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Efficacy of Three-Dimensional Plating Systems in the Management of the Mandibular Fractures - A Literature Review

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The advent of three-dimensional (3D) technology has brought about a huge revolution in the field of oral and maxillofacial surgery. It has a wide range of applications from designing custom plates and screws to reconstruction of an entire part of the oral and maxillofacial region. One such advancement is the three-dimensional plating system. Maxillofacial trauma is one of the most common cases encountered by an oral surgeon, and the nasal bone and mandible are the most susceptible to fractures. Fracture fixation was initially based on two principles: rigid bicortical fixation and semi rigid monocortical fixation based on Champy's lines of osteosynthesis. However, both these principles had their own disadvantages with the former not yielding to biomechanical forces and the latter having gap formation at the fracture line. To overcome the disadvantages in these two systems, the three-dimensional plating system was introduced. The system is designed with horizontal bars with vertical struts giving a quadrangular configuration. This configuration helps resist the biomechanical forces and stabilize the fracture fragments, and also reduce the postoperative infection and complications. This literature review aims at compiling and comparing the existing scientific evidence on the applications, advantages and complications of three-dimensional plating system and to arrive at a list of indications for the use of 3D plating system in mandibular fractures.

Keywords: three dimensional plate; strut; stability; miniplate.

1. Introduction

The introduction of technological advancement into any domain has a huge impact in improving the accuracy of the final outcome. Oral and maxillofacial surgery is a branch of health sciences that aims at improving the quality of human life by treating various diseases and disorders pertaining to the head and neck region. Over the past few decades, the

advancements in the field of oral and maxillofacial surgery have taken a huge leap, most of which are due to the introduction of technological innovation. Every field has revolutionized after the advent of three-dimensional technology including oral and maxillofacial surgery. The facial skeleton which includes the maxilla, mandible, facial bones and the cranial vault is a three-dimensional structure interspaced with muscles, nerves and blood vessels, forming a network. Any two-dimensional planning or treatment modality implemented in this region, will have its own setbacks. This is where the three-dimensional technology comes into play. Maxillofacial trauma is one of the most common reasons for operating in the maxillofacial region. The nasal bones, followed by the mandible, are the most common bones that sustain a fracture during any maxillofacial trauma. The position of the mandible makes it more prone to fractures and more than half of these fractures require a surgical intervention [1].

The purpose of fracture fixation by surgical intervention is to achieve a good reduction and immobilization of the fractured fragments. Osteosynthesis implies the functionally stable internal fixation of fracture fragments that permits an early recovery of function [2]. This is primarily achieved by the use of plating systems for fracture fixation. The introduction of plating systems into maxillofacial trauma made a paradigm shift from the treatment modality being a closed reduction and intermaxillary fixation to an open reduction and internal fixation, which in turn increased the possibility of favorable outcomes. The aim of any plating system is to achieve a very close anatomic reduction as possible and to ensure maximal bone healing in that position. There are two fundamental concepts of fracture fixation as follows: use of a rigid plating system with bicortical screws and champy's plating system using miniplates for internal fixation. The rigid plating system works based on the principle of compressive force generation by tight contact of fracture fragments [3]. However, a major drawback of this system is that it is highly susceptible to the effect of mechanical forces. To overcome this, champy's plating system was developed according to the lines of osteosynthesis of the mandible. According to Champy, there are tensile forces at the superior border and compression forces along the inferior border of the mandible. This system used easily bendable mono-cortical miniplates for fixation along the ideal osteosynthesis lines. However, the use of this system for long span fractures was doubtful as these were primarily load sharing plates rather than load bearing plates [4].

The shortcomings of rigid fixation and semi rigid fixation paved the way for the development of a three-dimensional plating system for fracture reduction, introduced by Farmand in 1992. The geometry of three-dimensional strut plates conceptually allows for three-dimensional stability and resistance against torque forces [5]. The principle of 3D plating is supported by the fact that the plates do not cross the lines of compression or tension, but instead rest on the weaker structure lines [2]. The stability is gained over a defined surface area of contact created by the quadrangular configuration of the plate and is not determined by the plate thickness or length [1-5]. A 1.0 mm thick 3D plate is as much stable as a thicker 2.0 mm miniplate, which is attributed to the configuration of these plates.

