ruthenbeck et al.	2013	Otorhinolaryngology	Faculty of Computer Science, Engineering and Mathematics, Flinders University, South Australia	Software operating alongside hardware	Endoscopic sinus surgery	Students and surgeons	Academic laboratory	Uninformed

(Continued)

Authors	Year	Course	Institution	Model type	Specialty/ Application	Target audience	Educational context	Duration of instruction
Lahanas et al.	2017	Laparoscopy	Laboratory Simulation Center for Medical Physics, Faculty of Medicine, National and Kapodistrian University of Athens	Software operating alongside hardware	Basic laparoscopies	Students	Academic laboratory	Uninformed
Jayakumar et al.	2015	Ophthalmology	Amrita Vishwa Vidyapeetham University	Software operating alongside hardware	Eye Cataract Surgery	Students	Academic laboratory	Uninformed
Vashney et al.	2014	Otorhinolaryngology	American Academy of Otolaryngology-Head and Neck Surgery Foundation	Software operating alongside hardware	Nasal sinus surgery	Students	Academic laboratory	7, 50 minutes
Barber et al.	2018	Otorhinolaryngology	American Academy of Otolaryngology-Head and Neck Surgery Foundation	Software operating together with hardware and printed 3D model	Nasal sinus surgery	Students	Academic laboratory	Uninformed
Cordeiro Neto et al.	2021	Angiology	Fortaleza General Hospital (HGF)	Software operating together with hardware	Vascular surgery	Students	Academic laboratory	Uninformed
Torres et al.	2020	Pediatrics	Brazilian College of Digestive Surgery	Hardware	Laparoscopic for neonatal surgery	Students and surgeons	Academic laboratory	Uninformed
This work	2021	Otorhinolaryngology	Federal Institute of Ceará	Simulation Software	Nasal endoscopy exam	Students	Academic laboratory	4 minutes

- Control of actions and movement;
- Cause immersion;
- Accessibility.

Based on the theoretical and practical knowledge acquired from the studies mentioned in [Table 1](#), this project was developed to simulate standard medical procedures of medical professionals' daily routines and provide the user with a practical and interactive way of acquiring such knowledge.

3 Proposed methodology

The method to develop the system involves using the software tools in such a way as to optimize the whole structure, as illustrated in [Figure 1](#). This method potentializes a better user experience during gamification as it preserves the quality of the regional mesh to be examined and eliminates the presence of elements that can compromise the simulator's performance. Thus, the methodology maintains the integrity and realism of the simulations.

3.1 System using computed tomography exam

A more realistic version of the nasal cavity was developed using a CT scan, which was imported into the InVesalius software environment. When importing the folders containing the medical images in DICOM files, the InVesalius system will load all the slices of the exam.

Another screen of this software environment presents data about the patient and the exam performed. Thus, all the exam slices are displayed and the respective information such as:

- Exam description: sinuses/face;
- Number of images generated by the exam: 301;

- Size of the image generated by the tomography device: 512×512 pixels;
- Spacing between slices: 1mm.

The images were regrouped by the computer software with intermediate cuts, jumping two out of three slices while preserving the integrity of the exam and retaining the effect of the 3D file. The result is a detailed and multidimensional view of the internal organs. The slices or cuts have a thickness of approximately 0.7mm. The difference between taking advantage of all the slices of the exam file or not is directly related to the impact the file causes regarding the amount of data represented, mainly in the details of the generated mesh. Consequently, all the slices result in a massive number of vertices and faces. After the import of the file is complete, the exam filtering configuration is required because parts that are not part of the nasal cavity appear as floating points in the file. This shortcoming is due to noise in the exam, which is detected when the file is imported into the Blender platform, causing a significant excess in file size. This amount of data affects the real-time execution of the system, causing computers with lesser processing capacity to crash.

The different settings that can be chosen to optimize the space occupied by the generated input files are assigned through the InVesalius software. The configuration is divided into four parts. The first is the choice of the number of slices to be imported. The second is the filter of the soft, hard, and liquid parts of the exam region. The use of the InVesalius software allows the segmentation of these pre-established regions.

To target a specific structure, the region of interest must first be defined. However, the software provides some pre-established settings for segmenting the images. For example, when choosing a configuration option, the software indicates the slice which area corresponds to the selected option. In this study, we segmented the adult epithelial tissue that varies between -718 and -177 UH. A green shade mask was used to highlight and visualize the area of interest. Depending on the exam and patient, it may be necessary to manually adjust the threshold value to suit the specific characteristics of each specific case. It may also be necessary to make small changes in the threshold when running the slices because the density of the material can vary with the displacement of the slices. By default, the Watershed technique is used to target the chosen region more efficiently. In the third step, the 3D surface of the region that the mask filtered and segmented is then created. Then in the fourth step, the segmented region is imported. The file is generated in the OBJ format, which contributes to optimizing the system.

The Watershed technique in this study was applied on the CT exam while still in the InVesalius software. The

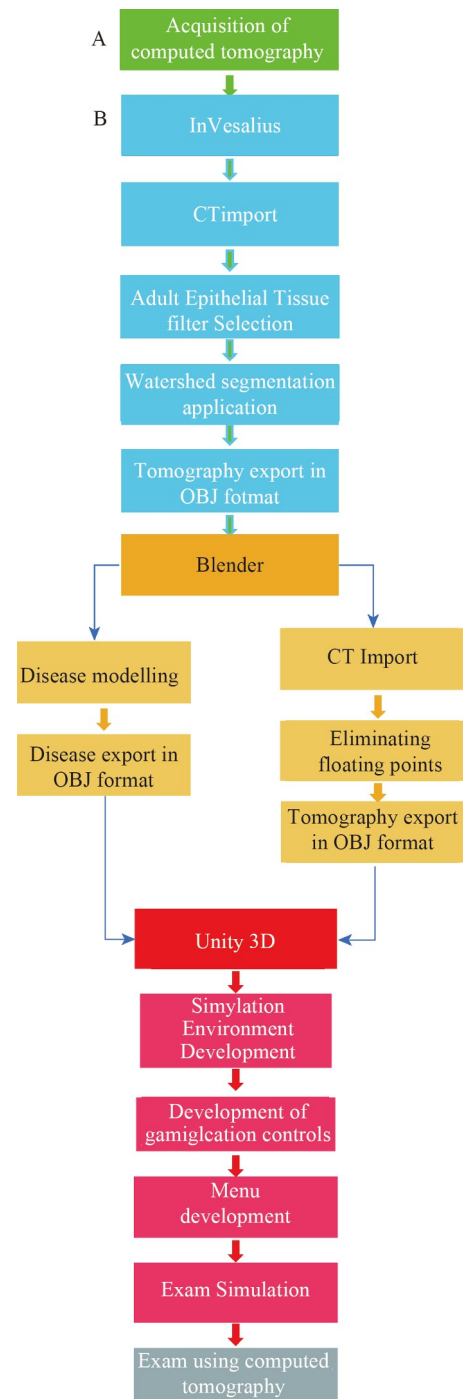


Figure 1 Workflow diagram of system development.

Watershed technique provides a better segmentation of the nasal cavity region, which is the region of interest in this case, and it can detach the adult epithelial tissue without noise when exporting the file. Without the Watershed technique, this process could result in loose meshes and undesirable floating points in the exported 3D file. Therefore, choosing the Watershed option and opening the editing panel is necessary to use it in InVesalius software. In order to clean the mask and help obtain a better result, the option "Overwrite mask" is chosen, and any data that may harm the segmentation are cleaned/removed. After cleaning, it is necessary to select the option "Consider brightness and contrast" for the system algorithm to consider the image being viewed, and if necessary, change the brightness and contrast in order to obtain better segmentation results^[57].

