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Research Article

Impact of 3D Printing in Reconstruction of Maxillofacial Bone Defects Experimental Study in A Military Hospital in Sana'a city Yemen

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Abstract

Background and aims: This study Explore's the use of Polyether ether ketone (PEEK) and Polymethyl methacrylate (PMMA) as alternative materials for 3D reconstruction of orbital bone defects. PEEK offers biocompatibility, lightweight properties, and radiolucency, while PMMA is renowned for its mechanical strength and ease of manipulation. Our prospective study aims include evaluating the durability and effectiveness of these materials, developing a standardized 3D reconstruction protocol from imaging data, and designing patient-specific implants through 3D printing technology. We will assess clinical outcomes regarding functional recovery and aesthetic results in patients receiving PEEK and PMMA implants, alongside enhancements in surgical techniques to minimize operative time and improve recovery. This prospective study aimed to use of 3D printing to reconstruct maxillofacial bone defects resulting from various injuries and assessment associated complications, evaluation and recovery experience and assessment of quality of life after operation

Materials & methods: A study at the Military Hospital in Sana'a, Yemen, found maxillofacial fractures in six patients who underwent maxillofacial reconstruction using 3D printing technology. The patients had previously undergone unsuccessful traditional treatments. The study involved preoperative assessments, CT scans, and functional evaluations. Custom 3D printed implants were designed using GOM and ATOS, and surgical procedures were performed under general anesthesia. PEEK and PMMA implants were used for craniofacial augmentation and reconstruction for our patients.

Results: A group of patients aged 20-43 years, with a mean age of 28.8 years, experienced pain, aesthetic deformity, limited mouth opening, difficulty eating, and bacterial infections. Causes included G.S.I, RTA, bomb explosion, and falls from height. Fractures occurred in various areas, with 83.3% resulting in a compound fracture, and 16.7% had simple and maxillary sinus fractures. The study found that all patients had unilateral fractures, with 33.3% having segmental fractures, 66.7% having displacement, and 50 having tripod fractures. Debridement operation was performed in all patients, with bone grafting and ORIF performed in 83.3%. Instability, insufficient, and infection were the most common reasons for failure. The study found that 66.6% of patients and physicians were satisfied with the results, while 83.3% reported excellent quality of life, with 83.3% of patients exhibiting good eating, speaking, social interaction, and emotional well-being.

Conclusion: This study highlights the potential of 3D printing technology in enhancing the outcomes of maxillofacial bone defect reconstruction by use PEEK and PMMA materials, especially in patients with prior treatment failures.

Keywords: bioceramics; maxillofacial bone defect; reconstructive surgical procedures; three-dimensional (3D) printing technology; PEEK; PMMA

Introduction

Decreased quality of life can be the result of critical functional and aesthetic problems caused by bone deformities in the maxillofacial region [1]. Infection, trauma, congenital conditions, or neoplastic surgery, can all be the cause of these deformities [1,2]. Reconstructive operation, which can be challenging for both surgeons and patients, is necessary to restore the functional and aesthetic roles of complex anatomical areas [1]. Polyether ether ketone (PEEK), autologous bone grafting, or titanium, have been used to coat bone defects in cases prior to acknowledged in the researches [3]. However, each material presents some limitations, raising the requirement for additional research to establish the superlative request for bone reconstruction in the maxillofacial locality. Biocompatibility, non-allergenic behavior, radio-opacity, affordability, ease of use, and adequate strength are all general prerequisites for an ideal implant [1,4,5]. Furthermore, implants with critical biological properties such as osteoconduction and osteoinduction to improve implant ingrowth and dimensional stability make them more useful for bone restoration [1,6,7]. The ability to passively host osteogenic cells, including osteocytes, and direct their migration into the graft to promote its ingrowth is known as osteoconduction [2,8]. To allow migration within a 3D structure, a microporous structure is required [9].

