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Review

3D Printing Approach in Maxillofacial Surgery in Iran: An Evaluation Using the Non-Adoption, Abandonment, Scale-Up, Spread, and Sustainability (NASSS) Framework

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Abstract: The integration of 3D printing technology in maxillofacial surgery in Iran represents a significant advancement in medical practice, offering unprecedented precision and efficiency in surgical procedures. Employing the Non-Adoption, Abandonment, Scale-Up, Spread, and Sustainability (NASSS) framework and the WHO Health Systems Framework, this study analyzes the complex impact and challenges of 3D printing adoption within the Iranian healthcare sector. Maxillofacial surgery has seen transformative progress with 3D printing's ability to produce accurate surgical models and customized implants. The results indicate a notable improvement in surgical precision and patient recovery times, alongside combatting identified barriers including technological access, cost, and skill acquisition. This conclusion underscores the critical need for targeted educational programs, policy support, and infrastructure development to overcome these obstacles. This paper highlights 3D printing's potential to revolutionize maxillofacial surgery in Iran, provided that comprehensive strategies are implemented to address the current limitations and fully leverage this innovative technology's benefits.

Keywords: maxillofacial surgery; NASSS framework; 3D printing; surgical innovation; healthcare technology evaluation

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1. Introduction

Three-dimensional (3D) printing is a modern technology that produces three-dimensional objects from digital designs. This essay will examine the application of 3D printing in maxillofacial surgery in Iran, including its advantages, limitations, and future prospects. One of the areas where 3D printing has shown great potential is in maxillofacial surgery. Maxillofacial surgery involves the diagnosis, treatment, and management of diseases, injuries, and defects that affect the head, neck, face, and jaw. In Iran, as in most countries, maxillofacial surgery is a significant area of medical practice and the use of 3D printing technology in maxillofacial surgery has brought about a significant revolution in the field of oral and maxillofacial surgery (OMFS). The 3D models developed from this procedure shorten the operation time and increase the accuracy of procedures, which accelerate the patients' rehabilitation and improve future health outcomes [1].

2. Materials and Methods

In this study, the NASSS technology implementation framework and the WHO Health Systems Framework were adopted as the analytical tool. These frameworks were selected for their effectiveness in helping researchers pinpoint both the facilitators of and barriers to the implementation of technology [2,3]. The NASSS framework provides a comprehensive, multidimensional examination of the essential components for successful technology implementation. The present article adopts a forward-looking approach informed by the NASSS framework to predict and identify potential facilitators and barriers to the integration of new medical technologies in conventional clinical settings. This approach is in line with the principles of responsible innovation (RI) which focus on proactive measures to ensure beneficial societal outcomes and navigate the processes needed to achieve these goals [4]. The NASSS framework is structured around seven domains, each representing a complex ecosystem [5]. It is important to consider these domains not separately, but as interconnected parts of a larger sociotechnical system that evolve through mutual interaction over time [6]. Each domain contains various sub-domains that expose different types of complexity in the intended program, highlighting the widespread impact of technologies that can initiate specific actions in different contexts. Domain 1 explores the complexities of health conditions in maxillofacial surgery, highlighting the intricate challenges presented by the coexistence of these conditions with other comorbidities. Moreover, the management of these conditions is significantly affected by sociocultural factors, such as poverty or race and ethnicity, which are vital in determining the condition's impact and the management strategies used in the context of 3D printing in oral and maxillofacial surgery [7,8].

Domain 2 explores the complexities of 3D printing technology, focusing on its operational effectiveness, reliability, and speed. This technology necessitates the development of new, specific skills for its successful application. Furthermore, the type of data generated by 3D printers, along with the management of these data and related privacy concerns, add further complexity to this domain [9]. Domain 3, titled the value proposition, explores the advantages for both creators (supply side) and users (demand side) including patients, the healthcare system, and payers like taxpayers or insurance companies. The challenge in this area lies in creating a strong business argument for the developers, proving the technology's cost-effectiveness, and confirming its appeal to users [10].

Domain 4, known as the adopter system, involves the healthcare personnel responsible for operating and maintaining 3D printing technology, along with the patients and staff expected to use it. The complexity in this domain arises from resistance among healthcare professionals and patients against adopting new technologies. This reluctance can stem from several factors, including resistance to change, unfamiliarity with the technology, or concerns over its ease of use and effectiveness [4]. Domain 5 relates to the healthcare organizations engaged in the process. The challenges in this area are connected to the organization's capacity to encourage innovation. This involves elements like effective leadership, solid decision-making mechanisms, and competent management of human resources, all vital for motivating staff, facilitating continuous education, and providing support. Moreover, the extent of work needed to bring about change, including activities such as software upkeep and modifications, adds to the complexity of this domain [11].

Domain 6 covers the wider ecosystem, incorporating factors such as the policy landscape, support from regulatory and professional bodies, and public opinion. This domain highlights how external factors influence the adoption and potential deceleration of innovative technologies. Aspects like social, political, technological, and economic conditions significantly affect how new technologies are received and incorporated into the healthcare field [7]. Domain 7 centers on the continuous integration and adjustment of the technology and the involved service or organization over time. The challenges within this domain may arise from the technology's failure to adapt to changing environments or the organization's lack of adaptability, including difficulties in learning and evolving. This emphasizes the need for adaptability and ongoing enhancement in both technological and organizational aspects to effectively implement and maintain innovative solutions [4]. We conducted a

survey among 12 maxillofacial surgeons via email in Iran to assess their awareness of digital technology and 3D printing. The survey covered various topics including familiarity with different 3D printing technologies, attendance at training programs, and perceptions of the need for increased education. Participants also identified the advantages and limitations of 3D printing technology. Additionally, the survey explored factors influencing the decision to use 3D printing technology and strategies to enhance patient education and involvement. We also examined the significance of patient awareness and preferences in the adoption of 3D printers for maxillofacial surgery, and proposed strategies such as comprehensive educational programs and financial incentives to promote adoption among patients.