The connectivity of the pixels that will be taken into account can be changed. In 2D, it is possible to select connectivity 4 and 8; in 3D, we can select 6, 18, or 26. The Gaussian standard deviation can be changed to smooth the image when applying segmentation. It is important to note that high mean and standard deviation values tend to smooth the image. Consequently, the algorithm selects fewer details and noise. The correct adjustment of these filtering parameters is essential, as the inadequate filtering of noise in the images can affect both the processing and the graphic quality, as shown in [Figure 2](#). As we can see, the arrows point out the presence of some undesirable noise. Finally, only the region with the largest surface is placed into the file before exporting it to the Blender platform.

After processing the CT examination file, the development elaborates the environment that receives the model file. Thus, the entrance environment was planned with an initial screen and a button with the name of nasal endoscopy, giving access to a new screen. The entire application can be prepared in six panels that together make up the Unity editing environment. The panels are display and execution panel, scene editor, objects allocated to the scene panel, object editor, and project folder location. Within the object canvas, the button was assigned, which became part of the object's hierarchy. It was positioned and centralized within the scene editor.

In order to prepare the first display screen, the background image was imported into the project, where it was positioned in the scene editor panel and allocated within a canvas object that is suitable for displaying interface screens. Unity allows the call of functions and the association of scenes and objects so that there is an interaction between them, in which everything can be done through settings adjustments that can be changed manually or through scripts. In the case of the button, for the following scene call interactions to occur, an appropriate script was attached to import the next scene. [Figure 3](#) shows the Unity development interface panel, elaborating the design of the first scene and the button that will open the next scene.

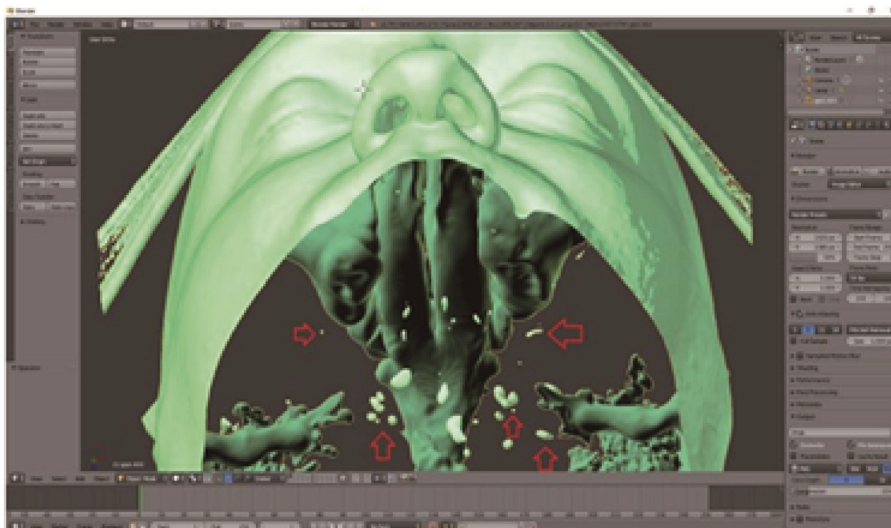


Figure 2 CT scan image in three-dimensional format with the presence of noise and loose stitches.



Figure 3 Unity development interface panel designing the first scene.

In the second scene, it will be the environment that will receive the TC 3D file. With access to the TC model package, it is possible to import the TC 3D file into the Unity software. It is important to note that when importing the package, it is necessary to allocate the textures and lighting configuration of the scene editor's development environment and adjust its tonality, brightness, and shadow production through the settings in the object editor. The same occurs when importing diseases and the modeled tool used for touch and navigation within the nasal cavity of the model. It is crucial to maintain the quality of realism as a model that is close to reality is used, which allows transmitting the maximum experience in virtual reality.

Another critical factor is the reaction to the touch between tool and disease. Each disease has a reaction to touch, which, according to its density and size, has movements that, when compared, are very similar to the real touch. For this, a script is developed for each disease as each disease has its particularity. Script files were associated with each modeled disease that can have their adjustment parameters configured through the object editor.

Next to the model, in the head region, we can observe a button with the illustration of a magnifying glass representing the zoom of approximation of the region of interest in the exam simulation. The bottom of the screen contains five buttons that have also been assigned and positioned conveniently in the scene editor. With specific functionalities, each button has its interaction action with the gamification environment. At the bottom left of the same screen, we see a counter that the simulation procedure starts to be timed according to the exam duration.

Treatment of the 3D CT scan examination file

When the 3D CT examination file is received, some vertices and faces of lesser interest need to be eliminated. Thus, the filtered file in the InVesalius software is imported to the Blender platform, where the mesh cuts are performed. In this case, another filtering is performed, changing vertices and faces and eliminating regions disconnected from the file. This application is only applied to the nasal cavity region, and therefore, the quality of this region must be maintained. The other regions, such as the skin of the face and the ear canal, can be altered or eliminated. [Figure 4](#) shows the steps taken in the Blender to handle this file.

[Figure 4a](#) shows the initial file exported by the InVesalius software without any treatment. Then, [4b](#) exposes the mesh with its vertices and faces of the file on the 3D surface. The mesh remains uniform and with a large volume of data because it currently has 1452272 vertices, 4314012 edges, and 2859297 faces. [Figure 4c](#) shows the result after excluding the loose loops and regions of lesser interest, such as the auditory canal and any noise

still present. In [Figure 4d](#), the mesh with its vertices and faces of the file on the 3D surface is exposed after merging the regions. Now the data have 255317 vertices, 699254 edges, and 443371 faces. Finally, [Figure 4e](#) shows the rear view of the 3D file after all treatments. Thus, a lightweight 3D file model is presented without loss of quality and with no visible noise or loose meshes that compromise the performance of the system.

The file is imported into the Unity software in the OBJ format generated by Blender in 3D. In the scene editor, the model is located such a way that the entire menu panel, buttons, and controls developed for the system can be activated quickly. In this way, the user has access to a more realistic and easy-to-use model.

In this simulation, the table used as support for the CT is modeled in Unity itself. The model to be examined is placed in the supine position. Therefore, ambient light is also assigned to the scene to highlight the model and make the examination location intuitive for the user.

