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Evaluation of Challenges in Designing Patient Specific Implants for Maxillary Defects Versus Mandibular Defects

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Introduction: Designing of patient specific implants is a complex process that involves precise planning to restore lost anatomic contours and to establish functionally stable rehabilitation with no compromise on aesthetics. Maxillary defects lead to loss of buttress of midface leading to destructive force transmission. Mandibular defects cause significant disfigurement and deviation of retained mandibular segment. Aim: The aim of this study is to evaluate the challenges in designing patient specific implants for maxillary defects versus mandibular defects. Materials and methods: 20 cases were included of which 10 were maxillary defects and 10 were mandibular defects, divided into groups 1 and 2 respectively. A difficulty index ranging from 1 to 5 was used to assess the following parameters: 1. Anatomical complexity 2. Establishing a functionally stable design 3. Integration of prosthetic components 4. Achieving symmetry or geometry . Statistical analysis was done using SPSS version 23.0. Results: The mean value for anatomical complexity and establishing a functionally stable design was higher in the maxillary defects group indicating greater complexity in designing. The mean value for integration of prosthetic components and achieving symmetry or geometry was higher in the mandibular defects group indicating a significant challenge in functional and aesthetic rehabilitation. Conclusion: The maxillary and mandibular defects are both equally challenging in their own aspects for designing patient specific implants. Hence, a thorough understanding of the anatomic contours and functional requirements enables a perfect design to be achieved.

Keywords: Patient Specific Implants, Maxillary and Mandibular Defects, Anatomical Complexity.

1. Introduction

Reconstructive surgery is a complex process that involves meticulous planning, decision making, and execution to provide a comprehensive functional, and aesthetic rehabilitation. The process is tedious, time taking and involves skilled surgeons attempting to restore the continuity of defects, reestablish existing contours and to improve the functioning as well. The

standard reconstructive procedures for maxillofacial defects followed till date includes placement of a reconstruction plate, non vascularised grafts, or free vascularized flaps [1]. Of these, free vascularised fibula flaps are gold standard, as they allow simultaneous or delayed placement of implants, thus facilitating a better prosthetic rehabilitation [2]. The placement of a standard reconstruction plate offers no specific advantage other than retaining the mandibular segments in position. Non vascularised grafts also provide adequate bone for implant placement, however their viability in the long run is questionable. Prosthetic rehabilitation after reconstruction is a major challenge that can be attributed to the bulk of soft tissue encountered in cases rehabilitated with osseomyocutaneous or osseocutaneous flaps [3]. Additional debulking procedures increase the surgical burden inflicted on the individual. A single reconstructive option that addresses all the above mentioned complexities and challenges is the concept of patient specific implants.

Patient-specific implants have emerged as a cornerstone in the management of craniofacial defects, allowing for more precise and effective reconstructive interventions [4]. These implants are custom-designed to fit the unique anatomical contours of individual patients, addressing the limitations of traditional, off-the-shelf solutions. However, designing patient specific implants for maxillary and mandibular defects presents distinct challenges due to the differing roles and anatomical complexities of these regions [5]. The first challenge is incorporating prosthetic components to achieve normal occlusion. The second challenge is in establishing the facial form, width and projection. Further, geometric restoration of condylar position and soft tissue cover of the patient specific implant is also vital in case of mandibular and maxillary defects respectively [6].

The aim of this study is to evaluate the challenges in designing patient specific implants for maxillary defects versus mandibular defects.

2. MATERIALS AND METHODS

The study is a single center prospective observational study conducted from June 2022 to June 2023. All the samples planned for patient specific implant designing for reconstruction of maxillary or mandibular defects were included. The total sample size of the study was 20 divided into two groups of 10 patients each. Group 1 was maxillary defects and Group 2 was mandibular defects.

Designing protocol

The designing of patient specific implants for all the 20 cases was done by a single surgeon.

