THE RELATIONSHIP BETWEEN ENDOSTEAL IMPLANT DESIGN AND FUNCTION:

Maximum Stress Distribution with Computer-Formed, Three Dimensional Flexi-Cup™ Blades

*Maurice Valen**

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SYNOPSIS

Titanium dental implants are being used routinely as abutments for fixed and overlay prostheses. Biomechanical principles should be considered if one is to set criteria for functional implant design. Available alveolar bone has volume, borders and trajectory. Surgical insertion, three dimensional anatomical evaluation, and the need to absorb maximum occlusal forces should be the determining factors of design. The greatest amount of implant metal-to-bone support in a compressive mode must be achieved to insure long term success.[1,2] (Figure 1, 2)

IMPLANT SUCCESS = PROPER LOAD DISTRIBUTION

AREA OF METAL TO BONE SUPPORT IN A COMPRESSIVE MODE

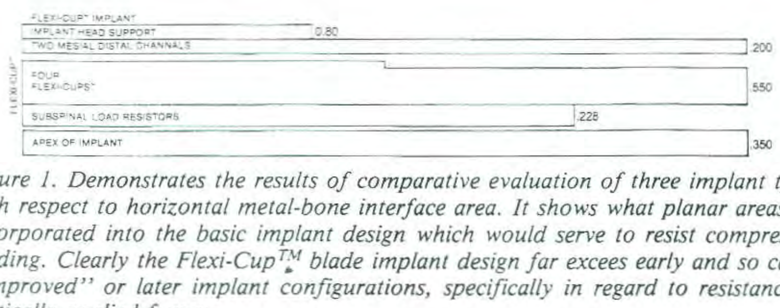

Figure 1. Demonstrates the results of comparative evaluation of three implant types with respect to horizontal metal-bone interface area. It shows what planar areas are incorporated into the basic implant design which would serve to resist compressive loading. Clearly the Flexi-Cup™ blade implant design far excees early and so called "improved" or later implant configurations, specifically in regard to resistance to vertically applied forces.

Various clinicians have stated that dental implants transmit stresses to the alveolar bone and maintain the height of the alveolar ridge.[3,4,5] What is not known is how much force can be tolerated by quantified alveolar structure before the bone is overstressed and dissolves. Further, to what extent can implant design significantly alter stress distribution within available alveolar bone?[6]

