

Augmented Reality in Surgical Oncology. A Literature Review

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Rezumat

Realitatea augmentată în chirurgia oncologică. Review din literatură

Introducere: Dispozitivele de realitate augmentată (RA) permit medicilor să asocieze vizualizarea datelor despre diagnostic, să stabilească proceduri de tratament pentru a îmbunătăți eficiența și siguranța muncii și să dezvolte instruirea chirurgicală a medicilor tineri. Această nouă abordare poate contribui la creșterea calității pregătirii medicale și la reducerea costurilor intervențiilor chirurgicale. Acest articol evaluează dacă realitatea augmentată poate îmbunătăți rezultatele procedurilor chirurgicale și posibilitățile de evoluție în viitor.

Metodă și Rezultate: Folosirea intraoperatorie a realității augmentate utilizând ochelarii Google Glass, pe care am proiectat imagini RMN/CT cu zonele anatomice invadate tumoral și/sau imagini de anatomie normală, ne ajută la desfășurarea intervențiilor chirurgicale, dar și la prezentarea lor ca și material didactic. Am efectuat și o recenzie a literaturii disponibile din 2011 până în noiembrie 2021 căutând în PubMed termenii „realitate augmentată” și „chirurgie oncologică”. Rezultatele căutării au fost 308 studii în acest domeniu și care dovedesc utilitatea metodei. Multe lucrări arată că performanța sistemelor de realitate augmentată este superioară și compatibilă cu tehnicile tradiționale imagistice.

Concluzii: Literatura de specialitate comunică un interes tot mai mare al chirurgilor cu privire la folosirea realității augmentate în operații. Procedura permite îmbunătățirea siguranței și eficacității tehnicilor chirurgicale, dar și prezentarea acestora

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studentilor și medicilor rezidenți. Metoda este inovatoare și trebuie abordată cu atenție înainte ca să fie implementată în practica de rutină.

Cuvinte cheie: realitate augmentată, chirurgie oncologică, ablație prin radiofrecvență, educație medicală

Abstract

Introduction: Augmented reality (AR) devices enable doctors to associate visualizing diagnostic data, to establish therapeutic procedures in order to improve work efficiency and safety and to develop the surgical training of young doctors. This new approach may contribute to an increase in the quality of medical training and a decrease in the costs of surgeries. This paper assesses whether augmented reality can improve the results of surgical procedures as well as its possible progress in the future.

Methods and results: The intra-operative use of augmented reality by using Google Glass glasses, on which we projected MRI/CT images of the anatomical areas invaded by tumors and/or images of normal anatomy, helps us to perform surgeries, as well as to present them as teaching material. We have also performed a review of the available literature, beginning with 2011 and ending with November 2021, by looking up the terms “augmented reality” and “surgical oncology” in PubMed. The results of the search were 308 studies in this field which prove the utility of the method. Many papers show that the performance of the augmented reality systems is superior and compatible with traditional imaging techniques.

Conclusions: The specialty literature reveals a growing interest on the part of surgeons regarding the use of augmented reality during surgery. This procedure enables the improvement of the safety and efficiency of surgical techniques, as well as their presentation to students and residents alike. The method is innovative and has to be carefully approached before being introduced into routine practice.

Key words: augmented reality, surgical oncology, radiofrequency ablation, medical education

Introduction

Augmented Reality (AR) is an interactive experience which uses the existing environment in the real world over which it superimposes computer-generated virtual information in order to enhance user experience. It is a system which incorporates three basic features: a combination of real and virtual worlds, real time interaction and an accurate 3D recording of virtual and real objects. The hardware components for AR are: a processor, a display, sensors and input devices (1,2). Modern devices such as smartphones and tablet computers (3) contain these elements and often include a camera and system sensors,

which make them suitable AR platforms (1,2).

Various technologies are employed in rendering AR, including optical projection systems, monitors, handheld devices and display systems, which are worn on the human body. AR displays can be rendered on devices resembling glasses. Versions include glasses which employ cameras to intercept the real-world view and re-display the augmented view through the eyepieces and devices where the AR image is projected through or reflected by the surfaces of the glass lens onto an LCD display (4).