It is difficult to duplicate the dynamic properties of native bone with those of standard implants. Growth factors, proper vascularity, and stability for osteoblasts, osteoclasts, and osteocytes all depend on a mineral matrix. Because autologous bone grafting contains osteoconductive, osteoinductive, and osteogenic qualities, it has the best biocompatibility and is consequently regarded as the gold standard [2,6,8–11]. Significant disadvantages include acceptor site resorption, donor site morbidity, restricted supply of appropriate donor bone, and extended surgical duration [6,10,11]. Because of its strength, osseointegration ability, and biocompatibility, titanium is a widely used material [5,12]. However, compared to bone grafts and bioceramics, it has a greater infection rate, produces radiological artifacts, and causes thermal discomfort [9,13,14]. PEEK implants have weak osteoconductive qualities, low bioactivity, and good strength [9,12,15]. Bioceramic patient-specific implants (PSIs) have attracted attention recently as a valuable alternative to traditional materials for the reconstruction of bone defects in the craniomaxillofacial region [6,12,16]. Three-dimensional (3D) printing technology has the probable to combine the biomechanical possessions of bioceramics in a PSI [12,17,18], a relatively new technique that is regarded as the future of transplant medicine [19]. Bioceramic PSIs can be printed using computer-aided design and manufacturing (CAD/CAM) to create a biocompatible scaffold that guides osteoblasts to replace bone defects in the craniomaxillofacial region without donor site morbidity [20]. The implant stimulates osteogenesis and fibrovascular ingrowth [18,21].

The most common form is hydroxyapatite (HA), which is occasionally mixed with growth hormones such bone morphogenic protein 2 (BMP2) [22, 23]. As an osteoinductive factor, BMP2 promotes angiogenesis and osteoblast development. A mix of osteoconductive carriers, such as HA scaffolds or autologous and allogenous bone transplants, are required for its application [2]. The therapeutic application of HA bioceramic PSIs in the craniomaxillofacial region is not well documented in research [9,16,17]. Furthermore, opinions about the ideal ratio of osseointegration to strength are divided [16,20]. The primary difference in mechanical qualities is the pore design, which is required to improve bone in growth in the implant [24]. For example, the conventional pore arrangement is not as robust as the triangular periodic minimum surface (TPMS) approach [20, 25]. The PSIs created for clinical cases in this study used TPMS [22, 23]. The aim of the study was to evaluate the biocompatibility and biomechanical behavior of HA bioceramic PSIs in relation to autologous bone implants, titanium, and PEEK. To illustrate the clinical outcomes of these implants in reconstructive surgery for maxillofacial bone deformities, six clinical examples were included.

Material And Methods

Study Design: A serial clinical follow-up study.

Study population: All patients attending the Military hospital between the first of January 2024 and the end of December 2024 (Time allowed for clinical work for the board's degree).

Data collection procedure: All patients who met the predetermined inclusion criteria were immediately admitted to the OMFD inside the Yemeni military hospital. There, they were given a detailed explanation of the study protocol and their written informed consent was duly obtained. A form created especially for this purpose is used to meticulously record pertinent demographic data, such as age, medical history, behavioral patterns, and contact information. The diagnosis process began with a thorough review of the patients' medical history, a careful clinical examination, and a thorough radiological evaluation, which included obtaining a standard CT scan with 3D reconstruction, including axial and coronal views, as a preoperative procedure. Furthermore, laboratory tests were carefully performed on each patient that was part of the study. Using 3D printing technology, these six patients underwent maxillofacial repair as part of their treatment. Six patients with maxillofacial bone abnormalities who had previously received ineffective conventional therapies were enrolled in this exploratory trial. All participants provided informed consent. Preoperative assessments involved medical history reviews, imaging studies (CT scans), and functional evaluations. Custom 3D printed implants were designed using GOM; ATOS, Braunschweig, Germany based on high-resolution CT scans to create accurate models of the defects. The implants were fabricated using 3D printing technology (FDM, SLA) with biocompatible materials such as PMMA in five cases, and PEEK in one case as material for craniofacial augmentation and reconstruction. Surgical procedures were performed under general anesthesia, where the failed grafts were removed and the 3D printed implants were placed and fixed using screws and plates. Postoperative care included monitoring for complications and follow-up assessments at 1, 2, 8, 12,16 weeks.