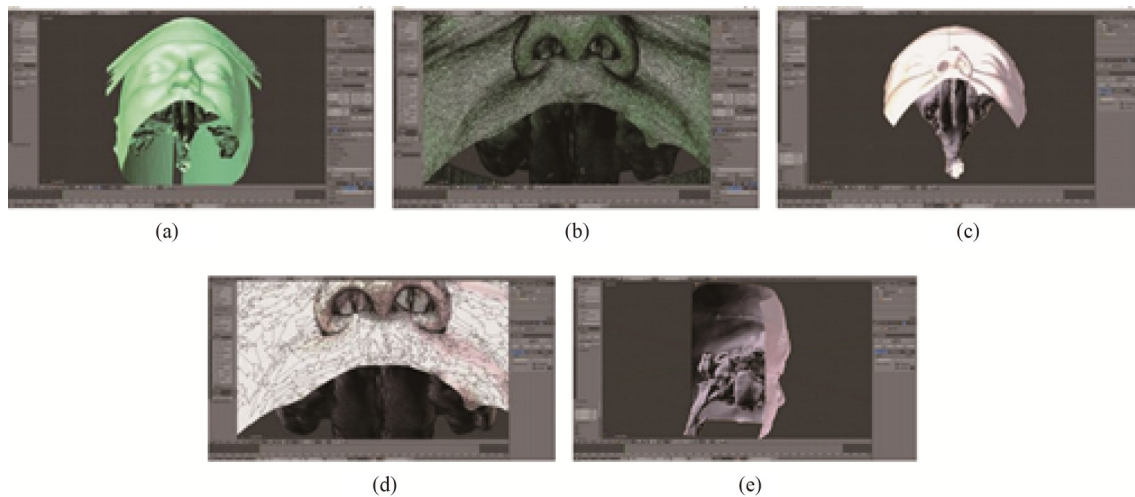


Figure 4 Treatment of three-dimensional mesh file of computed tomography examination: (a) file exported by software InVesalius, (b) exposure of the mesh with its vertices and faces of the file on the 3D surface, (c) result after exclusion treatment of loose meshes and regions of less interest, (d) exposure of the mesh with its vertices and faces of the file on the 3D surface after treatment and (e) front view of the file after treatment.

3.2 System operation

The software developed was composed of a didactic system for navigation and identification of diseases using tomography images for manufacturing a 3D model of the face and nasal cavities.

The 3D file model (CT) acquired for the application and the diseases modeled in the Blender software were imported into the Unity software, which allowed the development of the simulation system following the principles of gamification [58,59]. The software has an interactive and easy-to-use interface and has access to user resources. The control used resembles the control and gamification of computer games used today. Therefore, a computer was chosen for the software, and the entire control was adapted for its exclusive use. [Figure 5](#) demonstrates the usability flowchart of the software.

In this flow, as the user starts the procedure, a countdown starts automatically. Then, the camera and the instrument are brought closer to the region where the exam will be performed until immersion in the nasal cavity occurs. It allows for full navigation through the identification of pathologies. At the end of the procedure, the results of the adjustments are displayed on the panel.

The first screen shows the exercise options, and a click on the Nasal Endoscopy button displays a new screen, which will be the gamification interface. The system contains a menu composed of a runtime counter when starting the exam, and beside it, a set of buttons responsible for starting, stopping, ending, restarting, and showing the tool used, a vacuum cleaner. In addition to these buttons, there is a magnifying glass for increasing

the zoom. The magnifying glass allows the user to immerse himself inside the nasal cavity of the model.

The development and evaluation of the simulator used a computer with a medium configuration: Windows 10 operating system (64-bit), Intel core i5-7400 processor, 3.0GHz, 6MB cache, four cores, 8GB 2400MHz memory, GeForce GTX 1060 6GB wind force graphics card, and disk hard drive 1000GB SATA 64MB cache. This configuration was maintained throughout to accomplish all the tasks available in the software.

4 Results

The evaluation method adopted for this study is similar to other evaluations carried out in related studies found in the literature [20,21,48,49,60,61]. These studies were used as a reference to generate the results expected for this study. The materials developed, such as meshes, textures, lighting, control, a platform of use, and specific utilities, are mentioned and compared in the references. The studies presented simulate the different types of resources used during the procedures performed in executing an actual exam. Thus, through comparisons with authentic images, surveys seek to expose their results and highlight their validations. These references resulted in the development of Table 2, which shows the characteristics of each study.

4.1 Software control operation

All the simulator controls were adapted to the ones that already exist on a computer and user configurations in current computer games to help ease of use, better navigation, and simulation control.

The navigation keys on the computer keyboard serve to control the camera, which is responsible for viewing during navigation. The alphanumeric keys are used to control the movement of the camera and the four

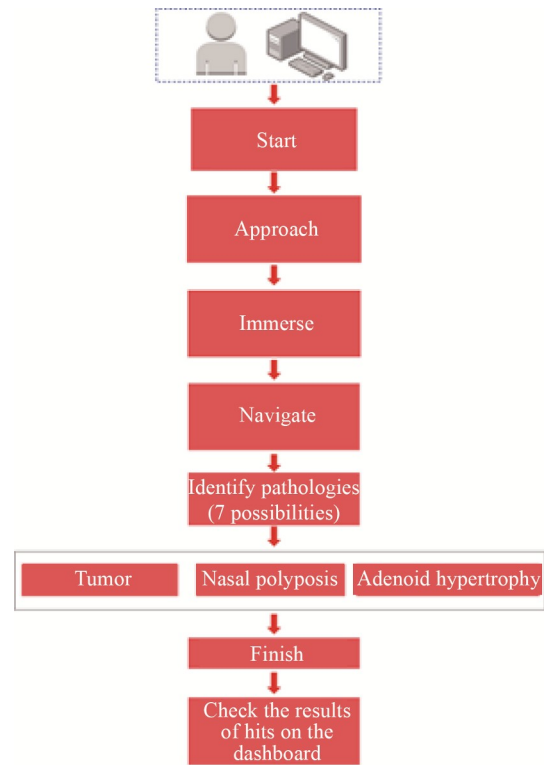


Figure 5 Diagram representing a typical system operation session.

Table 2 Comparison table of system characteristics

Atributos	Simuladores						
	Virtual FESS	Delineation and Splitting in Virtual Liver Surgery	Surgery Simulation Multi-modal Interactive System	Interactive Medical Simulator Using Leap Motion	Intelligent SDK for 3D Surgery Simulation	Photorealism in endoscopic sinus surgery simulation	Simulator using tomography
Data during simulation	X		X	X	X	X	
Results after simulation		X	X	X	X	X	X
Fidelity in textures		X			X	X	X
Lighting fidelity	X			X	X	X	X
Topology deformation		X	X	X	X	X	X
Loss of details		X		X	X	X	
Control hardware	Oculus VR +Enoscope	Phantom omni +3D device	Phantom omni	Leap Motion	Tablet	Phantom omni + Endoscope	Computer
Specialty / Application	Nasal endoscopy	Liver splitting surgery	Endonasal endoscopy surgery	Cataract surgery	Laparoscopic cholecystectomy	Endoscopic sinus surgery	Identification of pathologies by nasal endoscopy

movements (front, bottom, left and right) of the tool.

4.2 System using computed tomography exam

Based on a CT scan, the proposed simulator system simulates the nasal endoscopy exam and navigates inside a reconstructed nasal cavity. In addition, some common diseases displayed in the simulator at random and in the atlas version can be seen.

Figure 6a shows the scenario that appears when the exam starts. On clicking the Start button, the exam runtime counter will start, and the tool and the view of the exam camera are displayed on the screen. The user has control of the tool and camera like in the atlas version and a real exam. On clicking the magnifying glass button, the camera view approaches the 3D model in an appropriate position for immersion into the nasal cavity of the model, as shown in Figure 6b. Another magnifying glass click provides a complete immersion into the nasal cavity. The entrance of the nasal cavity can be seen in Figure 6c.

During sample navigation presented in Figure 6, we can see three types of pathologies (namely, nasal polyposis, adenoid hypertrophy, and a benign tumor) that will be displayed at random. These pathologies may or may not be present during a real virtual immersion. Figure 6d illustrates the presence of nasal polyposis. Figure 6e shows the reaction of the pathology when touched by the tool. Figure 6f shows the presence of another pathology, in this case, a benign tumor. Figure 6g shows the presence of the third pathology, adenoid hypertrophy. Finally, clicking Finalize brings up a notepad with the name of the pathologies that were present in the exam, as demonstrated in Figure 6h.