Before commencing the designing of the patient specific implant, a thorough clinical examination was done and the type of defect, soft tissue thickness and the extent of defect were recorded. For radiographic examination either a cone beam computed tomography or computed tomography was done with the mandible in occlusion. Impressions of the maxillary and mandibular arches made, casts fabricated and articulated for simultaneous planning of prosthetic rehabilitation. The CBCT or CT in DICOM format was converted into a stereolithographic format (.stl). The stereolithographic format was used for designing patient specific implants in the designing software. In case of defects where the contralateral side was normal, the same was mirrored to form the anatomic basis of designing of the defective side.

Offsets were designed, refined based on stress distribution pattern and screw holes provided for placement depending on the diameter of screws used. In cases with occlusal rehabilitation, prosthetic components were scanned and incorporated into the patient specific implant designing. Fit verification of the designed PSI was done using the printed resin models. The final patient specific implant was printed in the in-house Direct Metal Laser Sintering [DMLS] facility using titanium alloy powder.

Parameters assessed

The parameters were assessed in a scale of 1 to 5 to establish the ease or complexity of designing, wherein score 1 - very easy; 2- easy; 3- medium; 4 - difficult; 5 - very difficult. The scores were recorded for each of the following parameter

1. Anatomical complexity
2. Establishing a functionally stable design
3. Integration of prosthetic components
4. Achieving symmetry or geometry

Statistical analysis

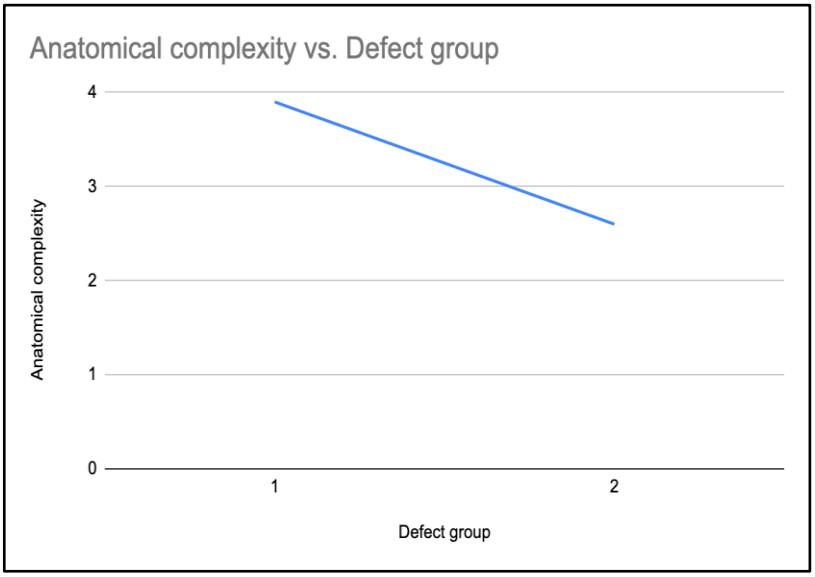
All statistical analysis was performed using Statistical Package for Social Science (SPSS, version 23.0) for Microsoft Windows. The data was expressed as Mean and SD. Inter group comparison done using Two - way ANOVA. A two-sided p value < 0.05 was considered statistically significant

3. RESULTS

Table 1: Represents the mean difficulty score for each parameter for Group A and Group B

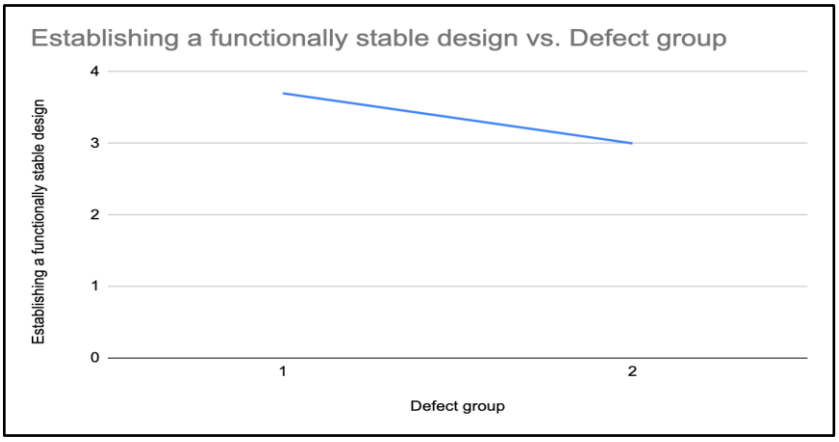
Defect group	Mean ± Standard deviation			
	Anatomical complexity	Establishing a functionally stable design	Integration of prosthetic components	Achieving symmetry or geometry
Group A	3.9 ± 1.0	3.7 ± 0.95	3.1 ± 0.74	3 ± 0.82
Group B	2.6 ± 0.7	3 ± 0.82	4 ± 0.82	3.5 ± 0.53

