EAES 2022

3D PRINTING TECHNOLOGY APPLIED TO MINIMALLY INVASIVE SURGERY TRAINING

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Co-funded by the Erasmus+ Programme of the European Union

Fondo Europeo de Desarrollo Regional
Una manera de hacer Europa

GR18199, TA18023
CPI-2019-33-1-TRE-14
621668-EPP-1-2020-1-ES-EPPKA2-KA

INTRODUCTION AND OBJECTIVES

Traditional training methods in minimally invasive surgery (MIS) are often based on static learning content and sometimes far from real clinical practice. The MIREIA (Mixed Reality in medical Education based on Interactive Applications) project is an Alliance that aims to combine the use of cutting-edge technology in immersive virtual technology and 3D printing with personalized learning content to promote a student-centered learning process.

As part of this project, the objective of this study is to analyze the state of the art of 3D printing technology for its application in MIS training.

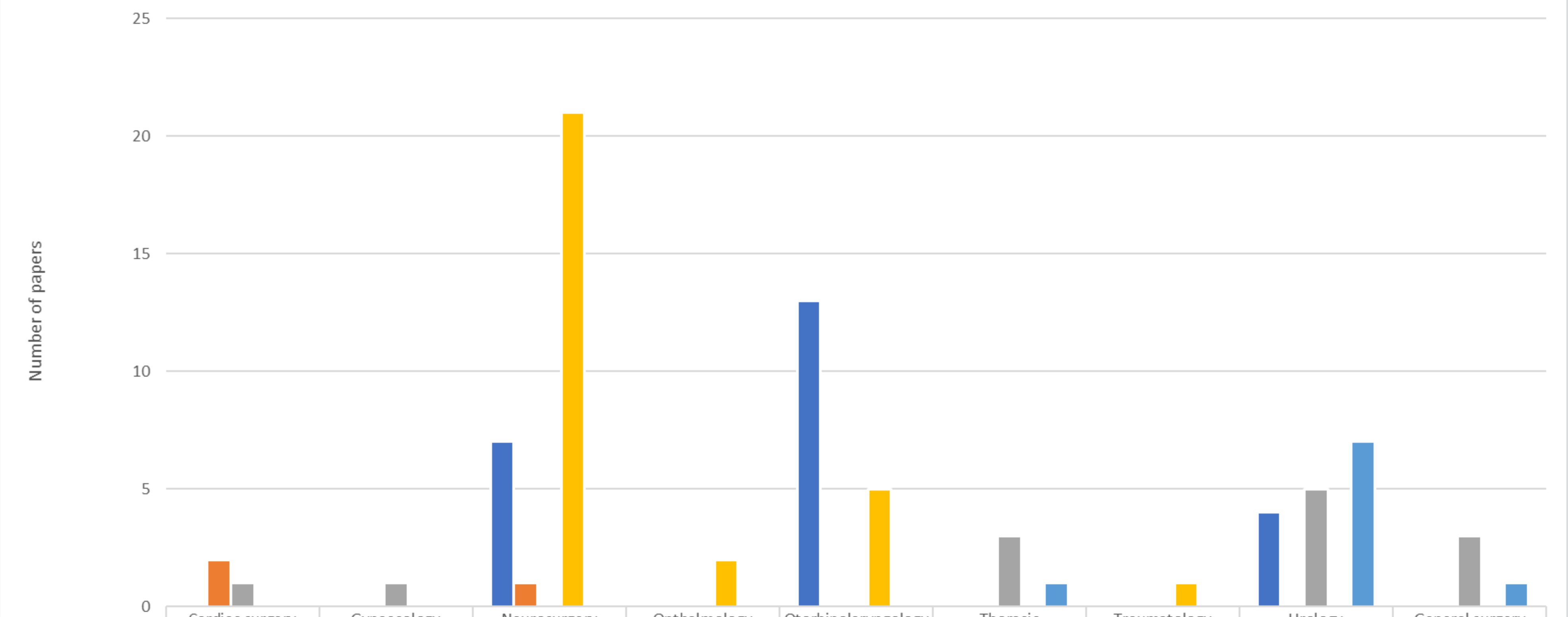
MATERIAL & METHODS

A structured bibliographical search was conducted in the PubMed database. We used a set of keywords related to 3D printing and MIS training to identify relevant studies published up to September 24, 2021.

