Major changes have occurred in the medical environment leading to an evolution from the traditional residency programmes to competency-based ones. Virtual reality (VR) represents a promising simulation resource for surgical training. Several types of VR simulators can be considered, depending on the level of immersion they offer. The goal of the article is to review the progress of VR simulation in plastic surgery (PS) training. A systematic search of the literature was performed on PUBMED/MEDLINE with the following key words: (Simulation OR Virtual Reality) AND (Education OR Training) AND Plastic Surgery from January 1998 to September 2019. A total of 244 results were found, and 80 of them were selected for abstract review. Sixty-four articles were selected for complete reading. Several attempts have been made to create VR simulators and most of them are non-immersive or partially immersive. The main conclusions of them are summarized. VR simulation has been proven to have a role in PS training, offering many advantages. Furthermore, VR simulation can be used for safety training, team interaction and decision-making education. Validation is a key point for acceptance of simulators. Further efforts are required to include simulation in PS curricula.

In real surgery, it is important to have a thorough, accurate, and detailed knowledge of the anatomical structure of the surgical target. This aspect is especially important in plastic surgery, where most of the surgical outcomes are directly connected to the patient's external appearance. With the development of computer graphics and sensors, VR and augmented reality (AR) have become technologies that can bring new opportunities for development of the diagnostic and operative techniques used in reconstructive plastic surgery and aesthetic surgery. As we already know, compared with 2-dimensional methods, 3D computer simulation enables more accurate, realistic, and intuitive diagnosis and surgical analysis. Although VR/AR technology cannot fully simulate humans' 5 senses of reality, many obstacles will be solved in the near future, considering the pace at which VR/AR techniques and sensors are being developed.

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For maxillofacial surgery, Fushima and Kobayashi [5] suggested a mixed reality-based system using a dental cast model and a 3D maxillofacial mesh model. The system synchronized the movement of the dental cast model in the real world and the 3D patient model in the virtual world. By making a 3D model move, following the transformation of the dental cast model, they performed orthognathic planning.

Research has been conducted into virtual surgery for cranio-maxillofacial complex fracture reduction with 3D patient bone mesh models (Fig. 3) [10,11]. Both such studies used a haptic device to manipulate bone fragments, but an immersive workbench and a piece of 3D eyewear were also used for simulation in the study of Olsson et al. [10].

AR-based navigation systems have been introduced for orthognathic surgery, providing overlaid images of real surgical views and virtual surgical plans for guidance [19,20,21]. Badiali et al. [19] used an HMD to display overlaid images to allow surgeons to follow virtual surgical plans when repositioning patient bones after maxillofacial osteotomies (Fig. 4). Zinser et al. [20] and Mischkowski et al. [21] used interactive portable displays with a camera to handle this system easily during surgery and displayed overlaid images on it (Fig. 5).
In facial contouring surgery, AR technology has also been used. Lin et al. [22] developed an AR-based system for mandibular angle osteotomy to overlay a 3D patient mandible model and a virtual planned 3D surgical guide model on a real surgical view via an HMD. This system helped surgeons to utilize a surgical guide of the planned position and to perform cutting procedures accurately.

An immersive workbench system with a haptic device to train for procedures of orthognathic maxillofacial surgery was developed by Wu et al. [26] and Lin et al. [27] (Fig. 8). These 2 studies specifically focused on LeFort 1 procedures. To allow surgeons to train for surgical procedures, the system was designed to provide functions of bone sawing, drilling, and plate fixation with haptic force feedback.

(A) A surgeon evaluating use of the simulator, and (B) the bone sawing procedure for 6 trials. Adapted from Lin Y, et al. J Biomed Inform 2014;48: 122-9 [27], with permission of Elsevier via Copyright Clearance Center.

