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Evolution of Dental Implant Fixture Designs: A Systematic Review

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Abstract: The evolution of dental implant fixture (DIF) is a fascinating journey through time. Dental implant is made up of three major components: the fixture, abutment and prosthesis. The fixture is the component that is inserted into the bone to act as an artificial root. Fixture design has evolved from pin, screws and blades to tapered cylindrical threaded types with surface modifications, collar designs from bone to tissue level, thread geometry, apex notches etc. There is limited data available presently on the evolution of fixture designs. Hence, literature search was carried out using electronic database search on PubMed and Google scholar for articles from 1800-2021 and a systematic review was undertaken to study the various changes in fixture designs along with their drawbacks, and modifications introduced to overcome them.

Key words: Dental implant fixture design, fixture crest design, fixture body design and fixture apex design.

I. INTRODUCTION

Stomatognathic system is complex, where hard and soft tissues functions with coordination. Loss of natural teeth due to trauma or any pathological condition will affect the normal functions of stomatognathic system [1]. Rehabilitation of lost tooth or teeth was undertaken using different materials and designs. Dental implants were a breakthrough in biologically-based research in recent decades that has brought the flexibility to actually replace both the root and crown portion of lost tooth/teeth with a high likelihood of prolonged service [2]. Dental implants offer an excellent alternative to the constrains of conventional prosthesis. Any dental implant replaces both the crown and root portion of a natural tooth. The root portion of the dental implant which is placed first within the alveolar bone to support the crown is termed as fixture. Dental implant fixture (DIF) designs have a direct influence on osseointegration to achieve primary stability and longevity of the dental implant [3].

DIF have evolved through time, different materials, sizes, shapes and surface designs were used. Initially DIF were pin, basket and blade shaped but presently screw and cylinder types have more acceptance and survival.

Modern implantology began in 1940 with the screw type implant introduced by Formiggini, the tooth shaped implant had a porous root type structure which was said to permit for bony ingrowth; however, results didn't support that claim. Linkow's blade shaped implant showed a success rate of 55% to 42-66% [4].

Endosseous implant (implants placed within the bone) development continued in material science and design characteristics, due to the success and sound research, osseointegrated endosseous implant like Brånemark system, core-vent system, IMZ system, osseodent system, steri-oss system and other implants have a reliable and predictable prognosis for rehabilitation procedures. The present study results of different fixture designs shows success rate of about 95-97% of designs derived from Brånemark system [5]. Hence, literature search was carried out using electronic database search in PubMed and Google scholar for articles from 1800-2021 with keywords such as "DIF design," "evolution in DIF," "fixture crest design," "fixture body design" and "fixture apex design." A total of 164 articles were identified out of which 93 were discarded as they were not specific to fixture designs, after screening the remaining articles a total of 28 articles were selected for the review. Standard text books of dental implantology were also referred, the same was reviewed and analyzed to study the various changes in DIF designs and their influence on the success or failure of dental implant fixtures.

ANCIENT DIF DESIGNS

In 5th century BC Hippocrates stated about the possibility of anchoring artificial teeth to the gums by using threads made of gold or silk so as to replace extracted elements. About 4000 years ago in China they carved bamboo sticks in the shape of pegs and drove them into the bone as a fixed replacement therapy. About 2000 years ago the Egyptians used precious metals with an analogous peg design [6].

ORIGIN OF MODERN IMPLANTOLOGY

Maggiolo in 1809 used of gold in the shape of a tooth root. In 1913 Greenfield EJ inserted a properly prepared artificial roots of iridio-platinum and mounting on an anchorage to which can be attached a full set of permanent, natural appearing teeth [7]. In 1939 Strock discovered that certain metals are better tolerated in bone than others. He used Vitallium, a combination of cobalt, chromium and molybdenum, and inserted it completely into the bone; he found that it was well integrated with the bone [8]. Lehman's in 1940s, introduced few very original implants named "expandable arch" implants which he placed successfully in patients and demonstrated their positive outcomes radiographically.

PRESENT DIF DESIGNS

The dental implant fixture which was introduced by Brånemark in 1952 was the most successful design because of good osseointegration and longer survival [9]. Zarb in 1987 described the conditions for dental implant research: Implant and prosthetic

design and performance which would withstand long-term functional and parafunctional forces. Brånemark system met the above condition which led to their acceptance throughout the world. In 1985, the American dental association which had yet to approve any implant system gave its provisional acceptance for Brånemark system then acceptance under the endosseous implant classification in august 1988. The fixtures of Brånemark system were made of pure titanium with machined threads on the outer surface as well as the inner channel. The top of the fixture has a hexagonal design. The apical portion of the fixture is tapered with four vertical notches located in this same region. In 1966 Linkow developed the blade type implant made from chromium, nickel and vanadium, their 10 year success rate was less than 50% [10]. The core-vent system developed in 1984 by Gerald Nizick had basket type implants, micro-vent screw type implants and screw vent implants. They all had holes in the apical end of the fixture. Their five year success rate showed to be 96% [11].