The aim of this literature review is to assess and study the existing literature evidence on the application of three-dimensional plating system in mandibular fractures, to elaborate on the results of various clinical trials, case reports and their outcomes. Based on the observations, to arrive at a list of indications for the use of three-dimensional plating systems in different mandibular fractures.

2. MATERIALS AND METHODS

An electronic search was initiated for scholarly articles on the 3-dimensional plating system in oral and maxillofacial surgery. The review consisted of two phases. Initially the title and abstracts of the articles obtained through the search were reviewed and relevant articles were selected. Then full text access was obtained for the selected articles. The search yielded 20 articles that were of high relevance to the current review and these consisted of a mixture of clinical studies and literature reviews.

3. RESULTS

Table 1:

Author and year	Study groups	Type of plating system	Parameters assessed	Outcomes
Sakr et al., [1]	Sheep hemi mandibles with bicortical Mandibular body fractures	3D titanium mini plates	Bending tests, compression test, force displacement measurements	3D plating systems had greater stability and resistance to deforming forces than conventional plating systems
Mittal et al., [2]	16 Parasymphysis, 7 LeFort level 1, 4 mandibular angle and 4 mandibular body fractures	3D titanium plates: Rectangular - 21 cases, square - 8 cases, double rectangle - 2 cases	Hardware complications, occlusion after treatment, Interfragmentary stability, complaints of trigeminal dysfunction, maximal mouth opening and signs of infection	Time taken for contouring, fixation and stabilization was lesser for 3D titanium plating systems
Rastogi et al., [3]	30 patients with non comminuted mandibular angle fractures	Single 3D titanium miniplate	Pain, swelling, malocclusion, mobility, mouth opening, paresthesia, infection and hardware removal.	3 dimensional plates can be used as an alternative for mniplates in the treatment of Mandibular angle fractures.
Pavan et al., [4]	20 symphysis and Parasymphysis fractures	3D stainless steel plates versus Champy's miniplates	Occlusion, infection, segmental mobility, wound dehiscence, neurological deficit	3D plates showed greater resistance to compression loads, lesser segmental mobility and infection rates
Melek et al., [5]	Isolated angle fracture of mandible	3D threadlock plates	Clinical parameters: Pain intensity, postsurgical edema, maximal mouth opening, sensory function, surgical wound, and occlusion. Radiographic parameters: Increase in mean bone density after three months.	3D threadlock plates are indicated for angle fracture as they possess high fracture fragments stability and establish harmonious occlusion
Bohner et al., [6]	Anterior mandible, body and angle fractures	3D mini plates	Infection, plate exposure, sensibility disturbance, pseudoarthrosis	Use of 3D plating systems for mandibular fractures resulted in a fracture reduction with a low complication rate and adequate surgical procedure time
Kumar et al., [7]	Mandibular angle fractures	Standard	Duration of surgery, pain	Patients treated with 3D plates

