Augmented Reality in Cardiology

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The augmented reality (AR) is an emerging technology that facilitates the comprehension of many situations that are difficult to understand otherwise. It is based on the superimposition of a virtual image on the real-world images. It is used as an assisting tool in areas of education, emergency, diagnosis, surgery and percutaneous interventions in cardiology, although all these areas are in their infancy period of using. In this review, the use of AR in cardiology is summarized with special reference to some studies.

Augmented reality (AR) can be defined as "An enhanced version of reality where live direct or indirect views of physical real-world environments are augmented with superimposed computer-generated images over a user's view of the real-world, thus enhancing one's current perception of reality "(1). The AR is one component of the spectrum of extended reality, which includes virtual reality (VR), merged reality, mixed reality and AR. It differs from VR that, nothing in VR is real, while in AR, some virtual objects are implemented in real world environment. Merged and mixed realities are usually regarded as one and named as mixed reality, which are between VR and AR.

"Augmented reality" has been firstly introduced as a term in 1990 by Caudell (2). He has used this technology in aviation industry to ensure adequate training experience. In AR, the user interacts with the virtual object, which is synchronously in conjunction with user's physical real environment. Therefore, users can see more than they can see without AR. The AR technology enables people to interact with 3D objects more easily, and therefore, decreases the cognitive load and enhances spatial skills (3). The AR technology also enables users to see some explanation about the situation at the same time and at the same perspective with the real world. (Fig. 1).

There are four categories of AR (1): (1) Marker-based AR; (2) Markerless AR; (3) Projection-based AR; (4) Superimposition-based AR. In marker-based AR, the AR is activated by a marker

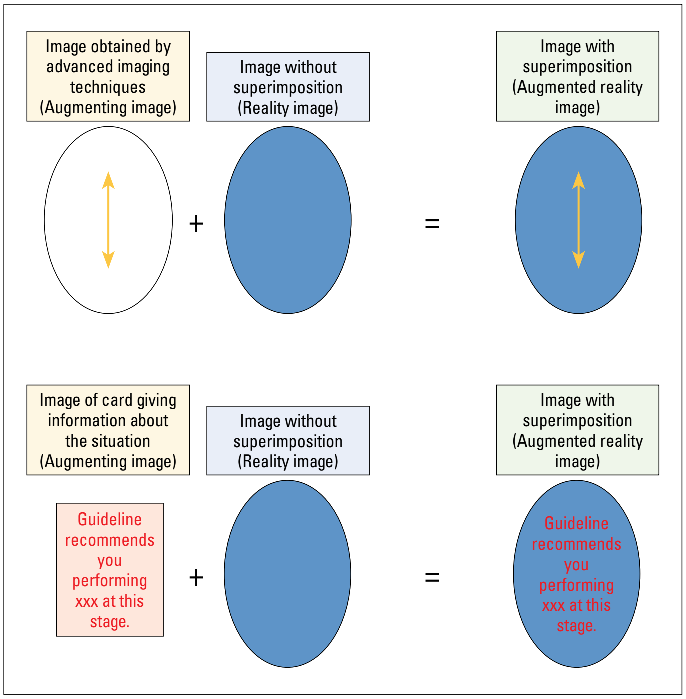

Figure 1. The pictural representation of augmented reality. In the upper panel, an image (augmenting image, virtual image), which is not possible to be seen at a special situation, is superimposed on the image obtained at that special situation (reality image). In the lower panel, instead of an image of an anatomic or physiologic structure, an image of an information card is superimposed on the reality image. This information is expected to be helpful in the operator's decision at that special situation

such as QR code, therefore needs a visual marker like camera. In markerless AR, frequently a GPS embedded in a device such as smartphone is used. The game of Pokemon-Go is an example of this type of AR. Projection-based AR send light to real world and enables interaction between the image and real world. Hologram

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Table 1. The use of augmented reality in health care

1. Education of patients and students
2. Emergency
3. Diagnosis
4. Surgery
5. Percutaneous interventions

is a typical example of projection-based AR. In superimposition-based AR, an augmented view of an object replaces the view of same object. Examples of this type of AR can be found in some furniture showrooms.

The devices used in AR applications are categorized into two groups: hardwares and softwares. The hardware systems include display devices, such as head-mounted displays, hand-held devices, projectors; user tracking systems, which tracks the movement of user and conveys the data to the software systems; haptic and force feedback, which enhances the sensations of the user (4). The software systems include various algorithms that allow the user to combine real and virtual images.