Parts of an endosteal implant fixture

DIF is created of mainly three parts namely neck/crest, body and apex (fig. 1).



Figure 1- Parts of endosteal implant fixture (Image courtesy of Glidewell Dental, Newport Beach, California) **Classification of DIF**

Table 1- Based on systems [5]		
Branemak implant fixture		
Core-vent implant fixture		
IMZ implant fixture		
Osseodent implant fixture		
Steri-oss implant fixture		
Table 2- Based on the shape [12]		
Blade implant fixture		
Cylinder implant fixture		
Screw shaped implant fixture		
1 able 3- Screw shaped implant fixture further subdivision [12]		
One piece implant fixture and two piece in fixture	nplant	



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Small diameter/ Mini implant fixture	
Bone level implant fixture and Tissue level implant fixture	
Table 4- Based on c	connection type [12]
External hex implant fixture	
Internal hex implant fixture	
Table 5- Based on platforms [12]	
Platform matching implant fixture	
Platform switched implant fixture.	
Table 6- Based on length of fixture	
Short fixture	6-9mm
Medium fixture	10-12mm
Long fixture	13-18mm
Table 7-Based on diameter	
Narrow	1.8-2.9mm
Regular	3.0-5.8mm
Wide	>5.9mm

Discussion

FEATURES OF DIF DESIGN

The in detail discussion on each part of DIF is carried out in the sequence of fixture neck/collar, body and apex.

FIXTURE NECK/ COLLAR:

The implant collar is a transition area between the prosthesis and the body of the implant. Initially fixtures had smooth neck and were submerged completely within the bone for proper osseointegration; marginal bone loss was more in smooth neck fixtures which led to the introduction of roughened collar fixtures. The rough collar increases the surface area and helps in better osseointegration. In time period only two-piece fixtures were available and surgery was carried out in two stages. However studies have shown that osseointegration can also be achieved in non-submerged implants, with similar performance regarding marginal bone levels while preventing the need of a second surgery, allowing immediate or early loading of the implants saving the time of treatment [13], this was achieved by two-piece implants with transmucosal healing abutment or by employing a one-piece fixture. Studies have shown no difference within the survival rate of One-piece fixture with transmucosal collar versus two-piece fixture [14]. The collar of fixtures was later machined compared to the rough collar to achieve better soft tissue adaptation. However, the early failures were more in machined collars compared to that of rough collar [15]. To improve the survival of roughened collar fixtures microthreads were added to it, a study by Glibert et al shows success rate of 96.4% of these implants [16]. Karlsson et al. in a study on Aster implants reported one year survival rate of 98.6% for machined, 100% for rough, and 100% for rough-surfaced micro-threaded neck fixtures [17]. In order to preserve crestal bone levels platform switching was introduced. Platform switching provides a biomechanical advantage in osseointegrated implants by shifting the stress concentration area far from the cervical bone-implant interface. Different designs for implant-abutment prosthetic connections are available like external and internal connection [18]. External prosthetic connections were the first prosthetic connections in wide use on screw-type fixtures. However, it was not ideal when used for single-crown and partially edentulous restorations because the abutment screw was subjected to more lateral loading than in splinted restorations, internal prosthetic connection fixtures were developed to overcome these drawbacks. They are hex type or conical type. The conical connection interface area had improved abutment stability, fit, and seal performance [19]. Most root-form fixtures are bone-level fixtures, because they are designed to be placed with the collar at or near the bone crest, they help in formation of the soft tissue emergence profile of the implant restoration. Fixtures that are designed for placement with the collar at or near the soft tissue margin

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are referred to as tissue-level implants. In 1961 Gargiulo et al said that the formation and maintenance of biological width of the soft tissue is crucial and it depends on the crestal bone level [20]. Tissue-level fixtures were developed to increase the distance of the implant–abutment interface from the bone surface to provide the required biologic width. Bone-level designs were later developed with conical connections and platform shifts, which serve similar goals [21]. Increasing the fixture diameter increases the implant surface area available for force transfer to the bone. Larger diameter fixture resists occlusal forces better. A study by Olate et al has shown that wide implants have lower losses (2.7%) than regular (3.8%) and narrow (5.5%) implants [22]. Tarnow et al said that fixtures located at sites with <3 mm inter-implant distance have more crestal bone loss than at sites where the implants were standing >3 mm apart [23].

BODY OF THE FIXTURE

Early fixtures were non-threaded smooth type, they commonly had parallel walls. To increase surface area of the fixture, threads were added and to mimic the natural root anatomy the fixtures were tapered as they go apically. Study of threaded implant bodies shows a greater percentage of bone-implant contact compared with non-threaded cylinder implants [24].