The WHO describes a health system as comprising all activities primarily aimed at improving, restoring, and preserving health [3]. It highlights that a well-functioning health system operates smoothly with trained, motivated health workers, has a maintained infrastructure and a reliable supply of medicines and technology, and is supported by sufficient funding, solid health plans, and evidence-based policies [3]. These elements are referred to as the WHO's health system "building blocks" [12,13]: service delivery, health workforce, health information systems, medical products and technologies, health financing, and leadership/governance. Effective service delivery ensures safe, efficient, high-quality, patient-focused services are accessible to everyone in need, at the right time and place [12,13]. A strong health workforce is crucial, consisting of qualified and responsive professionals like doctors, nurses, and pharmacists, ensuring the best health outcomes [12,13]. A robust health information system gathers, analyzes, and shares critical health data promptly [12,13]. The system also guarantees access to essential, high-quality, and cost-effective medical products and technologies. Adequate health financing is vital for allowing access to health services without financial burden. Finally, effective leadership and governance involve clear policy direction, oversight, regulation, and accountability. Enhancing the health system means fostering better interactions among these building blocks to improve public health equitably and sustainably [6,14].

3. Results

We utilized the WHO and NASSS frameworks to assess the use of 3D printing technology in maxillofacial surgery within Iran (Figures 1 and 2). This analysis centers on the domains of the NASSS framework identified by Greenhalgh et al. [6], which represents one of the most comprehensive frameworks for evaluating the sociotechnical aspects of innovation implementation in healthcare.

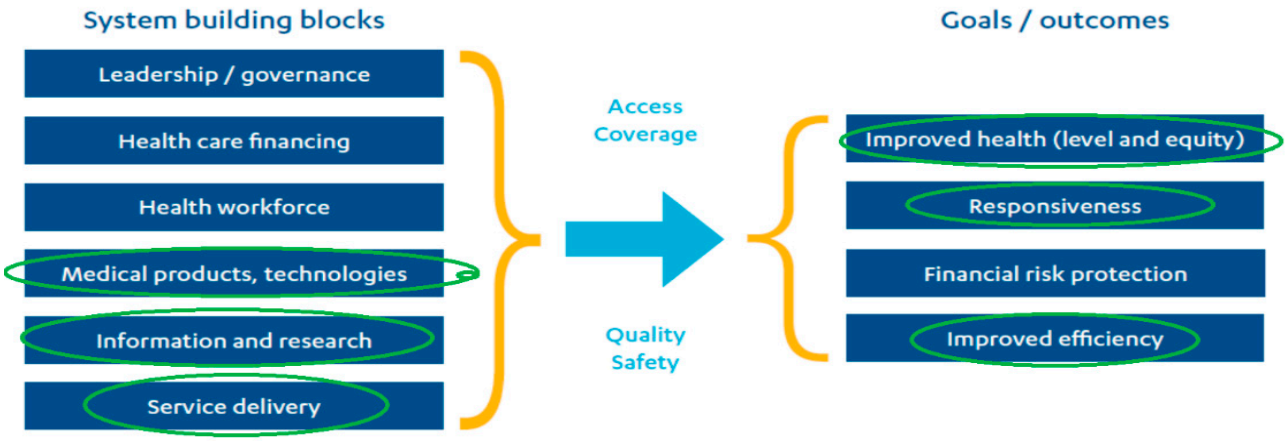

Figure 1. The WHO Health Systems Framework diagram, adapted from [3], highlights the building blocks and outcomes significantly influenced by 3D printing adoption (circled in blue).

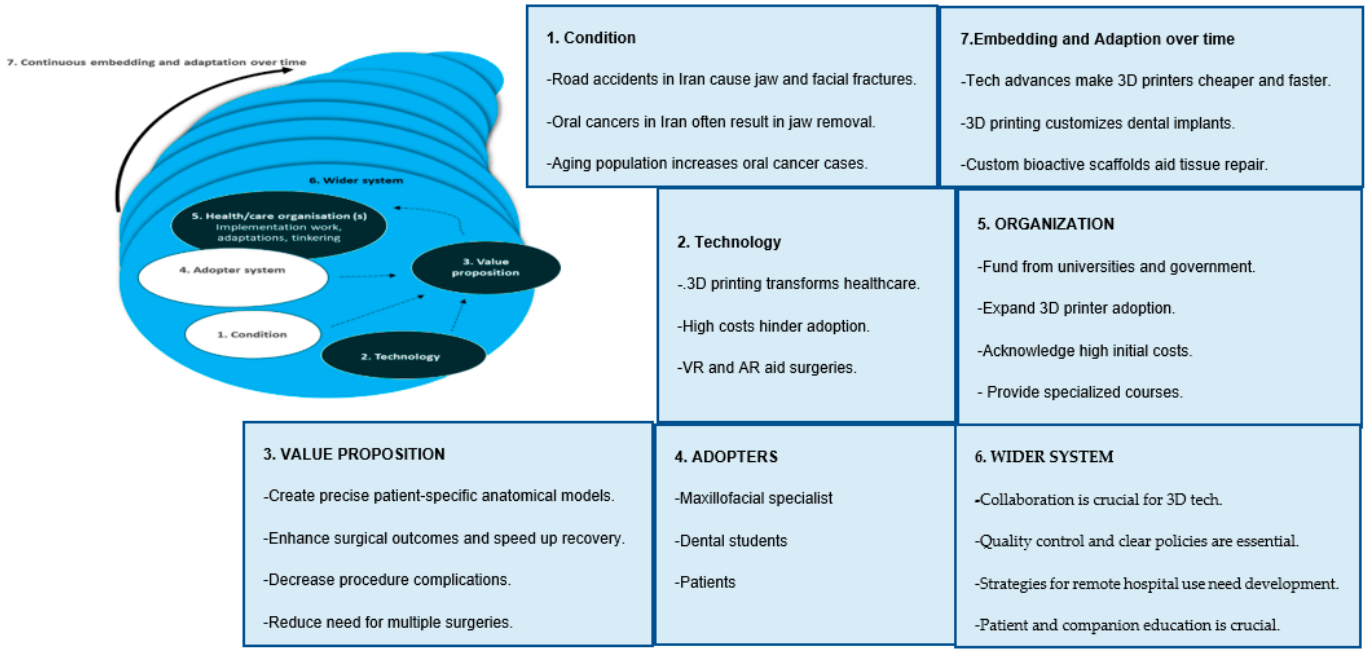

Figure 2. The NASSS framework for 3D printers' use in maxillofacial surgery provides a concise overview of the factors influencing the adoption, organization, spread, and scaling-up of 3D printers. The diagram, adapted from [6], illustrates this framework.