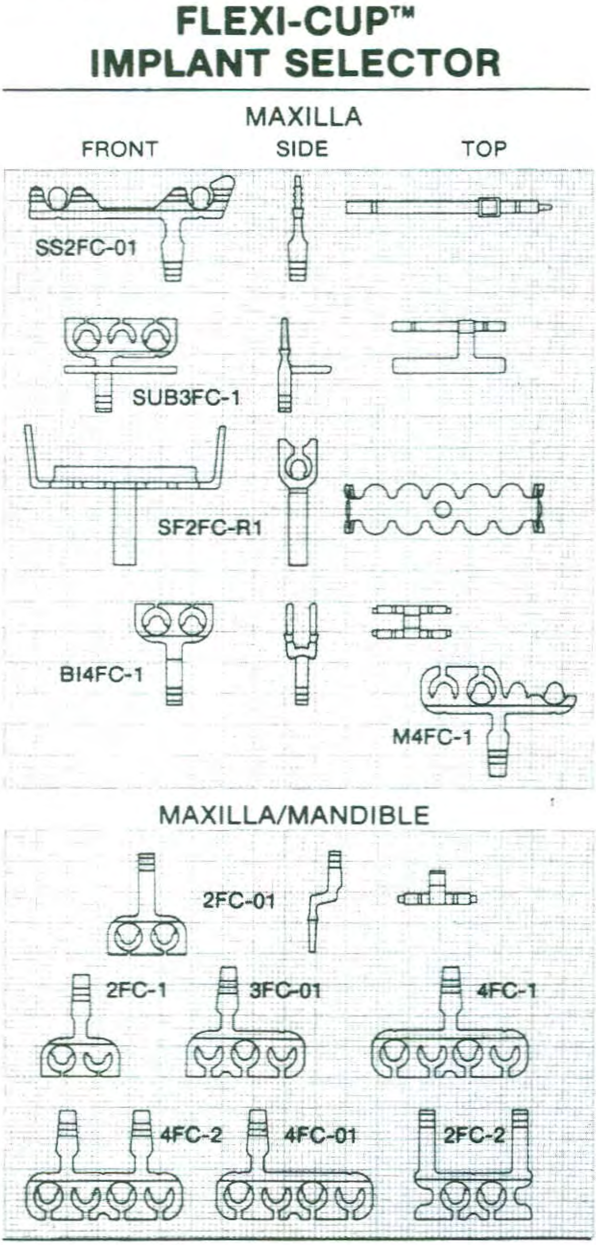

Figure 2.

INTRODUCTION

All blade type implants are different. They function under different circumstances, under different load factors, and because of their specific designs, they all have to function differently within the same alveolar region. Because of complex variables, such as an individual's gnatho-dynamic muscular system, the presence of elevator muscular forces, class two and class three lever factors,[7] and a clinician's general inability to determine completely the state and topography of remaining alveolar bone, implantology has tended to be an "art form." In order to overcome these undeniable limitations, the author proposes that three dimensional computer formed implants, which achieve maximum theoretical occlusal load distribution, should be routinely used on a clinical basis.

The primary purpose for the Flexi-Cup™ implant design (Figure 3) is to prevent settling within alveolar bone and to achieve greater immediate fixation when compared to "standard" blade designs. These concepts evolved from a patent filed January 2, 1974. After considerable testing preliminary preclinical results were presented to the American Academy of Implant Dentistry, Dallas, Texas, in 1979.[8] Originally, the lateral wings of the Flexi-Cup™ implant were facing upward. They were manufactured with conventional machining processes. They did not result in the physiological three dimensional function sought. (Figure 4)

Unaltered Grain Structure Prevents Fractures

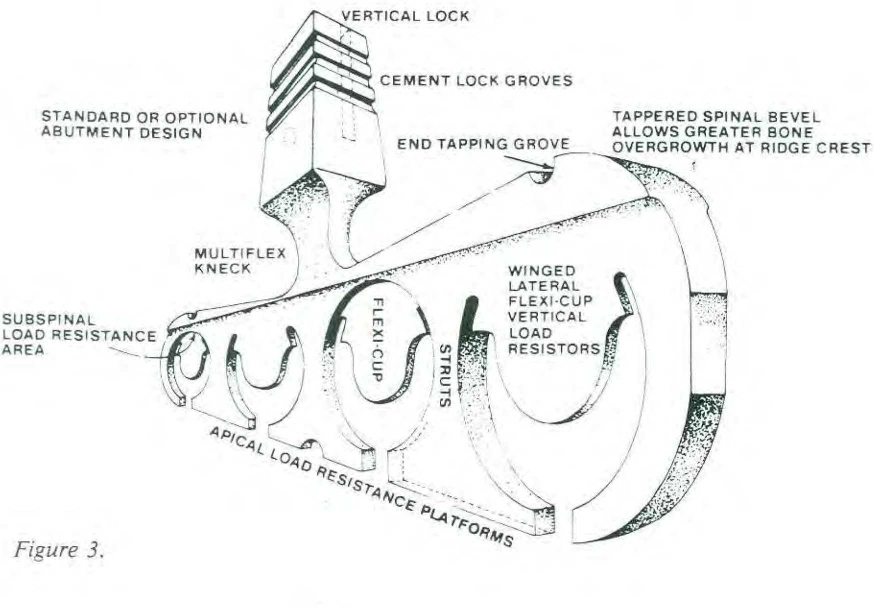

Figure 3.

Figure 4. Pre-clinical designs which were discarded due to minimum comparative distribution of occlusal stress.

COMPUTERIZED FOR FUNCTION

The simple machining or forging processes used to manufacture conventional titanium implants do not result in physical and mechanical properties which would provide optimal physiologic stress distribution.