For orthopedic fracture reduction surgery, there are wire training simulators using VR. Seah et al. [28] used the haptic device and the 3D bone mesh model for training in positioning Kirschner wires in distal radius fracture reduction surgery. Moreover, Thomas et al. [29] proposed a mixed reality-based wire navigation simulator that was composed of a real drill, plastic bone model, and a 3D bone model. This may be used for interochanteric fractures. TraumaVison [30] is a commercial product used to simulate orthopedic trauma surgery using a haptic device. In addition, it provides a virtual fluoroscopic image and a 3D mesh model to establish a sort of training for fracture reduction and implant placement. OssoVR [31] is a virtual reality-based simulation platform that can be used to train for surgical procedures immersively using an HMD and tracked hand-held controllers (Fig. 9). The surgeon interacts with the virtual world naturally using his or her hands. In orthopedic surgery, most VR-based training studies to improve surgical skills such as bone drilling and burring have used a haptic device for the surgeon's tactile experience [32,33,34]. The system developed by Wong et al. [33] additionally included 3D eyewear to facilitate the user's immersion.

A general view of the immersive virtual reality (VR) environment being used by a resident. The operator is using haptic devices in both right and left hand which mimic the operating room environment. The virtual image is projected on a screen in front of the resident. Adapted from Alaraj A, et al. Neurosurgery 2015;11 Suppl 2:52-8 [36], on the basis of Open Access.

From the results of our literature survey, VR/AR technologies applied to plastic surgery can be categorized into 3 areas: surgical planning, navigation, and training. VR-based surgical planning utilizes VR technology and a patient-specific model for optimal preoperative planning. VR-based surgical navigation often combines AR technology to guide the operation with more useful information (the patient's anatomical features and/or preoperative planning). VR-based virtual training has also been extensively investigated, and many commercial products are already available for educational purposes in medicine. The results of surveying the state-of-the-art technologies in each category were reported in the Results section. Herein, we would like to highlight the main advantages of VR/AR in plastic surgery, which are as follows:

Computer-based training simulators have been used extensively, most notably in flight simulation. Over the past 20 years, surgical simulators have been developed, initially for training of minimally invasive surgery and more recently for open surgical simulation. The key effort in today's surgical simulation field is to develop metrics to evaluate how well the skills learned in a simulator translate to improvement in real surgical skills, execution of procedures, and team cooperation in the operating room. The American College of Surgeons has begun implementing a phased approach to introduce simulation in training and education for general surgery. The authors believe that a
similar training plan should be mandated for plastic surgery, to take advantage of the use of computers, virtual reality, and simulation in the training of plastic surgery residents and to explore the value of this technology for continuing medical education and maintenance of certification. This article gives a brief background and history of surgical simulation and its technology, followed by a detailed description of the three phases of the American College of Surgeons' plan and how the authors propose that each phase be implemented, with modifications as applicable for trainees in plastic surgery.

The most recent development in simulation is the use of virtual reality (VR), augmented reality (AR), and even artificial intelligence (AI) technologies. VR is touted for its ability to provide rare and complex experiences that are not often encountered in the day-to-day setting. Many VR programs focus on improving identification of anatomic variation and evaluating procedural knowledge. The drawbacks of VR are its expensive up-front costs and its inability to fully capture the physical aspects of surgery because of its lack of high-quality haptic feedback.

Cadaver and synthetic models are widely used for training in craniofacial surgery. Drawing the various lip and palate repairs on paper is a prerequisite for any trainee who enters the operating room; however, the actual dissection and soft tissue layers of the lip and palate are some of the most challenging to teach in plastic surgery. This is further accentuated by the anatomical variability in cleft lip and palate patients. As a result, various high-fidelity synthetic simulators with realistic physical properties and accurate anatomic representation have been validated for training in cleft palate repairs to increase the knowledge and confidence of trainees as they move through residency. One high-fidelity simulator incorporates the use of the 3-dimensional printing with silicone casting that not only enhances skill development but also has the added benefit of low cost and high portability. This model was developed from the computed tomography scan of a patient and adjusted by highly trained cleft surgeons. The tensile strength and feel of tissues were also adjusted based on recommendations by the surgeons. Impressively, the model with simulation requires everything from inserting the Dingman Retractor to raising mucoperichondrial flaps to the final suture closure. Furthermore, it contains a low-cost insertable cartridge that can be easily changed out after each training exercise.