		miniplates versus 3D rectangular mini plates	assessment, postoperative mouth opening, occlusion, stability of fracture segments, hardware failure, radiographic evaluation of fracture reduction	exhibited greater postoperative pain and reduced mouth opening, but had better fracture reduction and stability
Mohammad et al., [8]	Isolated Anterior mandibular fractures	Standard two miniplates versus 3D miniplates	Postoperative condylar position, occlusion, rigidity of fixation and intraoperative time	3D plates provided superior restoration of postoperative condylar position, and better segmental stability
Mohd et al., [9]	Mandibular parasymphysis fractures	Stainless steel 3D miniplates versus stainless steel Champy's miniplates	Occlusion, mobility of fracture segment, pain, wound dehiscence, neurological deficit, and infection	3D plates in parasymphysis fractures gives better dimensional stability and carry lower morbidity and infection rates
Prasad et al., [10]	9 parasymphysis, 2 symphysis, 7 angle and 2 body fractures	2.0 mm 3D stainless steel miniplates	Occlusal stability, lingual splaying, paresthesia, infection, masticatory difficulty	Early recovery of normal jaw function, uneventful healing, good union and stability, and significant reduction in lingual splaying
Ebenezer et al., [11]	Mandibular angle fractures	3D miniplates	Healing, union of fracture site	All patients exhibited good healing, union of fracture site and minimal weight loss due to early reinstatement of jaw function
Kalfarentzos et al., [12]	Mandibular angle fractures	Square 3D miniplates, Straight 3D miniplate, two plate system, single miniplates	Mechanical behavior: Load stiffness values, facture gap distraction	3D square plate system provided the most favorable mechanical behavior
Malhotra et al., [13]	15 parasymphysis, 6 symphysis,1 body and 3 angle fractures	3D plate versus conventional miniplates	Adequacy of fracture fixation intra-operatively, postoperative radiologic evaluation of fracture reduction	3D plates have lesser overall complication rates and in the mandibular anterior region and they have lesser foreign hardware than conventional miniplates
Yadav et al., [14]	Symphysis and parasymphysis fractures	Titanium miniplates versus 3D titanium plates	Pain, edema, occlusion, distraction of inferior border, intraoperative time	3D plates have lesser foreign material, reduced operation time and less cost of treatment
Saad et al., [15]	Anterior mandibular fractures	3D miniplate versus two conventional miniplate	Operative time, occlusal stability, mouth opening, fracture stability	3D miniplates can be used as an alternative to conventional miniplates for anterior mandibular fractures, and also had lesser intraoperative time
Guruprasad et al; [16]	Mandibular fractures	Rectangular 3D mini plates	Interfragmentary Stability	Closed quadrangular 3D plates used for fixation had better interfragmentary stability during the follow up period

Pavan Kumar et al., [17]	Mandibular fractures	3D locking plates	Operating time, occlusion, pain, infection, mobility of fracture fragments, soft tissue dehiscence, neurological deficit	Significant reduction in operating time, easy to use and three-dimensional stability at the borders were observed on using 3D plates
Bhowmick et al., [18]	Subcondylar fractures of mandible	4 hole single miniplate, 4 hole double miniplate, inverted Y miniplate, lambda, trapezoidal and delta plates	Von Mises stress deformity analysis	Trapezoidal plate has the greatest stability due to its configuration, while a lambda plays has the least stability ans is indicated only for cases where the bond near sigmoid notch is very thin in nature.
Aurora et al., [19]	Anterior mandibular fractures	Three dimensional plates versus conventional miniplates	Wound dehiscence, infection segmental mobility, postoperative occlusion, significant postoperative complications, and radiological evaluation of reduction, and fixation	3D plates provides three dimensional stability with low morbidity and infection rates. However, the results were not statistically significant.
Sadhwani et al., [20]	Mandibular fractures	3D plates vs 2D miniplates	Infection, occlusal discrepancy, malunion, nonunion	3D plates are advantageous over 2D miniplates by their increased resistance to torquing forces, reduced morbidity and need for intermaxillary fixation.
Thapliyal et al., [21]	Mandibular fractures in mental foramen region	Single 3D plate versus 2 miniplates	Finite element analysis, ease of fixation, neurosensory deficit, bite forces, occlusion and adequacy of fracture fixation.	3D plate was successful in providing satisfactory fixation and was observed to be better in terms of lingual control and masticatory efficiency.
Barde et al., [22]	Mandibular anterior fractures	3- dimensional plates versus champy's miniplates	Operating time, average pain, post operative infection, occlusion, wound dehiscence, post operative mobility and neurological deficit.	3 dimensional plates are significantly better than champy's miniplates in terms of occlusion, stability and infection rates
Chaudhary et al., [23]	Mandibular subcondylar fractures	Trapezoidal 3 dimensional plate	Radiographic examination, signs of malocclusion, facial nerve injury, or infection with local rise in temperature, inflammation, and pus discharge	Patients with gross displacement of condylar fragment, major reduction in posterior facial height, and deranged occlusion can be successfully managed by open reduction of condylar fracture and its fixation using 3-D plates
Jain et al., [24]	Mandibular anterior fractures	3D plates versus miniplates	Bite force analysis	Better stability observed in 3D plates with simultaneous stabilization of superior and

				inferior borders
Pal et al., [25]	Displaced mandibular angle fractures	3D matrix miniplates	Postoperative complications and occlusion	3D plates are preferred for their better stability in displaced angle fractures.