Graph 1: Line graph representing the difference in the mean difficulty scores for anatomical complexity in group 1 and group 2.



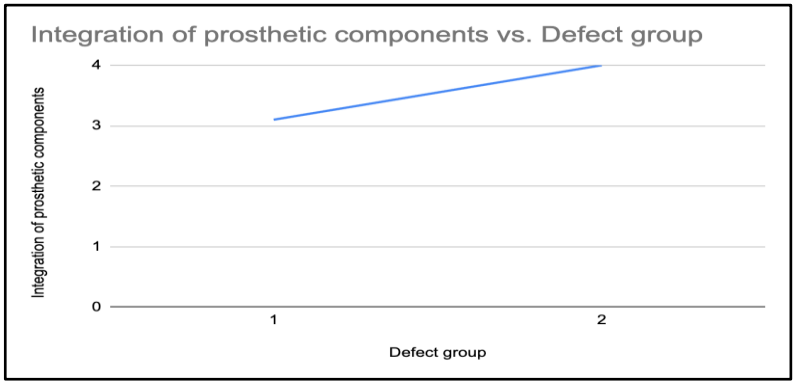
[Group 1 - MAxillary defects; Group 2 - Mandibular defects]

Graph 2: Line graph representing the difference in the mean difficulty scores for establishing a functionally stable design in group 1 and group 2.



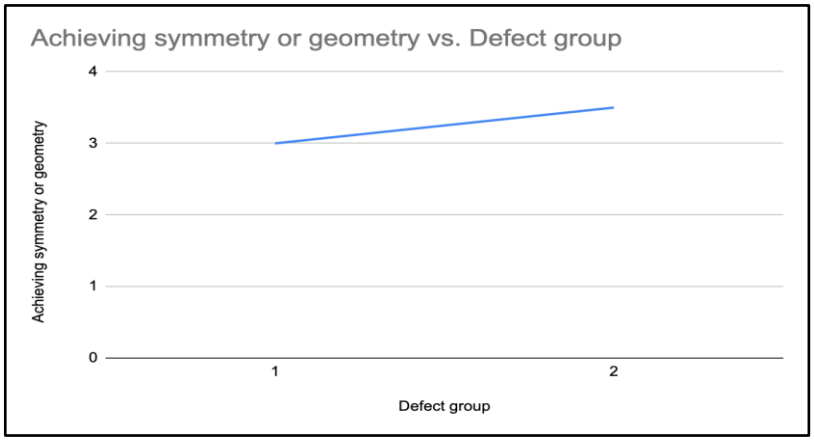
[Group 1 - MAxillary defects; Group 2 - Mandibular defects]

Graph 3: Line graph representing the difference in the mean difficulty scores for integration of prosthetic components in group 1 and group 2.



[Group 1 - MAxillary defects; Group 2 - Mandibular defects]

Graph 4: Line graph representing the difference in the mean difficulty scores for achieving symmetry or geometry in group 1 and group 2.



[Group 1 - MAxillary defects; Group 2 - Mandibular defects]

4. DISCUSSION

The results of the study reveal that there is a significant difference between designing patient specific implants for maxillary and mandibular defects. According to Table 1, the mean difficulty score for anatomical complexity and establishing a functionally stable design was higher for the maxillary defects group, indicating greater difficulty while the scores for integration of prosthetic components and achieving symmetry or geometry was higher for the mandibular defects group.