Computerized laser disintegration techniques were utilized to transform titanium stock with known metalurgical properties into Flexi-Cup™ blade implants without significant alteration of the metal. This represented a complete departure from prior technology which resulted in blade implants which were not optimally functional.

Titanium stock with a known modulus of elasticity and a specific yield strength was selected. The modulus of flexture and the modulus of stiffness were computed to function harmoniously with each other. Strong geometric cross sections of metal (modulus of stiffness) versus thinner geometric designs were selected for strength, function and flexture (modulus of flexture), so that Flexi-Cup™ implants would function three dimensionally within available bone. (Figure 5, 6)

It is also possible (and reasonable in thin ridge situations) to utilize Flexi-Cup™ blade implants in a "conventional" manner without attempting to achieve maximum resistance to vertical loading by spreading the Flexi-Cups. (Figure 7)

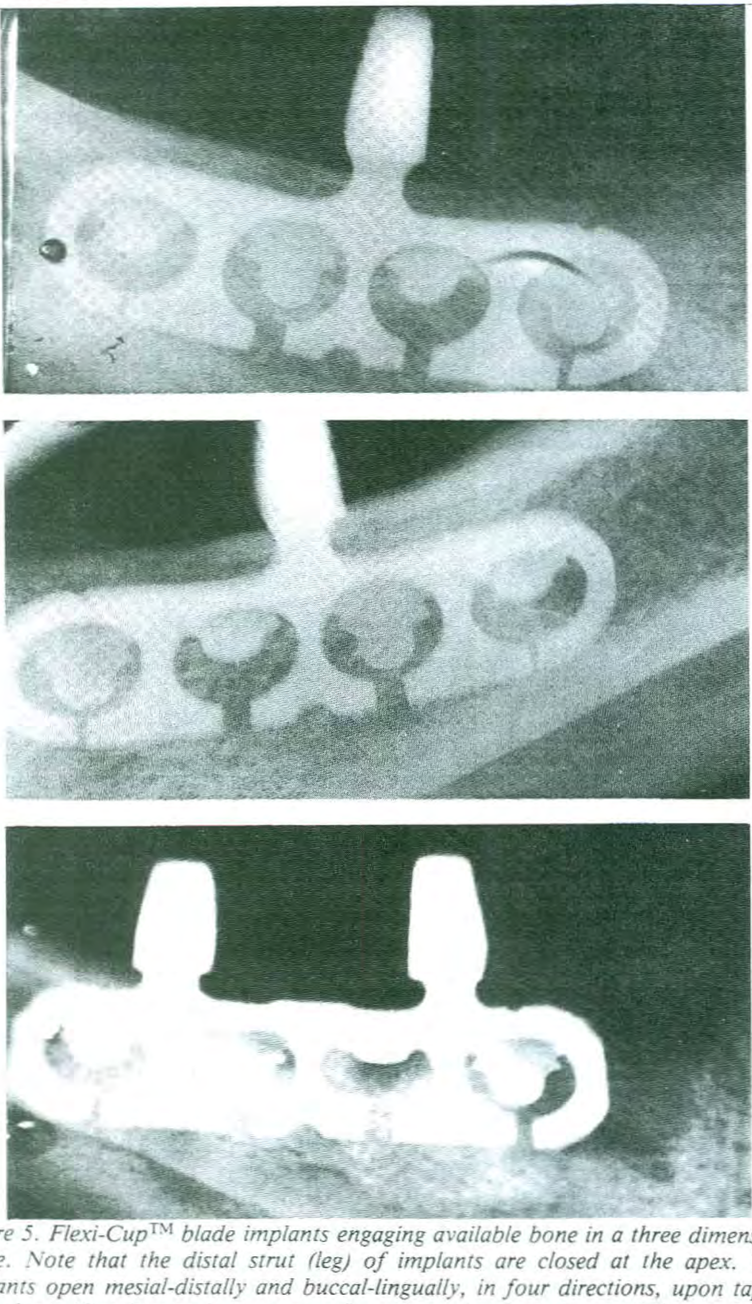

Figure 5. Flexi-Cup™ blade implants engaging available bone in a three dimensional mode. Note that the distal strut (leg) of implants are closed at the apex. These implants open mesial-distally and buccal-lingually, in four directions, upon tapping into place. If resistance is encountered, such as the dense bone of the roof of the mandibular canal, the implant will compress.