4.3 Mesh and textures evaluation

In order for the simulator to present a greater degree of realism, it is necessary to pay attention to the deformation characteristics of the mesh when the interaction forces are applied. In addition, textures similar to the real thing must be obtained^[21], which requires correct usage of brightness and shading. These together, combined with a good texture of the material, enable excellent results in such applications^[48,60]. Figure 7a gives a comparative evaluation of what was developed with reality [20].

Figure 7a shows the nasal cavity with nasal polyposis pathology. Right next to it, in Figure 7b, the simulation of the polyposis present in the nasal cavity of the 3D model of the simulator is illustrated, with the brightness and viscosity present according to the real one. Figure 7c shows the walls of the nasal cavity with the presence of glare and reflection caused by the illumination of the examining instrument on the viscous surface containing the nasal fluids. Figure 7d shows the nasal cavity wall present in the simulator using CT. The exact characteristics of texture, brightness, reflection, and mesh modeling are the same as the real one. Finally, Figure 7e shows the soft tissue reaction of the nasal polyposis when touched by the tool. Figure 7f illustrates the mesh deformation when touched by the tool inside the simulator.

In [49], the lack of texture realism is noted. We can perceive no interaction between the brightness and the material used to simulate the model. Similarly, this lack was also noticeable in a multimodal interactive system for simulating surgery with an endoscopic approach presented in [61]. The 3D model used in the system does not provide the similarity required in simulators as it does in this present study that followed the guidelines of the photorealism simulators for the simulation of endoscopic sinus surgery developed by [21] and the design simulator and division for virtual liver surgery developed by [20]. A comparison of the characteristics of these studies cited can be seen in Table 2.

4.4 Method for survey results

Table 2 provides a brief description of the systems that address the same theme and use similar technologies. Table 2 is divided into eight parts, which are:

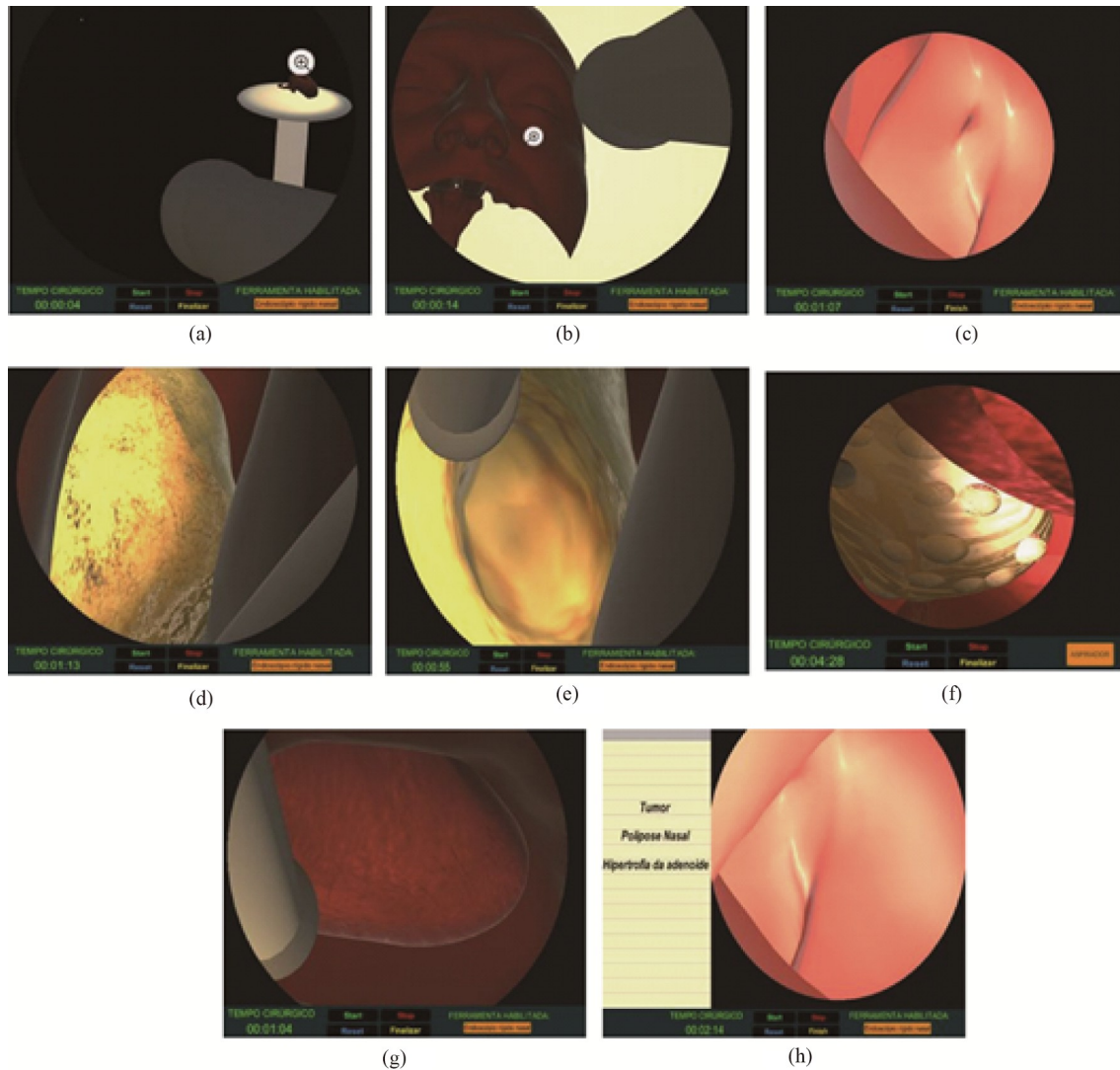


Figure 6 The sequence of display of screens during the execution and navigation of the simulator using the Computed Tomography exam: (a) Input screen of the simulator, (b) screen displayed when starting the exam, (c) screen displayed when clicking on the magnifying glass, (d) screen displayed when clicked on the immersion loupe, (e) screen displayed when traversing the nasal cavity illustrating nasal polyposis, (f) screen showing the touch reaction when touching the tip of the tool on soft walls, (g) screen showing the presence of benign tumor, (h) screen showing the presence of adenoid hypertrophy and (i) screen displayed when clicking on the Finish button.