Statistical Analysis: Data analyzed by using statistical software SPSS version 20 (SPSS Inc., Chicago, IL, USA). Descriptive analyses: proportions, percentages, and frequency distribution were performed.

Results

Table 1 shows gender and age distribution of six patients who underwent maxillofacial reconstruction using 3D printing technology, a case series at the Military Hospital in Sana'a City. There are 100% males and 0.0% females, the mean age of the group was 28.8 years ± 9.3 years and the ages of patients ranged from 20 to 43 years. Table 2 shows the complaints of patients who underwent maxillofacial reconstruction using 3D printing technology before the operation. 50% of patients had pain, 100% had aesthetic deformity, 33.3% had limited mouth opening, 16.7% had difficulty eating and 16.7% had bacterial infection. Table 3 shows the etiology of maxillofacial fractures in patients who underwent maxillofacial reconstruction using 3D printing technology. In 33.3% the cause was G.S.I, 16.7% direct impact (RTA), 50% bomb explosion and none due to falls from height (0.0%). Table 4 shows the locations of facial and maxillofacial fractures in patients who underwent maxillofacial reconstruction using 3D printing technology. The fracture occurred in the mandible in 16.7%, in the maxilla in 50%, in the nose in 16.7%, in the cheekbone (zygoma) in 66.7%, in the orbit in 83.3%, and in the frontal in 33.3%. Table 5 shows the types of maxillofacial fractures in patients who underwent maxillofacial reconstruction using 3D printing technology. Comminuted fracture occurred in 83.3% of patients, and 16.7% had simple fracture and maxillary sinus fracture. There were no cases of compound or complex fractures. Table 6 shows the orientation of jaw and facial fractures in patients who underwent jaw and facial reconstruction using 3D printing technology. Unilateral fractures were recorded in all patients (100%), 33.3% had segmental fractures, 66.7% had displacement, and 50 had tripod fractures. Table 7 shows the types of previous operations and reasons for failure of the first operation for maxillofacial fracture patients who underwent maxillofacial reconstruction using 3D printing technology. Debridement operation (devitalization) was performed in all patients (100%), bone grafting was performed in 33.3% and open mandibular fixation (ORIF) was performed in 83.3%. Considering the reasons for previous failure, instability occurred in 33.3%, insufficient in 100% and infection in 33.3%.

Table 8 shows the impact of injuries on the ocular tissues among maxillofacial fracture patients who underwent maxillofacial reconstruction using 3D printing technology. The papyrus plate was affected in 50% of patients, the orbital rim in 66.7%, the lateral wall in 83.3%, the floor in 66.7% and the roof in 16.7%. Table 9 shows the postoperative follow-up among maxillofacial fracture patients who underwent maxillofacial reconstruction using 3D printing technology. Considering the follow-up after 1 week of operation, wound opening occurred in 16.7%, facial asymmetry occurred in 16.7%, infection occurred in 16.7%, instability occurred in 16.7%, scar formation occurred in 33.3%, and continuous antibiotic use occurred in all patients (100%). At 2-weeks follow-up, there was 16.7% wound opening, no facial asymmetry (0.0%), 16.7% infection, 16.7% instability, 33.3% scarring, and 33.3% continuous antibiotic use. At 16-weeks follow-up, there were no wound opening, facial asymmetry, infection, instability, facial nerve injury, and antibiotic use, and only one case of scarring was recorded. Table10 shows the postoperative evaluation and recovery experience among maxillofacial fracture patients who underwent maxillofacial reconstruction using 3D printing technology. The physicians and patients were very satisfied with the results in 66.6% of cases, 16.7% had a satisfied result, 16.7% had a normal result and no cases of dissatisfaction with the results occurred. Table 11 shows the postoperative assessment and quality of life among maxillofacial fracture patients who underwent maxillofacial reconstruction using 3D printing technology. 83.3% of patients reported the ability to eat well, speak well in 83.3%, social interaction in 100%, emotional well-being in 100% of cases, and the quality of life of patients was excellent in 83.3% of patients.