Constructing an AR view requires some steps to be taken (5). Firstly, the hardware and software should be set up. Afterwards, the virtual and real image should be aligned by the software. In this step, some landmarks are needed. In the component recognition step, the initial points are defined. This is followed by motion tracking step, in which virtual reality procedure is combined with augmented reality process. The last step is the extension step, in which data is prepared for display.

The use of AR in health care has been started in nineties; however, it didn't receive much attention until the high technology products have been introduced in 2000s. The use of AR in health care is summarized in Table 1.

Education of patients and students

Experience is one of the most effective way of the education. It provides a visualized learning environment, and therefore, makes reasoning easier. Besides, more experience is associated with fewer complications (6). However, there is limited opportunity for gaining experience because of the limited number of suitable learning opportunity (i.e. number of suitable patients), unwillingness of the subjects (i.e. unwillingness of patients for being assessed and managed by a novice) and concerns about safety of the subjects (i.e. unproper management of patients, resulting in various complications). Actually, the AR has been firstly used as learning and training tool to overcome these issues. In accordance with the usefulness of the AR related educational activities, the number of articles about educational use of AR is increasing (7).

Lamounier et al. (8) have used AR for education purposes. As a cardiologic data, they used the heart beat and simulated it with the help of AR. The simulation of the heart was superimposed on the chest of the subjects with different age, gender, heart conditions and other anthropometric features. The subjects were asked to exercise to increase heart beats. The change in heart beat was directly visualized with the help of AR. They suggested that this system can be used in training of both medical students and patients.

Barsom et al. (2) have assessed the effectiveness of AR in medical training in a systematic review. They used five validity criteria: face validity, content validity, construct validity, concurrent validity, predictive validity. For definitions, the readers are recommended to read this paper. They have also found that AR was used as a training tool in three major areas: laparoscopic surgery, neurosurgery and echocardiography. Use in echocardiography was made possible by two commercial ways: The CAE VIMEDIXTM® ultrasound simulator (9) and The EchoCom® (10).

The CAE VIMEDIXTM® ultrasound simulator consists of three main components (9); a mannequin, a transducer and a linked computer workstation. It works similar to flight simulators. The mannequin is a lifelike one that allows users to perform echocardiography as if it is a real person. The echocardiographer can perform the procedure with three transducers: transthoracic, transesophageal and FAST probe. During examination, augmented reality image and the two-dimensional image are displayed at the screen simultaneously so the trainee can understand where he/she is visualizing and improves his/her assessment of spatial relationships. For this reason, it may play an important role in learning echocardiography in future. In the systematic review of Barsom (2) et al, this device has been found to be valid in terms of facial validity, but there was no data for assessing the other categories of validity.

The EchoCom® simulator consists of a mannequin, a transducer with 3D tracking system and a computer application (10). There is a split screen, on which the ultrasonic image and AR image are shown simultaneously. The system uses real ultrasonic images recorded by an echocardiography device and derived from 3D echocardiographic data sets. The authors and participants have found the system useful in training. The validity was tested for face, construct and content validities and found to be valid in terms of these validities. Barsom (2) et al have also suggested that the system is valid in these three aspects.

Kiourexidou et al. (11) used a web-based program to use AR in teaching human heart anatomy. Although the system was not tested in classes, their system has potential in educating the medical students about human anatomy. The system seems to decrease the need for cadavers for learning anatomy in future.

Emergency

Use of AR in emergency has potential to decrease errors, increase adaptation to quickly changing environment and enabling access to knowledge and information easily. The value of the emergency use of AR is less established than educational areas. In one of the few studies, Siebert et al. (12) tested the AR as a means to increase adherence to AHA guidelines in pediatric cardiopulmonary resuscitation. In their study, they used Google

Glass® to provide the users to see the cards simultaneously with the mannequins, which were designed to simulate pediatric cardiopulmonary resuscitation with various scenarios. The cards were containing the AHA Guideline flow charts of each step and the next step to be taken. The use of AR did not affect the defibrillation time but improved performance and adherence to the guideline.