- Data during simulation: A display of data (such as the applied force of the tool on the organ tissue, blood pressure, and execution time) or reports is presented during the execution of the simulator;
- Results after simulation: Data or reports are displayed when the simulator has finished running. In this case, depending on the theme followed, data or reports display everything that occurred during the simulation, for example, total time, failures, and scores;
- Fidelity in textures: This indicates when the simulation resembles the reality. In this approach, the simulator imitates the real textures of the organ tissues;
- Lighting fidelity: This indicates when lighting interaction occurs, according to the execution of movements during the simulation. The presence of light rays originating from a point on the object is noticed converging with materials, causing refractions, and shadows;
- Topology deformation: This indicates when the 3D object mesh deformation occurs, causing deformation of the tissue of the simulated organ. Topology deformation generally occurs when the tool used by the user touches the tissue of the simulated organ;

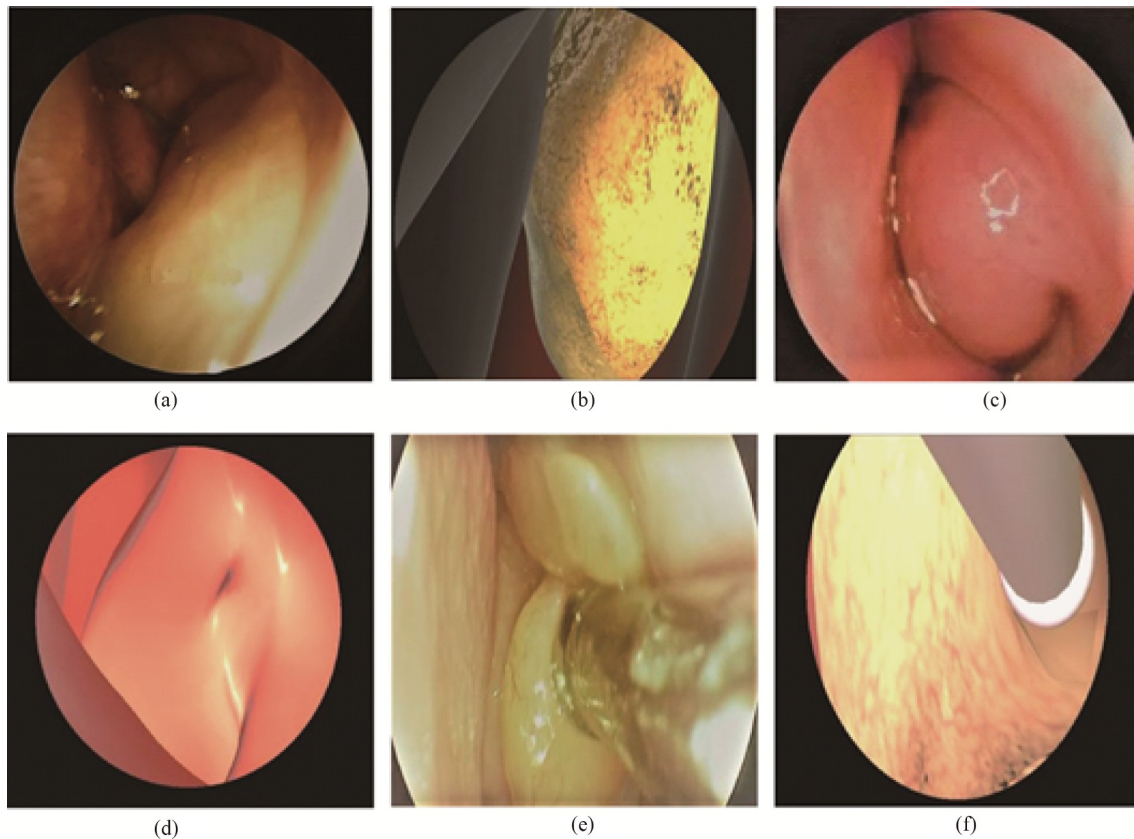


Figure 7 Comparison of mesh and texture modeling results: (a) image of nasal polyposis^[62], (b) nasal polyposis modeled for simulator, (c) image of the nasal cavity^[62], (d) image of nasal simulator cavity using Computed Tomography, (e) image showing the reaction of nasal polyposis to the touch of the tool and (f) illustration of deformation of the mesh when touched.

- Loss of details: This occurs when the simulator imitates the curves of tissues in organs and sections of cavities. The presence of details in the simulator is essential for the occurrence of user immersion together with textures, lighting, and deformation of mesh connected with the reality;

- Control hardware: This shows how the user interacts with the system, transmitting the movements to the simulator;

- Specialty and application: This indicates the purpose of the simulator.

The penultimate column of [Table 2](#) presents the version of the simulator developed in this work. The system's characteristics help to understand its features and the focus of the study. Furthermore, this shows its advantages and, thus, its contributions in this segment.

[Table 2](#) highlights the points of greatest interest in applications of these studies^[20,21,48,60]. The main characteristics present in each study are marked with "X". In this case, the first simulator shown in [Table 2](#) is the Virtual FESS that displays data during the simulation and is reliable in terms of lighting. However, there is no display of the results at each end of the simulation run. Furthermore, it did not maintain the fidelity to the fabric simulation textures, and it does not present the topology deformation when touched by the tool. In addition, there is a loss of important color details of textures and brightness.

The second column in [Table 2](#) is Delineation and Splitting in Virtual Liver Surgery, which displays data at the end of the simulation, the fidelity of the textures in terms of their similarities to the reality, and deformation of the topology of the simulated tissue mesh when touched by the tool. However, it does not present the loss of details of the quality of the simulated fabric. Moreover, the simulator does not display data during its execution and does not maintain the similarity regarding the brightness quality.

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are displayed both during the execution of the simulator and at the end of the execution. Then points of failures and successes are presented. In addition, it presents a good mesh deformation during the interaction with the tool used. However, it does not have a good quality of texture and simulated brightness. This lack of quality introduces a loss of detail and, therefore, affects the quality of the simulator.

In [Table 2](#), the fifth study tries to present a complete form of a simulator, except for the fidelity regarding the quality of the textures on the simulated objects. In this case, the simulators that present a higher level of fidelity to reality are the Intelligent SDK for 3D Surgery Simulation and Photorealism in endoscopic sinus surgery simulation—presenting all the characteristics shown in [Table 2](#).

The version of the simulator developed in this study is present in the last but one column of [Table 2](#). It is possible to observe all the characteristics of the simulators. In this case, there is no data display during the execution of the simulation. Despite that, the presence of all the other characteristic points regarding the quality of the simulation is confirmed, and there is no loss of essential details as seen in the Virtual FESS, Delineation and Splitting in Virtual Liver Surgery, Surgery Simulation Multimodal Interactive System, and the Interactive Medical Simulator Using Leap Motion. In addition, compared with the other simulators, as can be seen in the seventh column of [Table 2](#), the system developed in this study has an accessibility facility, as it is possible to be installed on a computer and the user can use the peripheral resources already present (keyboard and mouse) to interact during the simulation. Knowledge acquisition occurs through virtual environments of gamification coherently and practically^[63–65].

Execution time of the entire simulation depends on the number of diseases to be detected, which can take up to 2–4min. CT files are pretty dense with information. Thus, computing performance and user comfort still remain challenging to achieve, requiring better quality configuration computers. For this reason, it was essential to minimize the number of vertices, edges, and faces that are most suitable.

5 Conclusions

This study shows a differentiated approach to simulate the nasal endoscopy exam procedure in a virtual system using advanced graphic rendering. Furthermore, it provides a realistic environment for the training of the exam procedure. A method of filtering and remodeling in a triangular mesh is proposed, which can serve as a new model for the simulation system for nasal endoscopy exams and can be used to identify pathologies.

The proposed approach allows developers of new training sets to optimize their applications, transforming the 3D model used in a lighter and more compact file while maintaining the graphic quality, realism, and required processing. Then, it will be possible to prepare practical tests and improve training efficiency. As a result, this study allows the user to obtain the necessary practical skills without risk to actual patients in conditions that resemble the real-life operating room, thus, significantly reducing the number of surgical errors, improving the perception of identification of different pathologies, and serving as a tool that assesses the knowledge and skills developed by professionals. This study also shows the way gamification works in practice, its principles in a simulator system, its importance in practical application, simulator evaluation, and results.