4. DISCUSSION

The treatment of fractures in the maxillofacial region has gained enormous momentum over the years which can be attributed to the improved understanding of biomechanical properties, introduction of materials with superior biocompatibility without compromise on the mechanical properties. The primary therapeutic goal in fracture treatment is to gain a fracture reduction with maximum stability, minimum mobility of fracture fragments, restoring them in their anatomic position, with functionality and least morbidities [1]. Fracture treatment modalities are broadly classified as open and closed reduction methods. Open reductions method involves the use of different plating systems for accurate fracture reduction and fixation. A variety of plating systems are currently in use, and the choice of plating system depends on a number of factors such as the following; 1. Pattern of fracture 2. Region of fracture 3. Expected outcome after fracture reduction. The commonly used plates in oral surgery are primarily based on two principles: rigid and semi-rigid fracture fixation, with each having its own set of disadvantages. To overcome these, a system combining the advantages of both rigid and semi -rigid plating was introduced and was called the '3D plating system'.

The 3-dimensional plating system has a design that is easy to use. The 2 configurations available in the 3D plating systems are the straight and curved configurations, based on which they're named as gird plates and strut plates. An important distinguishing feature of this plating system is the presence of vertical struts interspaced between the horizontal bars, creating a three-dimensional cross stabilization [3]. Any structure in the maxillofacial region is subjected to a number of forces, in particular, the forces of the stomatognathic or the masticating system. The 3-dimensional plates are no exception to it and it is highly essential to analyze the mechanical properties of this system of plating. Malhotra et al., [13] have pointed out few basic yet significant biomechanical properties of the 3D plating system. According to their observations, 3D plates have better bending stability and resistance to out of the plane movement or torque. They also point out that a 1mm standard 3D plate can withstand traction forces measuring up to 690N, which is almost equal to the maximum load capacity of the mandible. These observations are similar to those made by Kalfarentzos et al., [14] according to whom, 2x2 mm square 3D plates have the highest torsional stiffness when compared to standard two plate system or single miniplates. These biomechanical properties contribute to the better performance of 3D plates, due to the stability gained in all three directions and due to the resistance to torque and malleability [19].

The positioning of 3D plates and selection of dimensions and configuration depends on the type and location of fracture. Mandibular fracture reduction possesses a challenge because of the combination of tension and compression forces at the superior and inferior borders respectively. When only one standard plate is placed at the superior border, there is buccolingual splaying at the inferior border, due to being subject to torsional or flexural forces [11].

The 3D plates are designed in a way to oppose these forces. The screws are placed on both sides of the fracture line rather than on a straight line. This creates a box configuration that covers a large surface area, providing greater resistance to torsional forces. According to the design 3D plates consist of two linear plates connected by reinforcing vertical struts. These struts prevent the opening of a gap at the fracture line particularly near the inferior border and in angle fractures of the mandible [11].