The benefits of augmented reality have been extended to the medical field, where they could play an important role. The development

of medical imaging technology focuses on acquiring information and data which can be viewed in real time. Accessing data in real time becomes increasingly important as they can be more rapidly and efficiently used in diagnosis and treatment. Real time access to 2D images or 3D reconstructed images during surgery can prove crucial, since, thus images of tumors, their position at the level of the parenchyma of an organ or their relationship to the adjacent anatomical elements (blood vessels, bile ducts, nerves, etc.) can be viewed. The projection of 2D or 3D virtual images of the various pelvic (cervix, ovary, uterus), breast or liver neoplasms over the real image in the injury facilitates the dissection of the pelvic anatomical elements (uterus, ovaries, iliac vessels, ureter) and the excision of the tumor in good conditions. At the level of the breast, the display of 3D reconstructed images associated with the real image in the injury (tumor and lymph node stations) can facilitate the radical excision of the tumor, the discovery of the sentinel node and the axillary lymphadenectomy in the Berg stations I and II (5,6).

The main goal of this paper is to signal the rapid development and the connection between augmented reality and the surgeon, starting from the experience of applying AR during surgery, on selected cases. Likewise, the method is useful in the field of medical education and in the context of online teaching to present anatomy and surgical techniques to the students and the residents.

Material and Method

The Google Glass device we purchased, a brand of smart glasses developed by the Google company (*Fig. 1*), allows its use to establish operational tactics. Thus, the Computer Tomograph (CT) or Magnetic Resonance Imaging (MRI) images of the organ showing a tumor formation are studied and reconstructed three-dimensionally by using the RadiAnt DICOM Viewer Software (Digital Imaging and Communications in Medicine) by the Department of Radiology. Images are selected and loaded from the computer to the

device and superimposed over the image in the operator's field. The device is easy to use because, by voice command, the device allows the scrolling of images, from surface to depth, layer by layer. We used the device for the first time for patients with breast tumors. In this way, we can find out where the tumor or the sentinel node is located. We are currently working on an image stabilizer so that head movement does not alter the overlay of the real image with the virtual one.

The device also allows the possibility to take pictures and record short videos with the main operating times. At this moment we are working to send the images obtained in real time to a laptop/tablet via Bluetooth, but also to improve the resolution of the images. From the laptop in the operating room, the images are transmitted to the students in the amphitheatre. The device can be used as teaching material for students in studying 3D anatomy through AR and comparing intra-operative images with those in anatomy atlases.

To see how AR is used in oncology surgery, we conducted a literature review from 2011 to November 2021. PubMed was searched for the terms "augmented reality in oncology surgery". Only articles in English were studied. The results of the search were 308 studies in this field and which prove the usefulness of the method in the diagnosis and multidisciplinary treatment of cancer, most with applicability in: classic and laparoscopic surgery of liver tumors, neurosurgery, urology, gynaecology,



Figure 1. Google Glass - smart glasses developed by Google

breast, etc. These studies have proven the effectiveness of the procedure. Four percent of these articles also refers to the usefulness of the method in the study of anatomy by students.

Another selection criterion of the specialized literature was the use of Google Glass in surgery. Through this article we wanted to present the possibility of applying augmented reality using Google Glass in less-addressed fields, namely breast surgery and pelvic surgery (rectum, uterus). We chose these 2 areas also for technical reasons, namely, there are 2 fixed areas on which we can orient the Google glasses with the processed 3D image from the CT so that we can locate a small breast tumor or the sentinel lymph nodes or the pelvic organs. The number of publications regarding the use of various devices (glasses, tablets) on the 2 themes (breast / pelvis) are extremely few (4 for breast), pelvis – uterus (1). We excluded experimental studies, but we chose some studies related to the usefulness of augmented reality in the medical education of students. We preferred the anatomy lessons that allow the superimposition of the augmented reality image over the open surgery anatomy lessons and we excluded the simulation studies for training skills in laparoscopic surgery and which we only mentioned as a possibility of future use alongside reality virtual.