All the simulated procedures in this endoscopy exam were checked and compared with the standard procedure. Compared with simulators based on real-time mesh manipulation rendering, the proposed approach demonstrates its precision in virtual endoscopy through its graphic quality. Consequently, the system developed in this study may be considered accurate and appropriate to be used in standard medical practices. The graphic quality and accessibility of the proposed method make it competitive compared to other methods used in similar applications found in the literature. The file optimization method used in this study makes development and processing agile, and as a result, it is feasible and can serve as a basis for other researchers carrying

out this type of research.

However, this study was limited to simulating nasal endoscopy. The simulation does not use specific hardware and aims to detect only the following pathologies: hypertrophy of turbinates, septal deviation, adenoid hypertrophy, nasal polyposis, and tumor.

Therefore, it is necessary to perform a complete medical validation of the system and a deeper quantitative analysis of the results, in addition to surveying the educational impact on medical education institutions. The search for new technologies and updating the literature review can also be considered in the future.

Declaration of competing interest

We declare that we have no conflict of interest.

References

- 1 James M. Should not be implanted in isolation after infarction. *BMJ*, 2011, 342(jan11 2): d83
DOI: [10.1136/bmj.d83](https://doi.org/10.1136/bmj.d83)
- 2 Sturman N, Tan Z, Turner J. "A steep learning curve": junior doctor perspectives on the transition from medical student to the health-care workplace. *BMC Medical Education*, 2017, 17(1): 92
DOI: [10.1186/s12909-017-0931-2](https://doi.org/10.1186/s12909-017-0931-2)
- 3 Gavazzi A, Bahsoun A N, Van Haute W, Ahmed K, Elhage O, Jaye P, Khan M S, Dasgupta P. Face, content and construct validity of a virtual reality simulator for robotic surgery (SEP Robot). *The Annals of The Royal College of Surgeons of England*, 2011, 93(2): 152–156
DOI: [10.1308/003588411x12851639108358](https://doi.org/10.1308/003588411x12851639108358)
- 4 Kenney P A, Wszolek M F, Gould J J, Libertino J A, Moizadeh A. Face, content, and construct validity of dV-trainer, a novel virtual reality simulator for robotic surgery. *Urology*, 2009, 73(6): 1288–1292
DOI: [10.1016/j.urology.2008.12.044](https://doi.org/10.1016/j.urology.2008.12.044)
- 5 Judkins T N, Oleynikov D, Stergiou N. Objective evaluation of expert and novice performance during robotic surgical training tasks. *Surgical Endoscopy*, 2009, 23(3): 590–597
DOI: [10.1007/s00464-008-9933-9](https://doi.org/10.1007/s00464-008-9933-9)
- 6 Whittaker G, Aydin A, Raison N, Kum F, Challacombe B, Khan M S, Dasgupta P, Ahmed K. Validation of the RobotiX mentor robotic surgery simulator. *Journal of Endourology*, 2016, 30(3): 338–346
DOI: [10.1089/end.2015.0620](https://doi.org/10.1089/end.2015.0620)
- 7 Ibáñez M B, Delgado-Kloos C. Augmented reality for STEM learning: a systematic review. *Computers & Education*, 2018, 12310
DOI: [10.1016/j.compedu.2018.05.002](https://doi.org/10.1016/j.compedu.2018.05.002)
- 8 Diéguez Pérez M, Coro Montanet G, Gómez Sánchez M. Implantación y evaluación del uso de escenarios clínicos Como herramienta de aprendizaje en el grado de odontopediatría. *REDU. Revista de Docencia Universitaria*, 2017, 15(2): 113
DOI: [10.4995/redu.2017.6353](https://doi.org/10.4995/redu.2017.6353)
- 9 Buzys R, Maskeliūnas R, Damaševičius R, Sidekierskienė T, Woźniak M, Wei W. Cloudification of virtual reality gliding simulation game. *Information*, 2018, 9(12): 293
DOI: [10.3390/info9120293](https://doi.org/10.3390/info9120293)
- 10 Danevičius E, Maskeliūnas R, Damaševičius R, Połap D, Woźniak M. A soft body physics simulator with computational offloading to the cloud. *Information*, 2018, 9(12): 318
DOI: [10.3390/info9120318](https://doi.org/10.3390/info9120318)
- 11 Helmreich R L. Managing human error in aviation. *Scientific American*, 1997, 276(5): 62–67
DOI: [10.1038/scientificamerican0597-62](https://doi.org/10.1038/scientificamerican0597-62)
- 12 Kreitler M, Heim J, Smith R. Virtual environments for design and analysis of production facilities. In: *IFIP WG 57 Working Conference on Managing Concurrency Manufacturing to Improve Industrial Performance*. Washington-USA, 1995
- 13 Bossak M A. Simulation based design. *Journal of Materials Processing Technology*, 1998, 76(1-3): 8–11
DOI: [10.1016/s0924-0136\(97\)00308-7](https://doi.org/10.1016/s0924-0136(97)00308-7)
- 14 Chowriappa A, Raza S J, Fazili A, Field E, Malito C, Samarasekera D, Shi Y, Ahmed K, Wilding G, Kaouk J, Eun D D, Ghazi A, Peabody J O, Kesavadas T, Mohler J L, Guru K A. Augmented-reality-based skills training for robot-assisted urethrovesical anastomosis: a multi-institutional randomised controlled trial. *BJU International*, 2015, 115(2): 336–345
DOI: [10.1111/bju.12704](https://doi.org/10.1111/bju.12704)
- 15 Wolford L M. Computer-assisted surgical simulation for concomitant temporomandibular joint custom-fitted total joint reconstruction and orthognathic surgery. *Atlas of the Oral and Maxillofacial Surgery Clinics*, 2016, 24(1): 55–66
DOI: [10.1016/j.cxom.2015.10.006](https://doi.org/10.1016/j.cxom.2015.10.006)