MAXILLARY DEFECTS

The maxilla, or upper jaw, plays a crucial role in the formation of the midface, including the

nasal cavity and the orbit. Defects in this region can impact both aesthetic and functional aspects, including speech, chewing, and nasal airflow. Designing PSIs for maxillary defects involves several key challenges:

1. Anatomical Complexity: The maxilla is intricately connected with surrounding structures, such as the nasal cavity, orbit, and sinuses. Accurate reconstruction requires a deep understanding of these connections to avoid compromising function or aesthetics [7]. Advanced imaging techniques, including CT and MRI, are essential for mapping these structures and ensuring a precise fit. The current study also reveals that the anatomic complexity of the maxillary region poses more challenge during designing [Table 1, Graph 1].

2. Functional Considerations: Maxillary defects can affect the patient's ability to perform essential functions such as chewing and speaking. The PSI must be designed to restore not only the anatomical contour but also the functional capabilities of the maxilla. This often involves incorporating features that mimic natural anatomical functions, such as occlusal surfaces and support for prosthetic teeth. Establishing a functionally stable design encompassing the buttresses of midface poses a challenge while designing maxillary patient specific implants [Table 1; Graph 2].

3. Aesthetic Outcomes: Given the prominent position of the maxilla in facial aesthetics, achieving a natural appearance is paramount. The PSI must be designed to blend seamlessly with surrounding tissues and maintain facial symmetry. Customization based on preoperative imaging and 3D modeling helps in achieving a satisfactory aesthetic result [8].

4. Integration with Surrounding Tissues: Successful integration of the PSI with the maxillary bone and surrounding soft tissues is crucial. The implant material must support osseointegration and be biocompatible to promote healing and stability [9].

MANDIBULAR DEFECTS

The mandible, or lower jaw, is vital for mastication, speech, and the structural support of the lower face. Designing PSIs for mandibular defects presents its own set of challenges:

1. Biomechanical Forces: The mandible endures significant mechanical forces during mastication and speaking. PSIs must be designed to withstand these forces and distribute them effectively to prevent implant failure [10]. This requires careful consideration of material strength and implant design. Further, incorporation of prosthetic components in the patient specific implants is necessary to achieve proper distribution of forces. This increases the difficulty levels of designing, as revealed in the current study [Table 1, Graph 3].

2. Complex Geometry: The mandible has a more complex geometry compared to the maxilla, with features such as the mental foramen, condylar processes, and ramus. Designing PSIs for mandibular defects involves creating implants that fit precisely with these anatomical features while providing adequate support and function [11]. Positioning the condylar element exactly as a mirror image of the normal side is challenging. Further, achieving a symmetrical design is difficult particularly in case of hemi-mandibular defects [Table 1, Graph 4].

3. Functional Restoration: Unlike the maxilla, which is less involved in chewing forces, the mandible plays a crucial role in mastication. The PSI must restore the functional occlusion, enabling effective chewing and preventing issues such as malocclusion or temporomandibular

joint dysfunction.

4. Soft Tissue Integration: The mandible is covered by soft tissues such as the buccal mucosa, which must be accommodated in the PSI design. Ensuring that the implant does not adversely affect soft tissue function or aesthetics is essential for a successful outcome [12,13].

COMPARATIVE ANALYSIS

While both maxillary and mandibular defects require patient-specific solutions, the design considerations differ significantly. Maxillary implants must prioritize aesthetic outcomes and integration with complex facial structures, while mandibular implants focus more on biomechanical strength and functional restoration [12]. Both types of implants must be tailored to the unique anatomical and functional needs of the patient, requiring advanced imaging and modeling techniques, as well as careful material selection and design [11].

5. CONCLUSION

The design of patient-specific implants for maxillary and mandibular defects involves addressing distinct challenges associated with each region's anatomical and functional requirements. Advances in imaging technology, 3D modeling, and material science are critical in overcoming these challenges and improving patient outcomes. By understanding the unique demands of each region, clinicians and engineers can collaborate to create implants that not only restore anatomical integrity but also enhance functional and aesthetic outcomes for patients.

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