Results

The Google Glass device gives the surgeon the freedom to perform surgical maneuvers and the voice command can activate the commands and display the selected photos as well as record short videos. The communication with the laptop/tablet can be done via Bluetooth. The device allows live video streaming transmission, which offers surgeons the possibility of consulting other colleagues or explaining to the students/residents the local anatomy and describing surgeries.

The modern manner of approaching surgical strategy in selected cases by using augmented reality has made the overlapping

of the real intra-operative pelvic and abdominal images with those of the 3D reconstruction become a step forward in recognizing the local anatomy, as well as providing a better orientation in the operating field and improved possibilities of tumor resection. The reconstructed images are stored on a laptop/tablet computer and then uploaded to the AR device. Thus, 3D images of vessels, nerves, ureters or other normal anatomical structures or local pathological changes are obtained and they can be compared or associated with the intra-operative image of the patient. Therefore, we can see a tumor of the liver, breast or uterus, pelvic and lateral aortic adenopathies, etc. three-dimensionally, and assess their relationship with the adjacent anatomical elements as well as the possibilities of surgical resection.

At the level of the breast, it may enable the study, layer by layer, of the anatomical structures and the localization of the tumor, of its shape and extensions so that it may lead to a limited resection - lumpectomy - yet within oncological limits (R0 resection) with an extemporaneous histopathological examination of the resection margins. At the level of the axilla, it may reveal the position of the first lymph node station, the coordinates of the other lymph node stations, their aspect and relationships with the blood vessels and other anatomical elements. The technique may be useful in order to discover the sentinel node and/or to perform the lymphadenectomy of the lymph node stations I and II (*Figs. 2, 3*).

The capacity of the device to be activated by voice command (hands free) is especially important in surgery, as it enables surgeons to control it without needing assistance or compromising the aseptic protocols.

From an educational point of view a new manner of delivering lectures and of learning evolves, which may increase the involvement of the students and of the residents in anatomical education and surgical simulations by using 3D visualizing methods of the anatomical regions and the advent of a new concept - 3D “virtual anatomy”.

The exponential increase of articles in

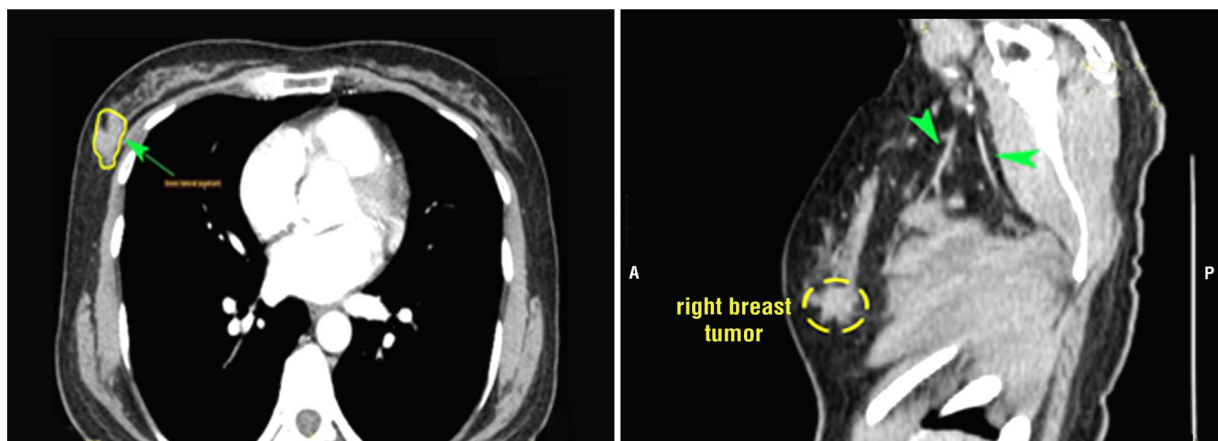


Figure 2. The CT (Computed Tomography) appearance of the tumor of the right breast and of the right axillary adenopathies