3.1. WHO Framework

According to the WHO Framework (Figure 1), the evaluation of the use of 3D printing technology in maxillofacial surgery in Iran is structured into two main components: assessment of system building blocks and the outcomes. We have evaluated and summarized below.

3.1.1. System Building Blocks

Service Delivery

The implementation of 3D printing technology in maxillofacial surgery can improve service delivery by providing more accurate surgical planning, reduce surgical time and costs, and potentially improve patient outcomes [14]. However, challenges such as technical issues with equipment and software, limited compatibility with other systems, inadequate training of healthcare workers, high implementation costs, and potential patient resistance to the technology may arise. It is important to address these challenges to ensure the safe and effective implementation of 3D printing technology in maxillofacial surgery [15].

Health Information Systems

The successful implementation of 3D printing technology in maxillofacial surgery requires accurate and reliable medical imaging data. Additionally, healthcare workers need to be adequately trained to effectively operate the technology to ensure high-quality care [15].

Medicinal Products and Technology

The accessibility of 3D printers, software, and the necessary materials for maxillofacial surgery can be a challenge [16]. It is imperative to ensure that these products and technologies are available and affordable to healthcare providers across the country [17].

The development and commercialization of new technologies can encounter roadblocks such as regulatory approval, intellectual property protection, financing and resources, market demand and competition, and technical limitations. The World Health

Organization can work with international organizations and stakeholders to improve access to 3D printers and materials for maxillofacial surgery.

3.1.2. Outcomes

Improve Health

By improving surgical planning and reducing surgical recovery time, 3D printing technology can potentially improve patient outcomes in maxillofacial surgery [18].

Responsiveness

Training healthcare workers to use 3D printing technology in maxillofacial surgery can have a significant impact on their practice in the future, improve clinical outcomes, increase efficiency and productivity, enhance patient satisfaction, and provide a competitive advantage in the job market for healthcare professionals [19].

Improve Efficiency

By streamlining surgical tool creation, 3D printing cuts time and costs in maxillofacial surgery. This can improve the efficiency of healthcare delivery in Iran [18]. It is important to identify appropriate funding mechanisms to support the implementation of 3D printers in maxillofacial surgery to ensure their affordability and sustainability in the long run [20]. Dentists and maxillofacial specialists in Iran have utilized 3D printing technology to address jaw and facial issues in their patients, resulting in favorable outcomes such as improved health and responsiveness, heightened patient satisfaction, and enhanced efficiency [21–23]. Furthermore, this method has led to a reduction in both surgical time and costs.

3.2. NASSS Framework

The 7 domains of the NASSS framework regarding the 3D printing approach in maxillofacial surgery in Iran are evaluated and summarized below (Figure 2).

3.2.1. Condition

Road accidents, oral cancers, and natural aging processes lead to conditions in which maxillofacial procedures in Iran are increasingly necessary. In Iran, the death rate due to road accidents is 5.63% of total deaths [24]. Most of these accidents involve motorcyclists who have sustained severe trauma and maxillofacial fractures, and 68.8% have required jaw and facial surgery [25].

Additionally, according to the latest WHO data published in 2020, oral cancer deaths in Iran reached 655 or 0.20% of total deaths. Iran ranks 176th in the world for the highest percentage of total deaths related to oral cancer (Figure 3) [26].

Health statistics from Iran show that more than 70,000 new cases of oral cancer occur yearly and, due to an increase in life expectancy, the percentage of the elderly in the country is quickly growing, which in turn increases the incidence of cancer in the next few decades.

Most oral cancers require surgery, and removing the cancerous mass often requires total or partial reconstruction of the patient's jaw [19]. Because maxillofacial injuries can cause significant long-term functional, cosmetic, and psychological complications, these injuries may also have significant economic consequences for patients because treatment may require a complex procedure [27].

The use of 3D printers in these conditions leads to saving time and has also been proven to be a valuable tool in the diagnosis, treatment planning, and surgical interventions of OMFS cases.

By producing accurate and customized models, surgeons can better plan and perform complex surgeries, leading to better patient outcomes [16,28–33].