A series of inclusion and exclusion criteria were considered to select the articles that best applied for our objectives. In general, articles whose subject was 3D printing in MIS training and written in English were selected. Those papers whose subject was incorrect, papers not written in English, abstracts, conference proceedings, and review articles, were not considered for this study. The articles finally included in this review were analyzed according to the following aspects: (1) materials, (2) equipment and software, and (3) applications of 3D printing technology in MIS training. The applications of 3D printing were organized into two main groups: (1) as a training method in medical and surgical anatomy and (2) as a physical model for training basic surgical skills in a laparoscopic training simulator.

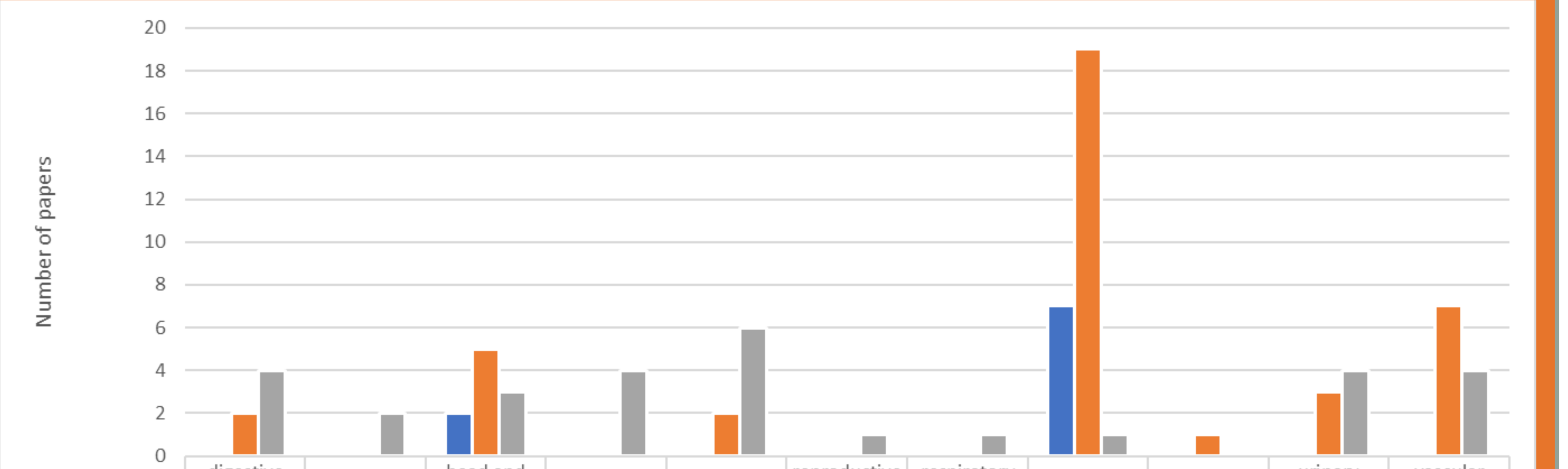
RESULTS

A total of 272 articles were considered for this study, of which 95 articles were finally selected. Neurosurgery, otolaryngology and urology were the surgical specialties that have shown the greatest application of 3D printed models for training (Figure 1). The skull was the most popular 3D printed structure for training in neurosurgery and otolaryngology (Figure 2). Other common structures were the head and neck for otolaryngology and the kidneys and urinary system for urology training. The most widely used fabrication technique was Fused Deposition Modeling, followed by ColorJet Printing (Figure 3). Stereolithography (SLA) was also used in about one in ten articles, mainly because of its higher resolution. Selective Laser Sintering was used in about one in twenty papers, due to its excellent resolution and mechanical properties of the resulting parts. Once the 3D model is obtained from the preoperative imaging study, post-processing is carried out to clean, smooth and adapt the model to the specific application. The most popular software for this purpose were Meshmixer and Materialise 3-Matic (Materialise NV). As for software for 3D printing preparation, the most popular was Ultimaker Cura (Ultimaker B.V.). Of the most commonly used 3D printers, we highlight equipment from Stratasys, 3D Systems, Ultimaker and Formlabs. Regarding the model validation methods used, most of them relied on subjective surveys and objective metrics to establish the similarity of the printed model to the actual anatomy (Figure 4).