Diagnosis

The use of AR in diagnosis of heart disease is fairly studied. In their study, Hemanth et al. (13) have assessed the value of AR in the diagnosis of heart disease. They used a mobile phone application, which was based on detecting the abnormality in heart sounds. The system was a marker-based AR, in which the mobile phone was used to detect heart sounds via an interfaced sound recording system and an application briefly called MYHEART®. The AR-assisted system could detect murmurs and extrasystoles with a considerable accuracy. The system seems not suitable for substituting the stethoscope, but has potential to be used by mobile phone users. It may enable the earlier diagnosis of some heart problems.

Surgery

Use of AR in surgery is a major purpose of AR developers because it has potential to decrease operation time and complication rate. Currently, most of the operations are performed with a little incision, which limits the sight of the surgeons. Endoscopic surgery has decreased this limitation but lack of manipulation to see what is not seen with a normal looking is still a challenge for surgeons. Preoperative assessment of the anatomic structures and making these structures visible by AR technology may further decrease this limitation. Not only the anatomic structures, but also some pathophysiologic parameters may also be visualized by this technique.

Falk et al. (14) have used AR for robotic bypass surgery in dogs and sheep. They have reconstructed the coronary artery tree and projected it into a videoscopic image. To obtain a correct image, they marked same landmarks on coronary theumographic view and endoscopic view. Afterwards, the corresponding landmarks were superimposed to obtain AR view of the coronary tree on videoscopic views. They have also used an algorithm that allows the superimposed view to move according to the motions of the surgeon's endoscopy. They concluded that AR has potential to facilitate the use of robots in surgery.

Cabrilo et al. (15) have used AR in surgery of cranial arteries. Preoperatively, they have obtained the three-dimensional images using 3-dimensional digital subtraction angiography, angio-magnetic resonance imaging and angio-computed tomography. They suggested that AR optimizes the procedure by providing essential anatomic information. In this study, they suggested that AR enables precise localization of donor vessels and recipient vessels and proper tailoring of the craniotomy. However, due to absence of control groups and low number of patients in these studies, impact of AR on patient outcome remains to be investigated in larger-scale randomized trials.

Szabo et al. (16) have used the AR in visualization of myocardial circulation during the cardiac surgery of 5 pigs. They used infrared temperature system to map the myocardial ischemia. They obtained a thermographic image and superimposed this image on the real time heart image. With this method, the surgeons were able to detect ischemia and reperfusion with a considerable accuracy and within a good duration. This was important because myocardial ischemia during coronary surgery may have serious complications and it is a significant concern for the operator.

Devernay et al. (17) used AR in robotically assisted minimally invasive cardiovascular surgery. They combined the usefulness of robots, such as remedying the decreased dexterity of the surgeon during surgery, and AR, such as enabling visualization of structures which cannot be seen normally. With the help of AR, the coronary artery locations were superimposed on the stereoscopic video image. They concluded that AR helps locating the coronary arteries on the heart itself, although the images of coronary arteries had been obtained few days before the operation.

Percutaneous interventions

Percutaneous cardiac interventions are usually performed under the guidance of fluoroscopic imaging. This technique comes along with a substantial exposure to radiation. In addition, some complex interventions necessitate full understanding of the pathophysiologic anatomy of the relevant structure. The AR may help in understanding the normal and pathological anatomy of the relevant structure, and therefore, it may indirectly decrease the radiation exposure time.

Zbronsky et al. (18) have used AR for occlusion of left atrial appendage. They claimed that they successfully implanted the occluder device with the help of holograms, which provided the three-dimensional view of the heart. However, details about how the AR was useful have not been given in the text.

De Buck et al. (19) have used the AR for patient specific guidance of cardiac catheter ablation procedures. They used the preprocedure magnetic resonance imaging of the patients to construct the 3D reconstruction images of the heart. The biplane fluoroscopic images were calibrated according to the magnetic resonance images. With this method, the electrophysiologists were able to get a good 3D perception of the atrial shape before and during the ablation procedure. This increased perception of the anatomy of atria caused a change in the treatment strategy in some patients. The procedure was further simplified by color coding, resulting in less mental load. They suggested that the major advantage of the AR-assisted system was to enable the electrophysiologist to prepare themselves to the procedure before the ablation procedure itself.

Although, there has been a tremendous increase in interest in AR (and VR) in the last two decades, there are still challenges, such as the long-term impacts of AR, ethical and legal issues

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and infancy of level of artificial intelligence supporting AR, to be addressed before its widespread use in medicine (20). Despite its some drawbacks, the AR technology has potential to be used widely in near future, especially for educational purposes.

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