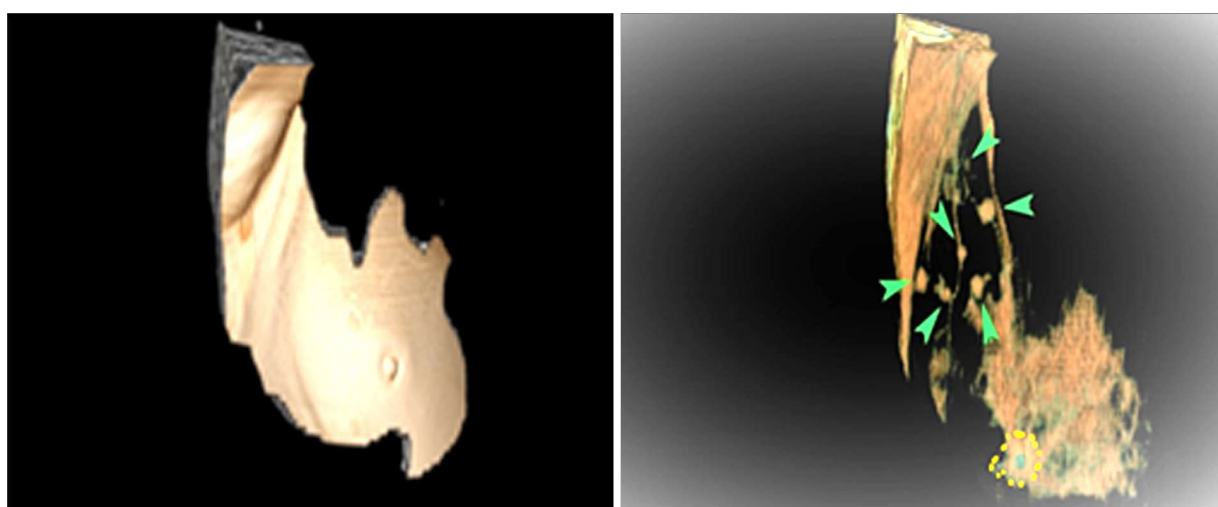


Figure 3. The 3D reconstruction of the CT image of the right breast and the AR (Augmented Reality) mode of projecting the anatomical structures onto Google Glass. The tumor is marked with a dotted line, while the arrows indicate the position of the right axillary lymph node stations and their relationship with the adjacent anatomical elements

recent years shows that, at the moment, augmented reality is successfully used in oncological surgery, namely in: liver surgery - resections (laparoscopic/open), neurosurgery, head and neck surgery, breast surgery, thyroid surgery, oncological gynecology, urological surgery (kidney and prostate cancers - together with robotic surgery). The possibility of visualizing real anatomical structures, such as cerebral convolutions, blood vessels, nerves and their trajectories, liver tissue, mammary gland, etc., allows control during tumor resection and the sacrifice of as little of the surrounding healthy tissue as possible. It also allows the surgeon to properly plan the

surgical intervention strategy, through digital simulation. AR can thus have an essential role in the training and medical education of students and resident doctors.

Discussions

The importance of augmented reality resides in the manner in which the components of the digital world overlap with a person's perception of the real world, not as a simple display of data, but by integrating sensations, which are perceived as natural parts of the surrounding world. Augmented reality was first introduced for commercial purposes in

the entertainment and gaming industry. Subsequently, its applications have extended to education, communications, medicine, etc (1,2).

One of the main applications of augmented reality was in medicine, in particular in order to support the organization, application and training in surgical procedures. The first AR systems were conceived by the US Air Force as early as 1992, with the aim of improving human performance during surgery (7). AR offers surgeons monitoring data about the patients according to the model of the head-up display of a fighter aircraft pilot and makes it possible to access and to superimpose the image records of the patient, including videos. Moreover, a virtual image based on Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) can be obtained, and this can be superimposed on a real image (1). Thus, augmented reality can be of great help in the medical field. It could be used to provide the surgeon with vital information regarding the relationship between the tumor and the adjacent anatomical elements and the surgical attitude to be assumed (8,9). In 2015, Microsoft announced the creation of Microsoft HoloLens, their first go at augmented reality. HoloLens is capable of projecting holograms for surgery based on infrared fluorescence (10). Augmented Reality can be efficiently used for pre-operative planning and completing the surgery. The pre-operative 3D reconstructed images can be modified and prepared for display in the AR mode (11-13).