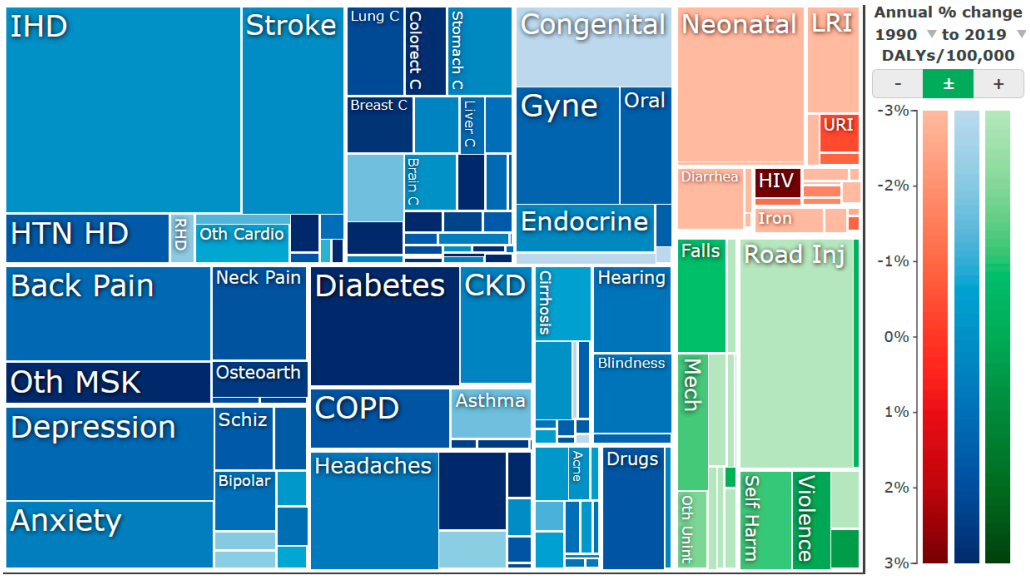

Figure 3. Iran (Islamic Republic of) Both sexes, All ages, 2019, DALYS. Annual mortality in Iran. Data adapted from [24]. According to this record, road injuries constitute 5.63% of total DALYs (4.83–6.58%), with an annual % change of −3.27%, and oral disorders constitute 1.31% of total DALYs (0.82–2.05%), with an annual % change of 1.52%.

3.2.2. Technology

The first 3D model was made in 1981 by Hideo Kodama at the Nagoya Municipal Industrial Research Institute using a photopolymer. Then, in 1984, Charles Hall invented stereolithography, the process of creating three-dimensional models using digital data. This new technology became popular among inventors who could now build and test their prototypes without incurring large costs. Then, in 1992, the first stereolithography (SLA) machine was built, which allowed for the creation of complex parts to be built layer by layer. At roughly the same time, the first selective laser sintering (SLS) machine was invented that could fire a laser at the photopolymer powder instead of the liquid (Table 1) [34].

In 2010, 3D printers were developed around the world for use in oral and maxillofacial surgery. Since then, Iran has made significant progress in using 3D printing technology for oral and maxillofacial surgery. In 2011, the Shahid Sadoughi University of Yazd surgical team used an Iranian-made 3D printer for maxillofacial surgery for the first time in Iran. The printer produced an accurate model of the jaw of a 48-year-old patient with SCC before surgery, which allowed specialists to match the reconstruction plate with the patient's face. This method resulted in a 35–40% reduction in surgery time as well as significant cost savings. Hazare Third Millennium Smart Machines Company, Tehran, Iran. Designed and manufactured the 3D printer, with support from Shinasa Investment Company (Tehran, Iran). By analyzing the patient's 3D CT scan images, the company produced the jaw sample with an error of less than 32 microns [35].

Three-dimensional models have additional uses besides the creation of patient jaw models. Three-dimensional models are also utilized to produce surgical guides and contouring of the osteosynthesis or reconstruction plates in the treatment planning phase of various oral and maxillofacial surgical procedures. The pre-bending of plates on a 3D model can offer higher precision compared to the conventional approach where bending is performed intraoperatively. Furthermore, the physical manipulation of the anatomical structures on a model during planning of the complex surgical procedures permits more control and better comprehension of the different surgical approaches. This allows surgeons to become familiarized with the intraoperative situation beforehand and lead to more predictable intraoperative results (Figure 4) [36].

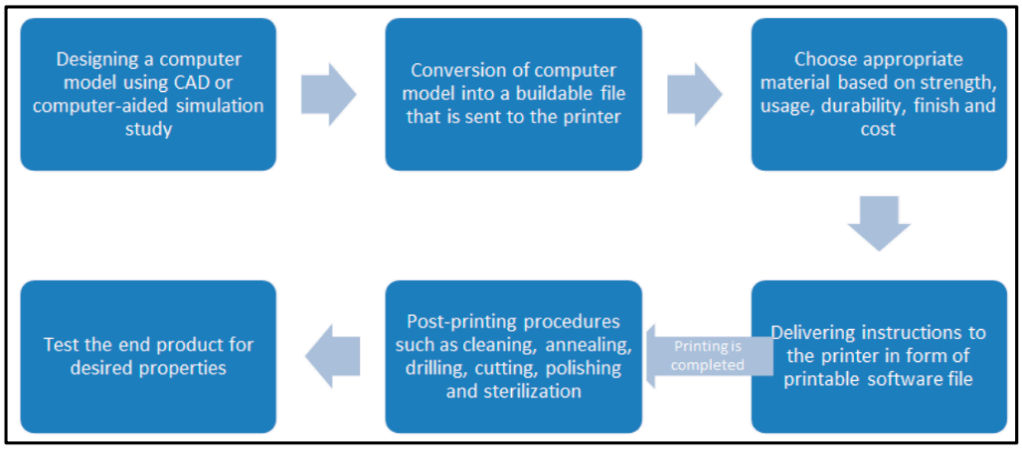

Figure 4. Adapted from [34]. A summary of the process of 3D printing in maxillofacial surgery.

The most common clinical indications of 3D printing in maxillofacial settings include dental implant surgery [37], mandibular reconstruction [38], manufacturing of anatomical models, producing surgical guides/splints, patient-specific implants [37], orthognathic surgeries [39], surgical guides for genioplasty and osteotomy [21], and prosthesis (Figure 5).