Characters	Number	Percentage
Sex		
Male	6	100
Female	0	0.0
Age in Years		
Twenties	3	50
Thirties	2	33.3
Forties	1	16.7
Mean	28.8 years	
SD	9.3 years	
Median	27.5 years	
Mode	20 years	
Min to Max	20 - 43 years	

Table 1: Gender and age distribution of six patients who underwent maxillofacial reconstruction using 3D printing technology, a case series at the Military Hospital in Sana'a City

Complains	Number	Percentage
Pain	3	50
Aesthetics deformity	6	100
Limited moth open	2	33.3
Difficulty to eat	1	16.7
Infection	1	16.7
Total	6	100

Table 2: Complaints of patients who underwent maxillofacial reconstruction using 3D printing technology before the operation

Etiology	Number	Percentage
G.S. I	2	33.3
RTA	1	16.7
Bomb explosion	3	50
Fall from height	0	0.0
Total	6	100

Table 3: Etiology of maxillofacial fractures in patients who underwent maxillofacial reconstruction using 3D printing technology

Sites	Number	Percentage
Mandible	1	16.7
Maxilla	3	50
Nasal	1	16.7
Zygoma	4	66.7
Orbit	5	83.3
Frontal	2	33.3
Total	6	100

Table 4: Locations of maxillofacial fractures in patients who underwent maxillofacial reconstruction using 3D printing technology

Types	Number	Percentage
Comminuted	5	83.3
Compound	0	0.0
Complex	0	0.0
Simple	1	16.7
Involved maxillary sinus	0	0.0
Total	6	100

Table 5: Types of maxillofacial fractures in patients who underwent maxillofacial reconstruction using 3D printing technology

Distant	Number	Percentage
Bilateral	0	0.0
Unilateral	6	100
Segmental	2	33.3
Displaced	4	66.7
Tripod	3	50
Total	6	100

Table 6: Distant of maxillofacial fractures in patients who underwent maxillofacial reconstruction using 3D printing technology

Characters	Number	Percentage
Types of operation		
Debridement	6	100
Bone graft	2	33.3
ORIF	5	83.3
Observation	0	0.0
Causes of failure		
Instability	3	50
Not enough	6	100
Infection	2	33.3
Other causes	1	16.7
Total	6	100

Table 7: Types of past operation and causes of failure in the previous operation for maxillofacial fractures patients who underwent maxillofacial reconstruction using 3D printing technology

Characters	Number	Percentage
Lamina papyrececa	3	50
Orbital rim	4	66.7
Lateral wall	5	83.3
Medial wall Floor	0	0.0
Floor	4	66.7
Roof	1	16.7
Isolated orbital	0	0.0
Total	6	100

Table 8: Effect of the injuries on eye tissues among maxillofacial fractures patients who underwent maxillofacial reconstruction using 3D printing technology

Characters	Follow up after				
	1 week	**2 weeks**	**8 weeks**	**12 weeks**	**16 weeks**
Wound dehiscence	1 (16.7)	1 (16.7)	0 (0.0)	0 (0.0)	0 (0.0)
Facial asymmetry	1 (16.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Allergy	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Infections	1 (16.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Instability	1 (16.7)	1 (16.7)	1 (16.7)	0 (0.0)	0 (0.0)
Scar	2 (33.3)	2 (33.3)	1 (16.7)	1 (16.7)	1 (16.7)
Antibiotics	6 (100)	2 (33.3)	0 (0.0)	0 (0.0)	0 (0.0)