Implant threads are described by their thread shape, thread pitch, and thread depth.

Thread pitch can be defined as the distance from a point on one thread to a corresponding point on the adjacent thread, measured parallel to the axis. Geramizadeh et al found that a thread pitch of 0.808 mm in the implant body area was optimal for stress distribution [25].

Thread forms in DIF designs include V-form, square shape, buttress, spiral shape and reverse buttress. The type of force applied at the implant–bone interface affects the strength and degree of osseointegration. Loads generated at the interface are of three types; compressive, tensile and shear forces. Fixtures are strongest under compressive loads and weakest to shear loads. Initial fixtures had V- shape designs, with these threads shear stresses were more, with the increased knowledge of stress patterns, the variants of V-shape thread design were developed, large square type gives rise to compressive stresses which are better tolerated. Geng et al conducted a finite element analysis on four thread form and found that V-thread and large square thread were the optimal thread shapes for their experimental stepped screw fixtures [26].

Studies have shown that in squared and buttress threads the axial load are mostly dissipated through compressive force, while V-shaped and reverse buttress-threaded implants transmit axial force through a combination of compressive, tensile and shear forces. V-thread and reverse buttress thread have shear force 10 times greater than that of square thread [27].

The thread depth is measured as the distance between the root and the crest of the thread. Thread width is the distance in the same axial plane between the coronal most and the apical most part, at the tip of a single thread. In a finite element analysis study by Ao et al found that thread depths greater than 0.44 mm and widths of 0.19-0.23 mm caused lowest stresses in moderately dense bone [28].

APEX OF THE FIXTURE

The apical region of the implant has features to facilitate insertion into the osteotomy and initiate engagement of the implant threads with the surrounding bone. Initial fixtures had variations in apex designs ranging from smooth rounded apex to flat end apex. The Brånemark system had tapered fixtures with four vertical notches in the apical end. Tapered apex were better accepted than parallel walled apex as they allowed some of the axial length of the implant to enter the implant site before the threads come into contact with the walls of the osteotomy. Small-diameter fixture apex typically tapers to a sharp point to advance into the bone below the implant hole without further site preparation [12]. The apical region may include a hole or slot feature through the implant body for bone to grow into and increase anchorage against torsional forces, these features are still found on some implant designs in use today, such as the Zimmer Screw-Vent implant. Few fixtures have helical self-tapping feature designed to reduce tapping force and collect bone chips.

SURFACE MODIFICATIONS IN DIF

In early days no modifications were made on titanium or titanium alloy. After 1980's several surface modifications were made to promote better osseointegration, especially for cases with poor bone quality. The modifications were made by either additive or subtractive process. The additive processes include titanium plasma-sprayed (TPS) surfaces, hydroxyapatite (HA) and nanocomposite coating, calcium phosphate coatings, ion deposition, photofunctionalization, oxidation and drug coating. Subtractive processes include electropolishing, mechanical polishing, blasting, etching and laser micro texturing. Both additive and substractive techniques have provided successful results [29].

CONCLUSION

The DIF designs have changed immensely from past times till now. In the crest design the micro-threaded and roughened surface have shown better results, platform switching has shifted the stress concentration away from crestal bone-implant interface. Tissue level fixtures initiate gingival collar formation after the first stage surgery itself compared to that of bone level fixtures. Internal hex connection reduced lateral forces on the fixture which was a drawback of external hex. Wider diameter collars fixtures have better prognosis compared to narrower implants, Anitua et al in 2021 said that fixtures of 3.3mm diameter in type IV bone show higher stress concentration than 4.75mm fixtures in type I bone. In the body, threaded fixtures with surface modifications have better osseointegration[30], the large square type thread designs generate compressive forces which are better tolerated by the bone. Longer fixtures have larger surface area to facilitate better bone contact, Olate Sergio in 2010 said that short fixtures (6-9mm) showed greater bone loss followed by long fixtures (13-18mm) and least in medium fixtures (10-12mm) [23]. In the apex design, tapered form with modifications such as grooves, slots, notches were added to increase surface area and collect bone chips, helical self-tapping feature in the apex increases tapping performance and induce bone collection. Holes and vents were instilled to facilitate bone growth through the fixture. Smaller fixtures have sharp apex to advance into the site without much preparation, flat end or rounded apex fixtures are preferred to prevent perforation of maxillary and nasal lining.

All these changes over the time have led to better osseointegration, durability and prognosis of the fixtures leading to their success. Knowledge about the modifications help us overcome the drawbacks of previous deigns of fixtures. Better fixture abutment

connection designs are required to combat situations with severe crestal bone loss, modification in present thread design to convert all forces generated to compressive forces, and application of 3D technology to that of conventional designs for better customization of fixture designs according to space available, bone quality and other factors that influence the success of implant treatment are required.

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