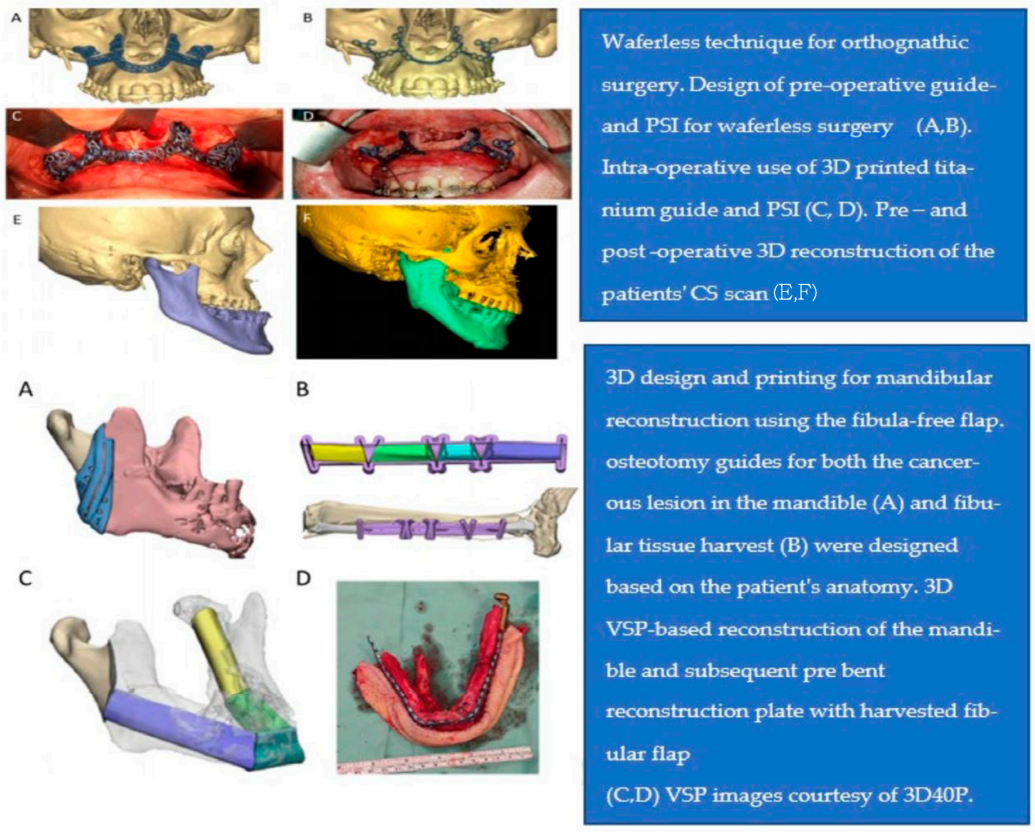

Figure 5. Applications of 3D printing technology in maxillofacial surgery. Adapted from [39].

Table 1. A review of the top 3D printer devices for maxillofacial surgery. The three most applicable techniques for 3D printing used in dentistry and maxillofacial surgeries are stereolithography (SLA), selective laser sintering (SLS), and fused deposition modeling (FDM) [39,40].

	Stereolithography (SLA)	Fused Deposition Modeling (FDM)	Selective Laser Sintering (SLS)
Materials for printing	- A variety of resins for photopolymerization, ceramic-filled resins, etc.	- Thermoplastic polymers such as polylactic-acid (PLA). - Acrylonitrile butadiene styrene (ABS). - Polycarbonate (PC). - Polyether ether ketone (PEEK), etc.	- Powder such as alumide. - Polyamide. - Glass particle-filled polyamide. - Rubber-like polyurethane, etc.
Approximate Accuracy	50 to 55 µm	35 to 40 µm	45 to 50 µm

For 3D printing technology to avoid pitfalls and complications, proper communication is needed. Specifically, proper communication between the radiologists and the digitized treatment planning team at the 3DP PoC center is essential to obtain the imaging needed to ensure the accurate design of instruments while avoiding the pitfalls of inaccurate anatomical details. By incorporating the skills of clinicians on site, as well as ensuring dialogue between treating physicians and engineers, the 3DP PoC can tremendously improve surgical outcomes and meet most of the needs of the surgical team (Figure 6) [39].

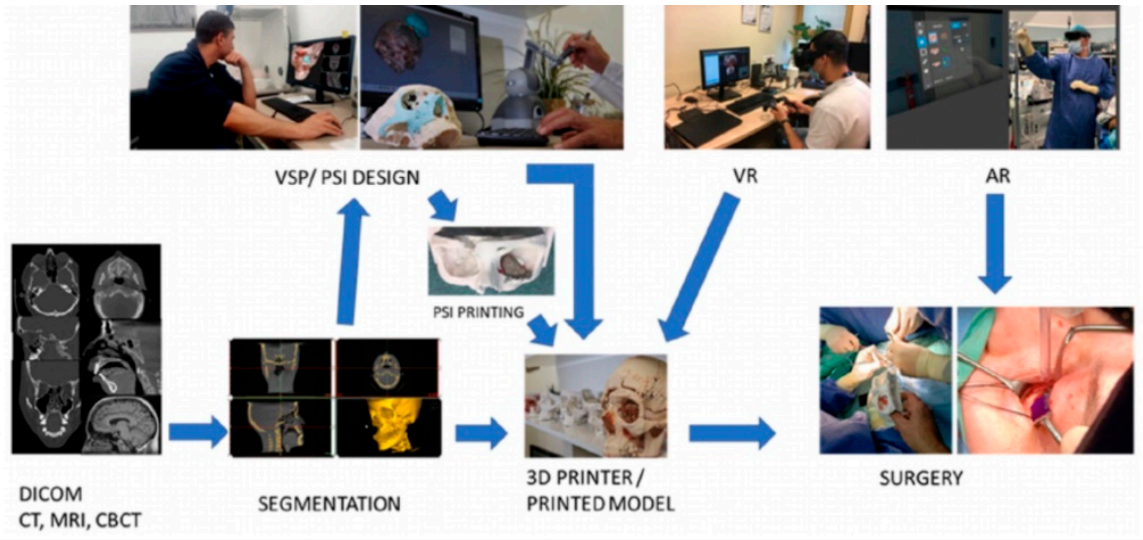

Figure 6. Adopted from [16]. Workflow at the 3DP PoC facility. Patients' volumetric data obtained after medical imaging are translated to a digital imaging and communication in medicine (DICOM) format, followed by segmentation and 3D rendering for virtual surgical planning (VSP) and patient-specific implant (PSI) design. Both models and implants are 3D-printed, sterilized, and subsequently used for surgery. Virtual reality (VR) is used for further evaluation and simulation before surgery. Augmented reality (AR) may assist the surgical team during surgery.