Table 9: The follow up after surgery among maxillofacial fractures patients who underwent maxillofacial reconstruction using 3D printing technology

Characters	Number	Percentage
Satisfied for results		
Very satisfied	4	66.6
satisfied	1	16.7

Natural	1	16.7
dissatisfied	0	0.0
Total	6	100

Table 10: Post operative assessment and recovery experience among maxillofacial fractures patients who underwent maxillofacial reconstruction using 3D printing technology

Characters	Number	Percentage
Eating well	5	83.3
Speaking well	5	83.3
Social interaction	6	100
Emotional well being	6	100
Satisfied quality of life	5	83.3
Total	6	100

Table 11: Post operative assessment and quality of life among maxillofacial fractures patients who underwent maxillofacial reconstruction using 3D printing technology

Discussion

In the current study, 50% of patients experienced pain, 100% experienced cosmetic deformity, 33.3% experienced limited mouth opening, 16.7% experienced difficulty eating, and 16.7% experienced bacterial infection. These findings are similar to those reported previously in that facial bone fractures, like other fractures, may be associated with pain, bruising, and swelling of the surrounding tissues (such symptoms can also occur in the absence of fractures). Fractures of the nose, skull base, or maxilla may be associated with severe nosebleeds [26]. Nasal fractures may be associated with nasal deformity, as well as swelling and bruising [27]. Facial deformity, for example sunken cheekbones or teeth that do not align properly, suggests fractures. Asymmetry can also suggest facial fractures or nerve damage [28]. People with a mandibular fracture often experience pain and difficulty opening their mouths and may experience numbness of the lip and chin [29]. Also with Le Fort fractures, the midface may move relative to the rest of the face or skull [30].

In the current study when considering the causes of injuries. 33.3% were caused by gunshot, 16.7% by Road Traffic Accident (RTA), 50% by bomb blast and none by falling from a height (0.0%). These findings differ from those reported elsewhere in the world where mechanisms of injury such as falls, assaults, sports injuries and motor vehicle accidents are common causes of facial trauma in children [29,31] as well as adults [32]. Indirect assaults and blows from fists or objects are also common causes of facial trauma [26,33]. Facial trauma can also result from war injuries such as gunshots and explosions which were the main cause in our study. Animal attacks and work-related injuries such as industrial accidents are other causes [34]. Motor vehicle trauma is a major cause of facial injuries where the impact usually occurs when the face hits a part of the interior of the vehicle, such as the steering wheel [35]. In addition, airbags can cause corneal abrasions and lacerations to the face when deployed [35].

In the current study, fractures occurred in the mandible (16.7%), the maxilla (50%), the nose (16.7%), the cheekbone (66.7%), the orbit (83.3%), and the frontal (33.3%). Also, the papyrus plate was affected in 50% of patients, the orbital rim in 66.7%, the lateral wall in 83.3%, the floor in 66.7% and the roof in 16.7%. These findings are similar to those reported previously, in which the most commonly affected facial bones include the nasal bone (nose), the maxilla, and the mandible. The mandible may fracture at the ossicle, body, angle, ramus, and condyle [29]. The zygoma (cheekbone) and the frontal bone (forehead) are other sites of fracture [36]. Fractures may also occur in the bones of the palate and those that join to form the orbit.

This prospective study aimed to use 3D printing to reconstruct maxillofacial bone defects resulting from various injuries and to evaluate the associated complications, evaluation experience, recovery and quality of life after surgery using materials PEEK and PMMA with the aim of avoiding bone grafting and reducing surgical time, an idea similar to the use of HA bioceramic blocks and particles already used in maxillofacial surgery in the 1980s [37,38]. However, it was difficult to prevent these particles from migrating [37]. Currently, these bioceramic materials can be used to fabricate PSIs [18]. HA bioceramic PSIs provide a volumetrically stable scaffold of biocompatible material for the reconstruction of maxillofacial bone defects [18]. PSIs, regardless of the material used, are superior to standard implants in terms of fit accuracy, reduced surgical time and risk of infection, stability and implant-bone contact [4,39,40]. In particular, when using surgical navigation, accuracy is enhanced [40]. The results of our study have confirmed previous facts.