- 16 Chang S C, Hwang G J. Impacts of an augmented reality-based flipped learning guiding approach on students' scientific project performance and perceptions. *Computers & Education*, 2018, 125226–239
DOI: [10.1016/j.compedu.2018.06.007](https://doi.org/10.1016/j.compedu.2018.06.007)
- 17 Papanikolaou I G, Haidopoulos D, Paschopoulos M, Chatzipapas I, Loutradis D, Vlahos N F. Changing the way we train surgeons in the 21th century: a narrative comparative review focused on box trainers and virtual reality simulators. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, 2019, 23513–18
DOI: [10.1016/j.ejogrb.2019.01.016](https://doi.org/10.1016/j.ejogrb.2019.01.016)
- 18 Lee J, Kim H, Kim K H, Jung D, Jowsey T, Webster C S. Effective virtual patient simulators for medical communication training: a systematic review. *Medical Education*, 2020, 54(9): 786–795
DOI: [10.1111/medu.14152](https://doi.org/10.1111/medu.14152)
- 19 Kesavadas T, Stegemann A, Sathyaseelan G, Chowriappa A, Srimathveeravalli G, Seixas-Mikelus S, Chandrasekhar R, Wilding G, Guru K. Validation of robotic surgery simulator (RoSS). *Studies in Health Technology and Informatics*, 2011, 163: 274–276
- 20 Shi Y F, Liu M, Xiong Y S, Cai C, Tan K, Pan X H. The simulation of delineation and splitting in virtual liver surgery. In: 2015 International Conference on Virtual Reality and Visualization (ICVRV). Xiamen, China, IEEE, 2015, 264–268
DOI: [10.1109/icvr.2015.44](https://doi.org/10.1109/icvr.2015.44)
- 21 Ruthenbeck G S, Hobson J, Carney A S, Sloan S, Sacks R, Reynolds K J. Toward photorealism in endoscopic sinus surgery simulation. *American Journal of Rhinology & Allergy*, 2013, 27(2): 138–143
DOI: [10.2500/ajra.2013.27.3861](https://doi.org/10.2500/ajra.2013.27.3861)
- 22 Fonseca A C, Melchels F P W, Ferreira M J S, Moxon S R, Potjeyd G, Dargaville T R, Kimber S J, Domingos M. Emulating human tissues and organs: a bioprinting perspective toward personalized medicine. *Chemical Reviews*, 2020, 120(19): 11093–11139
DOI: [10.1021/acs.chemrev.0c00342](https://doi.org/10.1021/acs.chemrev.0c00342)
- 23 Wu J, Westermann R, Dick C. A survey of physically based simulation of cuts in deformable bodies. *Computer Graphics Forum*, 2015, 34(6): 161–187
DOI: [10.1111/cgf.12528](https://doi.org/10.1111/cgf.12528)
- 24 Cooper J B, Taqueti V R. A brief history of the development of mannequin simulators for clinical education and training. *Quality and Safety in Health Care*, 2004, 13(suppl_1): i11–i18
DOI: [10.1136/qhc.13.suppl_1.i11](https://doi.org/10.1136/qhc.13.suppl_1.i11)
- 25 Ramirez A G, Nuradin N, Byiringiro F, Ssebuufu R, Stukenborg G J, Ntakiyiruta G, Daniel T M. Creation, implementation, and assessment of a general thoracic surgery simulation course in Rwanda. *The Annals of Thoracic Surgery*, 2018, 105(6): 1842–1849
DOI: [10.1016/j.athoracsur.2018.01.043](https://doi.org/10.1016/j.athoracsur.2018.01.043)
- 26 Singal A, Halverson A, Rooney D M, Davis L M, Kielb S J. A validated low-cost training model for suprapubic catheter insertion. *Urology*, 2015, 85(1): 23–26
DOI: [10.1016/j.urology.2014.08.024](https://doi.org/10.1016/j.urology.2014.08.024)
- 27 Veneziani G R. Instituto de Pesquisas Energéticas e Nucleares, SãoPaulo, 2017
- 28 Tack P, Victor J, Gemmel P, Annemans L. 3D-printing techniques in a medical setting: a systematic literature review. *BioMedical Engineering OnLine*, 2016, 15(1): 115
DOI: [10.1186/s12938-016-0236-4](https://doi.org/10.1186/s12938-016-0236-4)
- 29 Aimar A, Palermo A, Innocenti B. The role of 3D printing in medical applications: a state of the art. *Journal of Healthcare Engineering*, 2019, 20191–10
DOI: [10.1155/2019/5340616](https://doi.org/10.1155/2019/5340616)
- 30 Jastifer J R, Gustafson P A. Three-dimensional printing and surgical simulation for preoperative planning of deformity correction in foot and ankle surgery. *The Journal of Foot and Ankle Surgery*, 2017, 56(1): 191–195
DOI: [10.1053/j.jfas.2016.01.052](https://doi.org/10.1053/j.jfas.2016.01.052)
- 31 Bagaria V, Chaudhary K. A paradigm shift in surgical planning and simulation using 3Dgraphy: Experience of first 50 surgeries done using 3D-printed biomodels. *Injury*, 2017, 48(11): 2501–2508
DOI: [10.1016/j.injury.2017.08.058](https://doi.org/10.1016/j.injury.2017.08.058)
- 32 Ryan J R, Almefty K K, Nakaji P, Frakes D H. Cerebral aneurysm clipping surgery simulation using patient-specific 3D printing and silicone casting. *World Neurosurgery*, 2016, 88175–181
DOI: [10.1016/j.wneu.2015.12.102](https://doi.org/10.1016/j.wneu.2015.12.102)
- 33 Oyama K, Ditzel Filho L F S, Muto J, de Souza D G, Gun R, Otto B A, Carrau R L, Prevedello D M. Endoscopic endonasal cranial base surgery simulation using an artificial cranial base model created by selective laser sintering. *Neurosurgical Review*, 2015, 38(1): 171–178
DOI: [10.1007/s10143-014-0580-4](https://doi.org/10.1007/s10143-014-0580-4)
- 34 Doke S K, Dhawale S C. Alternatives to animal testing: a review. *Saudi Pharmaceutical Journal*, 2015, 23(3): 223–229
DOI: [10.1016/j.jsps.2013.11.002](https://doi.org/10.1016/j.jsps.2013.11.002)
- 35 Valentine R, Padhye V, Wormald P J. Simulation training for vascular emergencies in endoscopic sinus and skull base surgery. *Otolaryngologic Clinics of North America*, 2016, 49(3): 877–887
DOI: [10.1016/j.otc.2016.02.013](https://doi.org/10.1016/j.otc.2016.02.013)