Despite the potential benefits of 3D printing technology in healthcare, the issue of high implementation costs remains an additional concern. Given that the technology is still relatively new, the cost of equipment and materials required for 3D printing can be significant and sometimes prove cost-prohibitive. This may pose an insurmountable challenge for smaller healthcare facilities or those with limited financial resources.

In our survey, which involved 12 maxillofacial surgeons, 75% were very familiar with 3D printer technology in maxillofacial surgery, while 25% were somewhat familiar. Additionally, 91% use 3D printers personally. Of those, 66% have used and were aware of

SLA and SL, and 58% were aware of FDM. Regarding SLS, 33% were aware, and only 25% were aware of power binder printers and have used them. All surgeons who responded have attended some form of training program. Furthermore, all participants expressed a need to increase knowledge about 3D printers during undergraduate or postgraduate studies. Additionally, all 12 participants were interested in considering 3D printers in their regular workflow.

3.2.3. Value Proposition

Three-dimensional printing technology can provide highly precise and accurate surgical guides, implants, and models that fit each patient's unique anatomy. This can lead to improved surgical outcomes, faster recovery times, and increased communication and collaboration between healthcare professionals. Patients can benefit from improved surgical outcomes and personalized solutions tailored to their specific needs and anatomy. In general, this technology can create a better experience for the patient. In addition, the use of 3D printing can lead to long-term cost savings for patients and healthcare providers. While traditional surgical models and techniques may still be used, 3D printing can provide a more efficient approach, as well as providing more accurate and personalized planning and implementation of surgery [15].

Evidence has shown that 3D printing improves surgical outcomes and reduces complications in various medical fields, including oral and maxillofacial surgery. Additionally, the use of 3D-printed surgical guides has been shown to reduce the need for multiple surgeries and revisions, ultimately resulting in cost savings for patients and healthcare providers [18]. Overall, the value proposition of 3D printing in oral and maxillofacial surgery is that it can provide a precise, personalized, and cost-effective approach to surgical planning and execution that leads to better outcomes and better patient experiences. However, some points should also be paid attention to and efforts should be made to resolve such issues, such as the high cost of 3D printing, the limited materials available for medical applications, the time-consuming process [41], the possibility of errors in precision and accuracy, and regulatory obstacles that must be resolved. There is also a lack of standardization among different manufacturers and models, and the need for specialized knowledge and expertise are among the things that should be improved. By highlighting these challenges, the goal is to protect medical professionals and decision makers from possible disadvantages (Figures 7 and 8) [29].

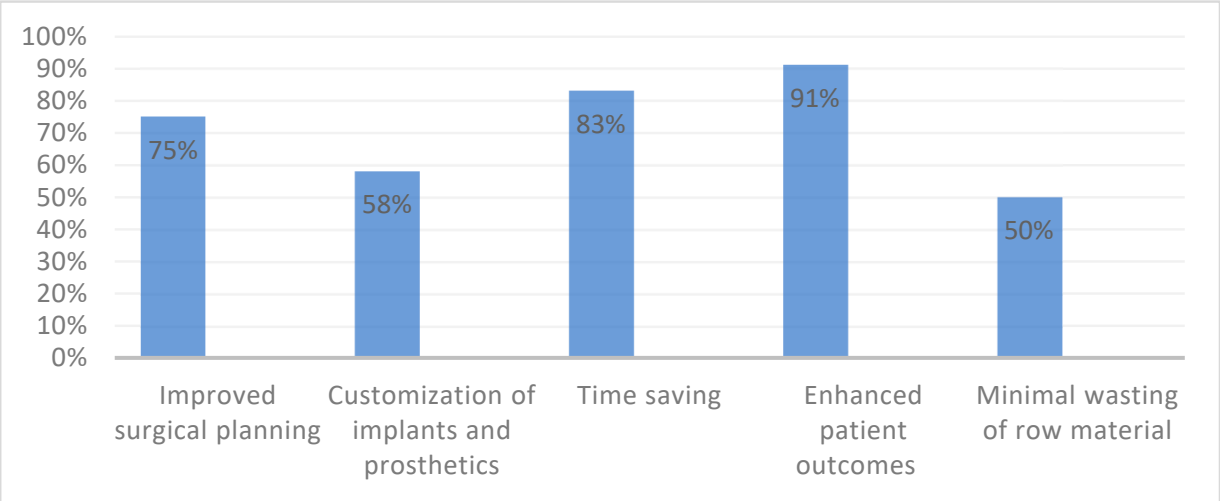

Figure 7. Survey responses of maxillofacial surgeons regarding advantages of 3D printing.

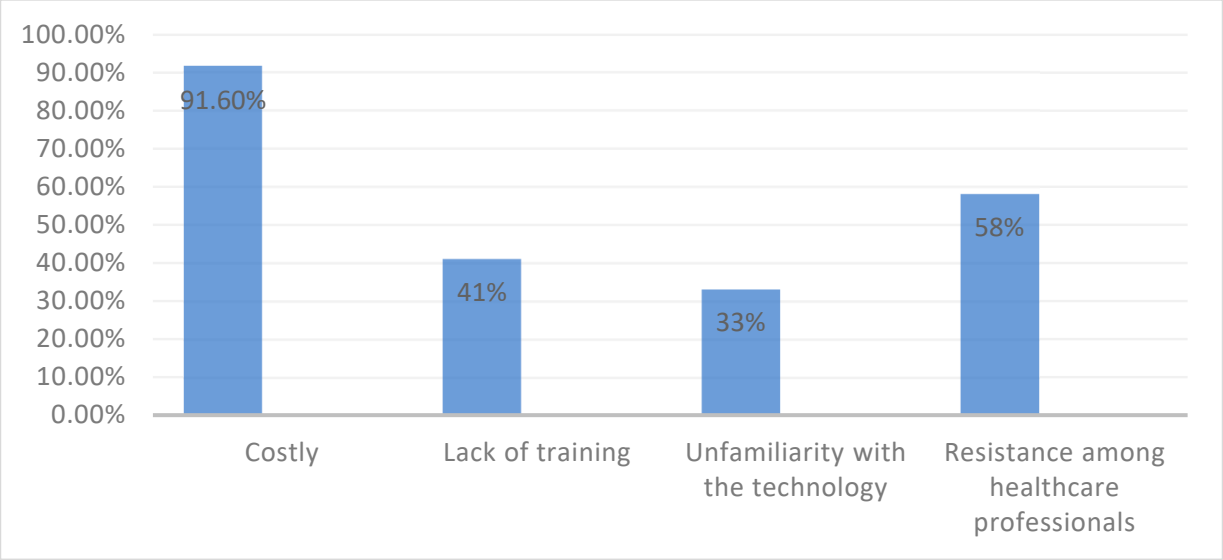

Figure 8. Survey responses of maxillofacial surgeons to challenges of using 3D printing.