In the present study, patients who underwent maxillofacial reconstruction using 3D printing technology were preoperatively treated using classical surgical methods. Preoperatively, 50% of patients experienced pain, 100% experienced aesthetic deformity, 33.3% experienced limited mouth opening, 16.7% experienced difficulty in eating and 16.7% experienced bacterial infection, but these problems disappeared after they underwent maxillofacial reconstruction using 3D printing technology using PEEK and PMMA implants. Bioceramic fillings are biomimetic and eliminate the need for bone grafting [17]. They are osteoconductive, and the large pores in the gyroids have the ability to direct bone cells and facilitate osteogenesis and fibrovascular growth in vitro [18]. In vivo, osseointegration could not be objectively assessed on CT images 16 weeks after surgery in the six cases. However, in the clinical cases performed by Verbist, et al. [40], a perfect osseous contact and signs of bone formation were observed between the bioceramic fillings and the bone [41,42,43]. This indicates beneficial healing, fibrovascularization and mineralization around the implant. Bioceramic fillings have proven to be beneficial due to their use as an internal filling rather than an external filling. This has led to an excellent aesthetic result in this important anatomical area. In order to be able to observe clear signs of osseointegration radiographically, a longer follow-up period of up to twelve months is required [9,16].

In the current study the post operative assessment and recovery experience among maxillofacial fractures patients who underwent maxillofacial reconstruction using 3D printing technology results showed that physicians and patients were very satisfied with the results in 66.6% of cases, 16.7% had a satisfied result, 16.7% had a normal result and no cases of dissatisfaction with the results occurred. These results are similar to that reported by researchers when they compare the maxillofacial reconstruction using 3D printing technology with classical surgery and bone grafts as their conclusions stated that “3D printed bioceramic implants have great potential in maxillofacial reconstruction surgery”. Studies show several advantages of these new implants over conventional techniques in terms of biocompatibility and biomechanical behavior; and various applications are possible. A longer follow-up period is necessary to evaluate the osseointegration process radiographically. However, due to their excellent biocompatibility and osseointegration ability, we recommend their use in load-sharing anatomical structures for reconstruction or aesthetic purposes. Further research is needed to evaluate the long-term effects of this promising biomaterial [41-44].

Conclusion

This study highlights the potential of 3D printing technology in enhancing the outcomes of maxillofacial bone defect reconstruction by PEEK and PMMA materials, especially in patients with prior treatment failures.

Limitations Of the Study

A limitation of the study is that the research was conducted to analyze a small, specific group of materials used in bone reconstruction in maxillofacial surgery. Both materials utilized are radiolucent materials, which poses challenges in monitoring and assessment. Additionally, polymethyl methacrylate (PMMA) requires sufficient thickness; insufficient thickness compromises its strength and increases the risk of fracturing when secured with screws. As pioneers in implementing this type of prosthetic in Yemen, we encountered difficulties related to the designer's capacity to achieve optimal alignment of soft tissues and appropriate thickness. This necessitated in-operation adjustments for several cases, this opens the door to the possibility of selection and publication bias. However, our search was conducted from a rigorous critical perspective, prioritizing the inclusion of the most relevant articles on this topic. Also, one of the main limitations of this study was not including long-term follow-up.

Data Availability

The accompanying author can provide the empirical data that were utilized to support the study's conclusions upon request.

A Dispute of Interest

There are no conflicts of interest in regard to this project.

Author's Contributions

Dr. Hamzah Hussein Mohammed Setten: Formal analysis, conceptualization, data organization, and clinical and laboratory examinations to obtain a board's degree in Oral and Maxillofacial Surgery. All other authors supervised the work, reviewed the article, and approved the final version.

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