As AR is developing, new applications in the health care field are discovered, such as: guidance during diagnostic and therapeutic laparoscopic surgeries, neurosurgery, ultrasound, ultrasound-guided punctures, etc. (15) and, consequently AR can be used to train professionals in the medical field. AR is used to perform incisions and preferred sectioning plans (5), to place laparoscopic trocars or to improve the localization of the tumors at the level of the organs, to assess and to optimize the surgical resection bulk (16). Siemens, Karl Storz and IRCAD Strasbourg (France) have developed a system of laparoscopic hepatic

surgery which uses AR to visualize tumors. Thus, in laparoscopic and robotic surgery, it compensates for the absence of tactile feedback during these procedures (8). Another benefit of AR is its capacity to help surgeons to operate on a difficult site after chemotherapy or neoadjuvant radiotherapy (5). The AR devices are most useful during the surgery of fixed organs, with reduced movement and distortion, as it is difficult to follow mobile organs. Bearing these in mind, the most frequently targeted fields for the use of AR are neurosurgery (17), hepatobiliary and pancreatic surgery and pelvic surgery (6,18-22).

The AR system may be useful for the precise detection of the sentinel node by using pre-operative SPECT/CT scanning of the lymph nodes. This enables the precise navigation towards the sentinel node and a targeted lymphadenectomy (13,14). There are studies regarding the applicability of the method in breast tumor surgery. The use of digital 3D models for the breast might pave the way towards a digital system as a non-invasive method for the intra-operative localization of the tumor (which is sometimes not palpable) and its complete excision, minimally sacrificing breast tissue, yet observing the principles of radical excision (R0) (23-25).

The acquisition of the first-generation Google Glass represented a challenge for us and we tried to make the transition from entertainment to applications in medicine and especially in oncological surgery. We first familiarized ourselves with the principles of augmented reality and started by taking intra-operative pictures. The next step consisted of the possibility of transferring the 3D CT/MRI images of the breast tumors into the memory of the glasses and displaying them on the screen so that they are super-imposed on the real image from the wound. The next step we are working on is to stabilize this image, because with the movement of the head, the augmented reality/real image ratio also changes. Basically, no matter how we move the head the position of the tumor at breast level must not change (model of a fighter pilot's head-up display). The device allows to

display images or record movies by voice command only. In this way, the surgeon has complete independence during the surgical intervention and can thus call on the advantages of AR. The goal is to perform the excision of a tumor formation with as little sacrifice of healthy tissue as possible, but in oncologically safe conditions. We are also working on the possibility of transmitting these images via Bluetooth to a laptop or tablet. The laptop allows to improve the resolution of the images, to record short intra-operative films and to transmit the images from the operating room to an amphitheatre where they can be viewed by students or residents.

Medical students as well as residents have to acquire many skills and a wide range of knowledge throughout the time in order to become competent practitioners. Anatomy in particular is one of the cornerstones of medical education. Without properly understanding anatomy, regardless of the field of health care, practitioners cannot efficiently run tests, since they require knowledge about the organs and the tissues. The AR technology can improve the practical skills of the students and the residents. Thus, anatomy remains one of the fundamental fields of medical education. Although the lessons taught on the cadaver are the gold standard in teaching anatomy to students and doctors, there are substantial financial and ethical constraints concerning their use. It has been demonstrated that using AR as a tool for studying the anatomical structures improves the knowledge of the trainee (26).