3.2.4. Adopters

Three-dimensional printing technology is increasingly being adopted in maxillofacial surgery, offering benefits to a wide range of stakeholders. The technology enables maxillofacial specialists and dentists to create customized implants and surgical guides, enhancing the precision and accuracy of surgical procedures. Patients can benefit from personalized implants and simulation of surgical procedures, improving their understanding of treatment plans. Radiologists can work with surgeons to develop 3D models of a patient's anatomy, aiding in their understanding of surgical sites and possible complications. Three-dimensional printing technology is also useful for universities and biomedical engineering companies, providing research opportunities and practical experience for medical and dental students. Overall, 3D printing technology has the potential to improve patient outcomes, increase surgical accuracy, and advance medical research in maxillofacial surgery [40–42].

3.2.5. Organization(s)

The Iranian government's National Medical Education Evolution and Innovation Plan is a demonstration of its commitment to improving healthcare through innovation. For this purpose, the evaluation of the policy process was conducted based on Michelle and Scott's policy process models. The policy implementation stage involved close collaboration with universities, medical schools, and stakeholders to implement the plan, including providing resources and support for new initiatives. The use of 3D printing technology can streamline the process of creating surgical tools, improving the efficiency of healthcare delivery in Iran [40]. This makes 3D printing a good candidate for the policy implementation stage of the innovation plan.

The main organizations that will use this technology are hospitals and dental schools across Iran. According to the article [42], one of the disadvantages of using 3D printers is their high price. In recent years, there has been a significant increase in the number of people using 3D printing technology, which has led to a significant drop in prices.

The future of the 3D printing market in Iran looks bright and it is expected to be welcomed by surgeons, maxillofacial doctors, mold makers, and especially academics in this field. Many universities have already expressed their interest in offering courses related to this technology, which further indicates its promising future in Iran.

The country has recently created a new department under the Presidential Office of Science and Technology dedicated solely to the advancement of manufacturing technology. This department, which is known as the Headquarters for the Development of Manufac-

turing Technologies and Advanced Materials, has announced a major project involving 3D printing and scanning, which is an indication that the adoption of 3D technology is increasing in Iran. The country is investing in 3D printing start-ups and incorporating additive manufacturing programs into numerous colleges and universities. Universities in Iran should allocate appropriate budgets for training novice specialists and conducting courses aimed at increasing awareness among general dentists. Equipping hospitals with 3D printers is also essential, with support from the government. Dedicated rooms for installing 3D equipment and using them would be beneficial for universities. Currently, the number of medical centers and hospitals utilizing 3D printers in Iran are limited, resulting in long waiting periods for patients requiring 3D-printed materials [29]. The Medical Equipment Office (MEO) and the Food and Drug Administration (FDA) in Iran receives a government budget for importing medical goods and supporting domestic entrepreneurs to develop projects in Iran, which should be allocated to provide 3D printers to all hospitals [43,44].

Dentists and specialists in Iran are required to undergo refresher courses every year to acquire new skills and stay updated with the latest advancements in dentistry. The Ministry of Health and Medical Education (MOHME) conducts these courses necessary for renewing doctors' licenses. However, more focus is required on the use of 3D printers and their benefits to surgeons [45], as these requirements are currently limited.

Iran produces 3D printers but still requires foreign markets to import the necessary tools and parts. Due to international economic sanctions, the government, the Ministry of Health and Medical Education (MOHME), the Medical Equipment Office (MEO), and the Food and Drug Administration (FDA) face many difficulties. These difficulties often result in marketers recommending cheaper devices with lower accuracy, discouraging surgeons from using them [20].

3.2.6. Wider System

Political/Policy Context

The Ministry of Health and Medical Education (MOHME) is responsible for setting policies and regulations related to healthcare services in Iran. Therefore, it is essential to ensure that the use of 3D printing in maxillofacial surgery aligns with the country's healthcare policies and regulations. The shortage of dental professionals, particularly in rural areas, is a major issue in Iran's healthcare system. The Supreme Council of the Cultural Revolution's plan to increase admission capacity in dental fields and distribute specialist doctors to disadvantaged areas is a step in the right direction. Additionally, allowing oral and maxillofacial surgeons to have offices in cities with shortages of such specialists can help alleviate the issue. Improving the quality of education and providing facilities to young medical and dental students can also address the shortage of medical professionals in the country. By addressing these issues, Iran can improve the access to necessary medical services for its population [46]. Improving the speed and accuracy of dental care through 3D printing technology could help further alleviate shortages.

Regulatory/Legal Issues

The use of 3D printing in healthcare presents regulatory and legal challenges, such as product liability, compliance with regulations, intellectual property, and privacy and environmental concerns. The absence of specific 3D printing laws makes it difficult for hospitals and manufacturers to protect themselves from liability and ensure compliance with guidelines. There is a need for quality control procedures to ensure compliance with CAD files, printers, software, and material guidelines [23]. Iran's Food and Drug Administration (FDA) regulates medical devices, including those produced using 3D printing technology. Obtaining appropriate approvals from the FDA and addressing legal issues related to liability and intellectual property rights are crucial when using 3D printing in maxillofacial surgery [43]. In addition, all 12 surgeons who participated in our survey agreed on the necessity of implementing rules to address regulatory and legal

considerations for patient safety and compliance when integrating 3D printing technology into their treatments.