	Cardiac surgery	Gynaecology	Neurosurgery	Opthalmology	Otorhinolaryngology	Thoracic	Traumatology	Urology	General surgery
Endoscopy			7		13			4	
ETD	2		1						
Laparoscopy	1	1				3		5	3
Microsurgery			21	2	5		1		
Robotic surgery						1		7	1

Figure 1. Application of 3D printing models for MIS training with regard to the surgical specialty and the type of minimally invasive technique.



	digestive system	eyes	head and neck	heart	kidney	reproductive system	respiratory system	skull	spine	urinary system	vascular system
Rigid			2					7			
Rigid and soft	2		5		2			19	1	3	7
Soft	4	2	3	4	6	1	1	1		4	4

Figure 2. Type of 3D-printed structure (rigid, soft, rigid and soft).

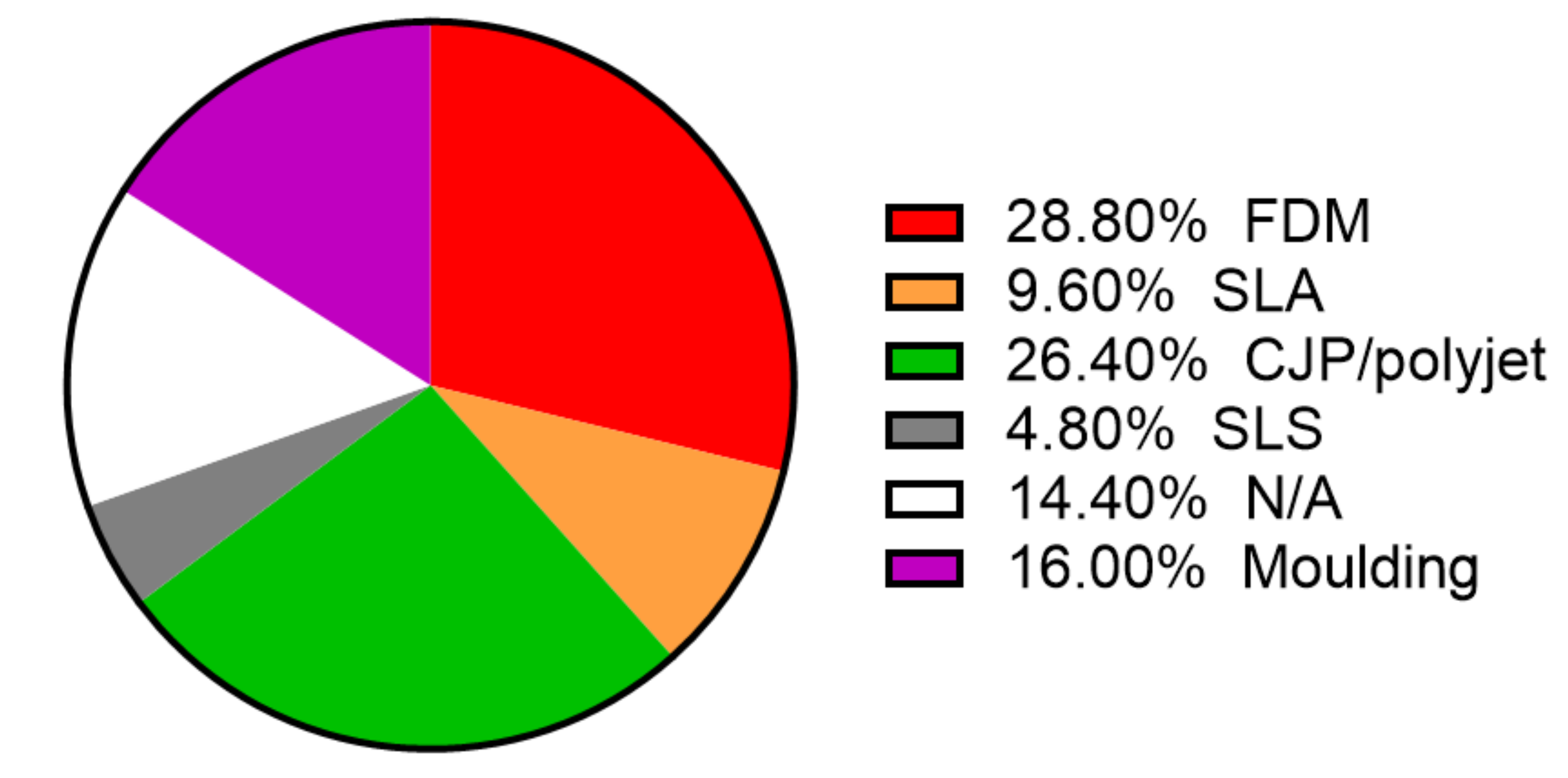


Figure 3. Fabrication techniques used to create the models.