- 36 Feins R H, Burkhart H M, Conte J V, Coore D N, Fann J I, Hicks Jr. G L, Nesbitt J C, Ramphal P S, Schiro S E, Shen K R, Sridhar A, Stewart P W, Walker J D, Mokadam N A. Simulation-based training in cardiac surgery. *The Annals of Thoracic Surgery*, 2017, 103(1): 312–321
DOI: [10.1016/j.athoracsur.2016.06.062](https://doi.org/10.1016/j.athoracsur.2016.06.062)
- 37 Joyce D L, Dhillon T S, Caffarelli A D, Joyce D D, Tsigotis D N, Burdon T A, Fann J I. Simulation and skills training in mitral valve surgery. *The Journal of Thoracic and Cardiovascular Surgery*, 2011, 141(1): 107–112
DOI: [10.1016/j.jtcvs.2010.08.059](https://doi.org/10.1016/j.jtcvs.2010.08.059)
- 38 Dargar S, Sankaranarayanan G, De S. System characterization of a novel haptic interface for natural orifice transluminal endoscopic surgery simulation. In: 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Chicago, IL, USA, IEEE, 2014, 375–379
DOI: [10.1109/embc.2014.6943607](https://doi.org/10.1109/embc.2014.6943607)
- 39 Głowiczki P, Lawrence P F. Journal of vascular surgery: cases and innovative techniques (JVS-CIT). *Journal of Vascular Surgery Cases, Innovations and Techniques*, 2019, 5(4): 602–606
DOI: [10.1016/j.jvscit.2019.11.011](https://doi.org/10.1016/j.jvscit.2019.11.011)
- 40 Torres A, Inzunza M, Jarry C, Serrano F, Varas J, Zavala A. Development and validation of a new laparoscopic endotrainer for neonatal surgery and reduced spaces. *ABCD. Arquivos Brasileiros de Cirurgia Digestiva (São Paulo)*, 2020, 33(4): e1559
DOI: [10.1590/0102-672020200004e1559](https://doi.org/10.1590/0102-672020200004e1559)
- 41 Sarti A, Gori R, Lamberti C. A physically based model to simulate maxillo-facial surgery from 3D CT images. *Future Generation Computer Systems*, 1999, 15(2): 217–221
DOI: [10.1016/s0167-739x\(98\)00065-x](https://doi.org/10.1016/s0167-739x(98)00065-x)
- 42 Nikolic D, Matovic M, Jeremic M, Cvetkovic A, Ninkovic S, Kojic M, Filipovic N. Hybrid SPECT/MSCT 3D computational preoperative simulation in breast cancer surgery. In: 2015 IEEE 15th International Conference on Bioinformatics and Bioengineering (BIBE). Belgrade, Serbia, IEEE, 2015, 1–5
DOI: [10.1109/bibe.2015.7367670](https://doi.org/10.1109/bibe.2015.7367670)
- 43 Novelli G, Tonellini G, Mazzoleni F, Bozzetti A, Sozzi D. Virtual surgery simulation in orbital wall reconstruction: Integration of surgical navigation and stereolithographic models. *Journal of Cranio-Maxillofacial Surgery*, 2014, 42(8): 2025–2034
DOI: [10.1016/j.jcms.2014.09.009](https://doi.org/10.1016/j.jcms.2014.09.009)
- 44 Shen X J, Hamam A, Malric F, Nourian S, El-Far N R, Georganas N D. Immersive haptic eye tele-surgery training simulation. In: 2007 3DTV Conference. Kos, Greece, IEEE, 2007, 1–4
DOI: [10.1109/3dtv.2007.4379402](https://doi.org/10.1109/3dtv.2007.4379402)
- 45 Kuronen-Stewart C, Ahmed K, Aydin A, Cynk M, Miller P, Challacombe B, Khan M S, Dasgupta P, Aho T F, Popert R. Holmium laser enucleation of the prostate: simulation-based training curriculum and validation. *Urology*, 2015, 86(3): 639–646
DOI: [10.1016/j.urology.2015.06.008](https://doi.org/10.1016/j.urology.2015.06.008)
- 46 Varshney R, Frenkiel S, Nguyen L H P, Young M, Del Maestro R, Zeitouni A, Saad E, Funnell W R J, Tewfik M A. The McGill simulator for endoscopic sinus surgery (MSESS): a validation study. *Journal of Otolaryngology-Head & Neck Surgery*, 2014, 43(1): 40
DOI: [10.1186/s40463-014-0040-8](https://doi.org/10.1186/s40463-014-0040-8)
- 47 Lahanas V, Loukas C, Georgiou K, Lababidi H, Al-Jaroudi D. Virtual reality-based assessment of basic laparoscopic skills using the Leap Motion controller. *Surgical Endoscopy*, 2017, 31(12): 5012–5023
DOI: [10.1007/s00464-017-5503-3](https://doi.org/10.1007/s00464-017-5503-3)
- 48 Jayakumar A, Mathew B, Uma N, Nedungadi P. Interactive gesture based cataract surgery simulation. In: 2015 Fifth International Conference on Advances in Computing and Communications (ICACC). Kochi, India, IEEE, 2015, 350–353
DOI: [10.1109/icacc.2015.20](https://doi.org/10.1109/icacc.2015.20)
- 49 Barber S R, Jain S, Son Y J, Chang E H. Virtual functional endoscopic sinus surgery simulation with 3D-printed models for mixed-reality nasal endoscopy. *Otolaryngology–Head and Neck Surgery*, 2018, 159(5): 933–937
DOI: [10.1177/0194599818797586](https://doi.org/10.1177/0194599818797586)
- 50 Neto P B C, de Souza Mendes M, de Souza I R, Vieira A N. Uso de simulador endovascular por residentes do Serviço de Cirurgia Vascular do Hospital Geral de Fortaleza: um relato de experiência. 2021, 4(3): 9810–9817
- 51 Firmino Filho J M. LCD-OpenPACS: sistema integrado de telerradiologia com auxílio ao diagnóstico de nódulos pulmonares em exames de tomografia computadorizada. 2015
- 52 Mustaqeem A, Javed A, Fatima T. An efficient brain tumor detection algorithm using watershed & thresholding based segmentation. *International Journal of Image, Graphics and Signal Processing*, 2012, 4(10): 34–39
DOI: [10.5815/ijigsp.2012.10.05](https://doi.org/10.5815/ijigsp.2012.10.05)
- 53 Foletto Lucas C. Técnicas de segmentação e classificação de imagens em exames de ressonância magnética nuclear. *Revista da Graduação*, 2014, 7(2)
- 54 Pareek M, Jha C K, Mukherjee S, Joshi C. Brain tumor detection using watershed segmentation techniques and area calculation. *International Journal of Informatics and Communication Technology (IJ-ICT)*, 2018, 7(2): 71
DOI: [10.11591/ijict.v7i2.pp71-76](https://doi.org/10.11591/ijict.v7i2.pp71-76)

- 55 Dhage P, Phegade M R, Shah S K. Watershed segmentation brain tumor detection. In: 2015 International Conference on Pervasive Computing (ICPC). Pune, India, IEEE, 2015, 1–5
DOI: [10.1109/pervasive.2015.7086967](https://doi.org/10.1109/pervasive.2015.7086967)
- 56 de Araujo A F. Método Para extração e caracterização de lesões de pele usando difusão anisotrópica, crescimento de regiões, watersheds e contornos ativos. UNESP-Universidade Estadual Paulista, Mestre, 2010
DOI: [10.5016/dt000607597](https://doi.org/10.5016/dt000607597)
- 57 Amorim P, Moraes T, Azevedo F, Silva J. unidade do Ministério da Ciência e Tecnologia. Software InVesalius-Guia do Usuário. 2013
- 58 Ašeriškis D, Damaševičius R. Gamification of a project management system. In: Proc of Int Conference on Advances in Computer-Human Interactions. Citeseer, 2014, 200–207
- 59 Ašeriškis D, Damaševičius R. Gamification patterns for gamification applications. *Procedia Computer Science*, 2014, 3983–90
DOI: [10.1016/j.procs.2014.11.013](https://doi.org/10.1016/j.procs.2014.11.013)
- 60 Kolsanov A, Nazaryan A, Ivaschenko A, Kuzmin A. Intelligent SDK for 3D surgery simulation. In: 2016 6th International Conference-Cloud System and Big Data Engineering (Confluence). Noida, India, IEEE, 2016, 384–387
DOI: [10.1109/confluence.2016.7508148](https://doi.org/10.1109/confluence.2016.7508148)
- 61 Hao J L, Xie X L, Bian G B, Hou Z G, Zhou X H. Development of a multi-modal interactive system for Endoscopic Endonasal Approach surgery simulation. In: 2016 IEEE International Conference on Robotics and Biomimetics (ROBIO). Qingdao, China, IEEE, 2016, 143–148 DOI:[10.1109/robio.2016.7866312](https://doi.org/10.1109/robio.2016.7866312)
- 62 Beverly hills sinus clinic, <https://beverlyhillssinus.com>, 2021
- 63 Mahmood T, Scaffidi M A, Khan R, Grover S C. Virtual reality simulation in endoscopy training: Current evidence and future directions. *World Journal of Gastroenterology*, 2018, 24(48): 5439–5445
DOI: [10.3748/wjg.v24.i48.5439](https://doi.org/10.3748/wjg.v24.i48.5439)
- 64 Vera J, Santos G. Can gamification contribute to computer modeling-driven biomedical research?. *Frontiers in Physiology*, 2018, 9908
DOI: [10.3389/fphys.2018.00908](https://doi.org/10.3389/fphys.2018.00908)
- 65 White E J, Lewis J H, McCoy L. Gaming science innovations to integrate health systems science into medical education and practice. *Advances in Medical Education and Practice*, 2018, Volume 9407–414
DOI: [10.2147/amep.s137760](https://doi.org/10.2147/amep.s137760)