Sociocultural Context

The adoption of 3D printing technology in maxillofacial surgery could revolutionize the way in which surgeries are performed but concerns over safety and efficacy in Iran may impact its implementation. Patients and community members may prefer traditional surgical methods and may require education on the benefits of using 3D printing in maxillofacial surgery. Providing replicas of the target area can increase patients' confidence and understanding of the procedure. Collaboration between hospitals, research institutions, and medical device manufacturers can help to promote the use of this technology, overcoming funding and resource-related barriers. Addressing sociocultural factors through education and collaboration can ensure that patients in Iran benefit from 3D printing in maxillofacial surgery [15]. Of the 12 surgeons who participated in our survey, 33% agreed that patients were not aware of the effectiveness of 3D printers in maxillofacial surgery, while 58% believed patients preferred traditional methods, and 33% had safety concerns. These attitudes and preferences significantly affect the adoption of 3D printers in maxillofacial surgery. All respondents believed that comprehensive educational programs, financial incentives, and a supportive organizational culture could encourage or facilitate the adoption of 3D printer technology among patients.

3.2.7. Embedding and Adaption over Time

As technology continues to advance, we can expect significant improvements in 3D printing, making these printers faster, more precise, and more cost-effective. This progress will make it easier for healthcare providers to adopt 3D printing in their practices, revolutionizing areas such as the production of dental implants with custom angles and the creation of customized bioactive scaffolds for tissue repair. Additionally, the industry is likely to see a surge in the number of companies offering comprehensive 3D printing solutions, including software, hardware, materials, and services, further expanding the technology's utility in the medical field [30].

4. Discussion

In this article, we analyzed academic publications and media publications authored by science and technology correspondents writing about 3D printers in maxillofacial surgery, and employed the NASSS framework to identify the seven different domains that the technology requires for implementation. The integration of 3D printing technology in maxillofacial surgery marks a critical advancement in personalized medicine, offering unique solutions tailored to the specific anatomical needs of patients [31]. This technology significantly improves surgical precision and outcomes by producing anatomically accurate models and implants, directly addressing the complexities of each patient's facial structure. It holds the promise of reducing operation times and speeding up recovery, thereby enhancing the overall efficiency of surgical procedures. However, the adoption of 3D printing in clinical settings is met with several challenges. The high costs associated with advanced materials and equipment, the need for specialized training for healthcare professionals to effectively utilize this technology, and concerns regarding the protection of patient data during the creation of personalized surgical aids are significant hurdles. Overcoming these obstacles is crucial for the successful application of 3D printing in surgery [32].

In the coming years, 3D printing technology is poised to revolutionize the field of oral and maxillofacial surgery (OMFS), making stride towards highly personalized medical treatments [16]. As this technology continues to evolve, along with the development of innovative materials, the creation of customized devices and scaffolds is expected to reach new levels of sophistication [47]. This advancement will significantly influence how surgeons address and repair damaged skeletal tissues, tailoring treatments to the individual needs of patients. The collaboration between researchers and surgeons will play a crucial

role in meeting the outstanding challenges in OMFS, driving technical advancements, and integrating 3D printing into routine clinical practice [48]. Moreover, the implementation of the 3D Printing Point-of-Care (3DP PoC) concept is set to transform the production of personalized medical devices and scaffolds across various settings, including hospitals, ambulatory surgical centers, and outpatient treatment facilities. This shift promises to enhance efficiency and precision and to achieve superior clinical outcomes, ultimately benefiting patients through tailored and effective treatment options [30].

To realize the full benefits of 3D printing in maxillofacial surgery, there must be a concerted effort to evaluate and adapt healthcare infrastructures, develop comprehensive regulatory frameworks, and ensure organizational readiness. These steps are essential to integrate 3D printing safely and effectively into clinical practice, highlighting the need for a collaborative approach among healthcare providers, policymakers, and technology developers.

The journey from the potential to the practical application of 3D printing in surgery involves navigating various domains, from the initial demand for personalized solutions (domain one: the condition) to the technological capabilities (domain two: the technology) and assessing the value proposition (domain three). It also requires engaging intended adopters and organizations (domains four and five) and considering the broader healthcare system (domain six) to facilitate the technology's adoption and scalability. Domain seven is where all of these efforts converge, ensuring that 3D printing technology not only fulfills current healthcare demands but also remains adaptable and innovative to meet future challenges. This final domain solidifies the technology's critical role in advancing surgical practices, highlighting the importance of continuous evolution and integration within the medical field.

5. Conclusions

This paper highlights the 3D printer approach in maxillofacial surgery in Iran. The NASSS framework was used to evaluate the factors affecting the application of 3D printer technology in this field. It was noted that more surgeons need to accept and use this technology to replace previous methods, and hospitals and the government should allocate more funds to increase its usage. The Ministry of Health and Medical Education (MOHME) can monitor its implementation closely to ensure its usefulness for doctors and patients.

Efforts should be made to increase the adoption and usage of 3D printers in maxillofacial surgery by training and educating oral and maxillofacial specialists and dentists on their use. Additionally, increasing awareness among patients by replacing previous methods with 3D printing can also contribute to its adoption. The use of 3D printers in maxillofacial surgery can provide more accurate treatments with fewer side effects and shorter treatment duration, benefiting both doctors and patients.

The advancements in 3D printing technology will also play a significant role in the future of maxillofacial surgery in Iran. The ability to create more complex and precise models will result in even more accurate treatments, and the availability of biocompatible materials will allow for the creation of custom implants and prosthetics that fit the patient's anatomy perfectly. As more hospitals and universities adopt this technology, the use of 3D printers in maxillofacial surgery is likely to become more common in Iran. With continued support and advancements in technology, it is expected to provide even more benefits to both doctors and patients in the future.

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