Observing the findings reported by various authors, as tabulated in Table 1, it is evident that different authors have used 3D plating systems for different fractures of the mandible. Initially an animal study was done by Sakr et al., [1] in sheep hemi mandibles depicting mandibular body fractures. The authors have subjected the models to compression and tension tests in a universal testing machine, and the forces applied simulated that of masticatory muscles. The results revealed that the 3D plates exhibited greater stability and resistance in comparison to one plate or two plate systems and were a less invasive and more biocompatible alternative [1]. Saad et al., [15] points out that titanium 3D miniplates are more effective than conventional plates in the treatment of mandibular anterior fractures and have very lesser complication rates than conventional plates. Another most important yet the most challenging fracture to reduce is the fracture of angle of the mandible. The most commonly used method is to apply a single miniplate on the external oblique ridge. However, this leads to gaps in the inferior border of the mandible, lateral movement of stabilized fragments. To overcome this, two miniplates were plated at the angle of the mandible, which increased the risk of postoperative infection. 3 dimensional plates were introduced to improve the fracture stabilization and to reduce the postoperative complications [3]. This concept has been supported by many other authors also. Melek et al., [5] used an extraoral approach with 3D threadlock plates to fix isolated angle fractures and the results proved to have lesser postoperative edema, better mouth opening and fracture stabilization. According to Prasad et al., [10], the use of 3D miniplates in angle fractures showed a significant reduction in lingual splaying. The control of lingual splaying is a challenging aspect in angle fracture reduction as an increase in lingual splaying is a common complication post fracture reduction and can lead to an infected hardware and its subsequent removal. Another important and common advantage observed by most of the authors was a reduced intraoperative time [2-18]. According to Bohner et al., [6], the mean intraoperative time ranges from 12-230 minutes when using 3 dimensional plates. The use of 3D plates in condylar fracture has been evaluated by Bhowmick et al., [18]. Their study reveals that the configuration of a 3D plating system fulfills the criteria of functionally stable osteosynthesis on the condylar neck with minimal periosteal stripping and maximal preservation of proximal blood supply leading to a better healing.

All the studies reveal a number of common advantages of using 3-dimensional plating systems. These plates have minimum implant material with maximum stability, and because of their miniature size, they can be easily placed through an intraoral approach. This is also because of the placement of horizontal crossbars perpendicular to the fracture line and vertical cross bars or struts parallel to it. Further, the periosteal stripping required for the placement of plates and screws is also very minimal for 3-dimensional plating [2,6,8]. The large free areas between the plate arms and minimal dissection permit a very good blood supply to the fractured fragments [14]. Further, these plates are also easy to operate due to their shape and profile,

which require very less contouring. According to Bohner et al., [6], 3 dimensional plates have shown a reduction in postoperative complications by around 58%. Wusiman et al., [20] contradict the findings of other studies by reporting that lag screws are superior to 3D miniplates in reducing the postoperative complications in mandibular fractures.

There wasn't any statistically significant disadvantage or complication that has been reported in the scientific evidence reviewed. Bohner et al., [6] has pointed out that infected plate removal might be a major disadvantage in case of 3D plating as the entire plate removal has to be done whereas at least one of the plates can be retained in case of conventional plating systems. In such cases it would be difficult to anchor a 3D plate and a miniplate will be easier to position and fix.

Aurora et al., point out another significant disadvantage of using a 3D plate in the area of fractures running through the mental foramina [19]. The highest stability and advantage of a 3D plate over a conventional miniplate is also observed in the symphysis and parasymphysis regions, as this region is the most susceptible to torsional forces [20]. However, the adaptation of a 3D plate in the parasymphysis region increases the intraoperative time, which increases the environmental exposure of the wound and precipitates as wound infection [21, 23]. The study by Chaudhary et al., [24] evaluated the role of 3D trapezoidal plates in subcondylar fractures. The study revealed that the fixation of subcondylar fractures had increased adaptability and stability than the conventional miniplates, and the results were statistically significant. The main contributing factor for the increased stability of the three dimensional plates is the presence of the additional vertical struts [25, 27]. Thus, the literature evidence indicates that three dimensional plates in mandibular fractures offer increased stability, improved fixation, lesser operator fatigue and lesser postoperative morbidity with early restoration of normal function.

5. CONCLUSION

The three-dimensional plating system proves to be superior to the conventional plating system in all aspects including intraoperative time, stabilization, resistance, biocompatibility, and postoperative complications. However, most studies have limited themselves to the application of 3D plates to mandibular fractures only. Further research must be initiated to explore the applications of 3D plating systems in other fracture regions of the maxillofacial region.

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