One way to do it would be by using the applications which allow users to see very detailed 3D images of the various body systems, when they move their mobile device over a target-image. Thus, AR may become a powerful learning tool for the medical practitioners throughout their whole training period (The da Vinci robotic surgical system) (2). In the past years, there has been a change in higher education and medical education from the traditional educational practice of lectures to online education. There is growing

evidence that this multimodal change (face-to-face and distance) in pedagogy together with the training through the simulation of reality improves the students' competences and skills, especially when compared with traditional learning methods (25-27). Moreover, in 2015 the international literature mentioned Google Glass as being useful in the students' learning process, the AR technologies helping trainees to engage in the exploration of the real world with the help of virtual images (28).

Augmented reality uses a computer-generated image which has an impressive effect on the way in which the real world is presented. Simultaneously with the development of technology and computers, AR will lead to a significant change in the prospects of the real world (29). The virtual experience is perfectly superimposed on the physical world, so that it is perceived as a more attractive aspect of the real environment. Thus, AR continuously changes the perception of the real world, while virtual reality (VR) completely replaces the real environment of the user with a simulated one (30). Virtual reality (VR) enables the users to "live" in a special environment, a virtual one, created and presented by the computers, i.e., an animated scene or a real location which was photographed and then incorporated into a virtual reality application. By means of a virtual reality device, the users can look up, down or any way they choose, as if they were actually there (29,31,32). Through VR young doctors can take the first steps in surgery by learning to wash their hands and forearms correctly, put on a surgical gown and perform surgical gestures and maneuvers by being virtually introduced into an operating room - Minimally Invasive Surgical Trainer – Virtual Reality (MIST-VR) (33-35).

Augmented reality and virtual reality will become the main use for the people's interaction with the computer. Thus, it is the recommendation of the World Health Organization (WHO) that the new technologies, such as virtual reality, augmented reality, and artificial intelligence should be used in the process of learning in the health

care field due to the high impact they have on doctors (36).

In the future, we intend to use our fifteen-year experience (2006-2021) in using RFA (Radiofrequency Ablation) for different tumors (174 patients with 192 applications used for hepatic metastases, cervical and ovary tumors, retro-peritoneal tumors, etc.) in order to develop an additional system of real time monitoring of the augmented reality type using temperature sensors inserted into the ablation area. A numerical model of the progress of the coagulative necrosis can be achieved through radioablation as well as the establishment of volume limits of surgery marked by isothermal surfaces (37,38). Thus, the limit of the cauterization site can be checked in real time, by augmented reality type monitoring (39,40). The temperature sensors can convey the temperature values, with alarm thresholds for limiting the operating site to the surgeon in real time, by means of an augmented reality type interface, such as the Google Glass product. The numerical modeling of the cauterized site will be performed using the Finite Element Method, implementing constitutive models of material with physical-thermal-mechanical parameters established based on previous research papers. Moreover, the volume of the destroyed tumor material can be monitored through intra-operative ultrasound, whereas the data will be conveyed in real time to the AR interface (12,41).

In the future, we intend to develop the application both by purchasing a new generation of Google Glass, but also by improving the resolution of the images and their transmission on the laptop/tablet. Through future projects and research, we want to expand the use of augmented reality in laparoscopic/classic pelvic oncological surgery (uterus, rectum, pelvic sentinel node), but also to combine the method with the application of radiofrequency ablation (where we have considerable experience) in the neoplastic pathology of solid tumors (liver metastases, cervical tumors, sarcomas). Also, by developing an appropriate software, AR

can be used in the training of resident doctors in the technique of laparoscopic surgery. Together with the 3D anatomy images it can provide, the method can contribute to the medical education of students.

Conclusions

Studies to date have shown that augmented reality systems may be involved in clinical and didactic activity, but further research is needed. Augmented Reality systems can revolutionize the field of surgery, allowing physicians to achieve better results by establishing more accurate diagnoses and operating tactics.

AR and VR offer additional benefits to students, through interactivity and pleasure in discovering 3D anatomy, so that they become reliable and in-depth learning tools in medical education.

The augmented reality system is innovative and must be approached carefully before being implemented in routine practice.

Conflicts of Interests

The authors declare there are no conflicts of interests.

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