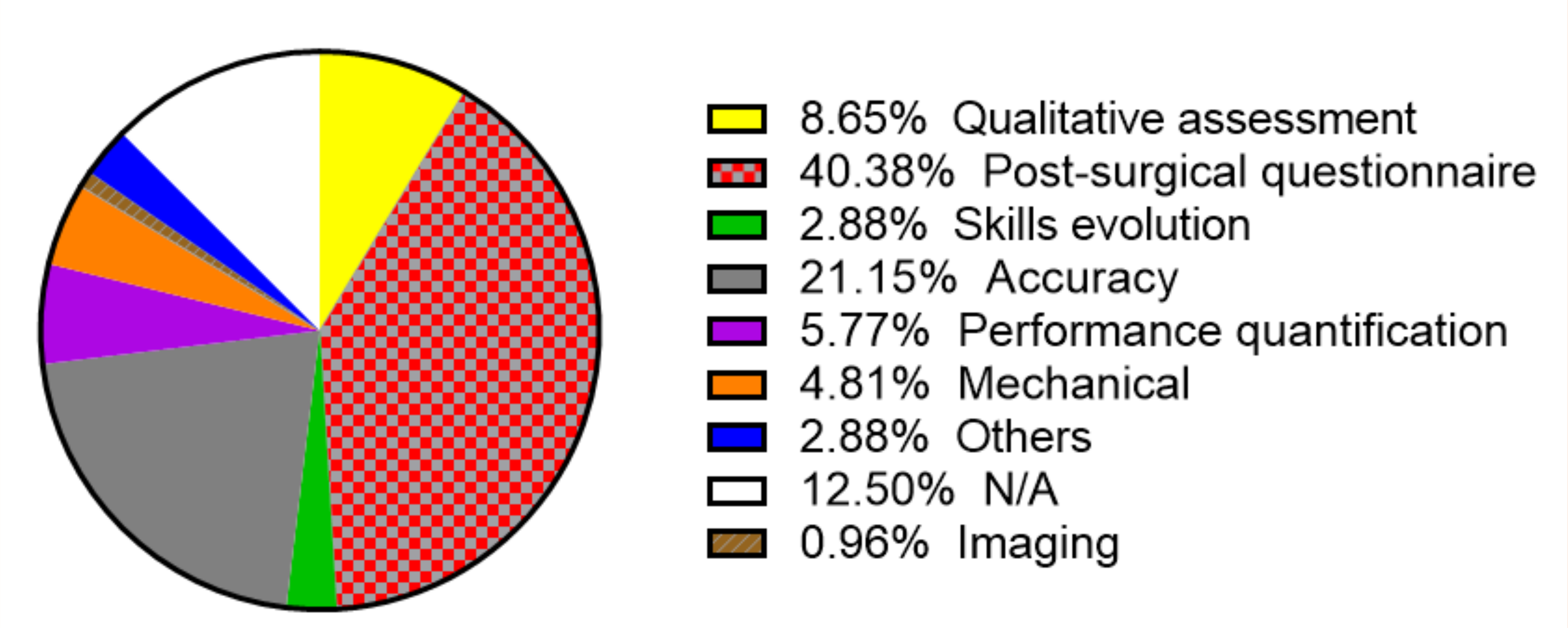


Figure 4. Methods to test the performance of the 3D-printed models

CONCLUSIONS

This study revealed a variety of techniques and materials used to produce 3D models for MIS training. In general, 3D-printed training models can belong to two domains, on the one hand models for anatomical learning (anatomical models), and on the other hand models for practical training (practical models). In order to achieve a suitable training model, two characteristics must be taken into account, the fidelity of the model and the simulation of the behavior (replication of functional aspects). To create models with both characteristics it is necessary to reach a compromise between them.