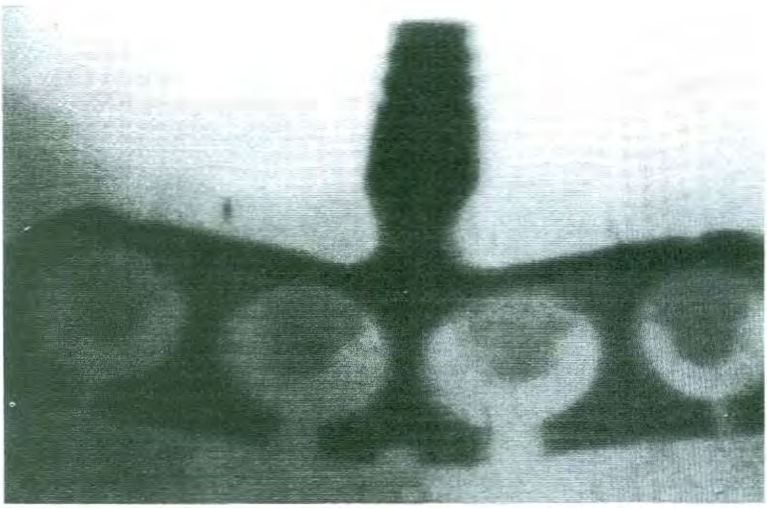

Figure 6 Note the concave curvature of the Flexi-Cup™ spine (shoulder) upon tapping implant. Due to the advantage of a three dimensional interlocking mechanism, the implant will open up according to the available bone.

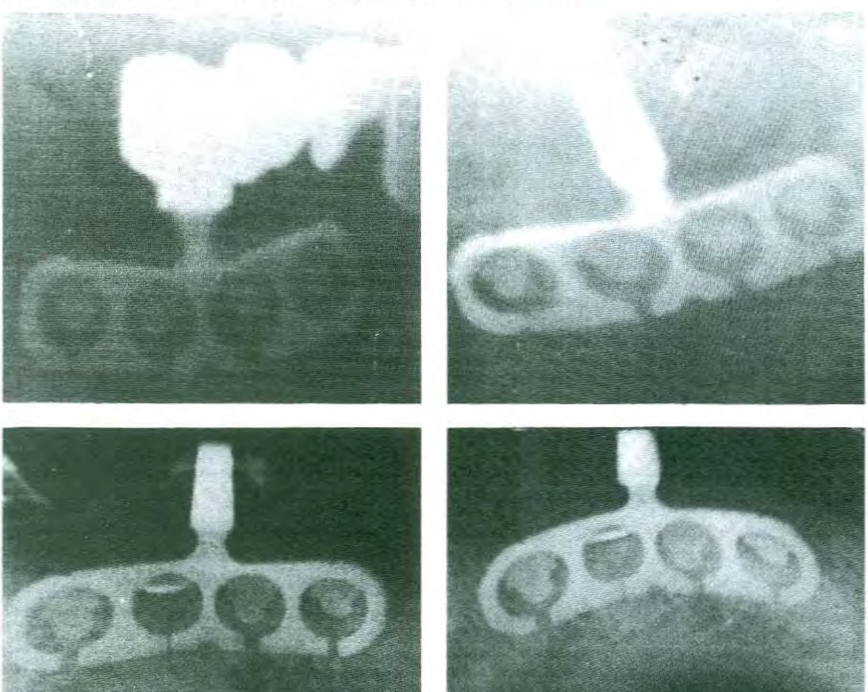

Figure 6a. Convex curvature of the implant spine develops when tapping Flexi-Cup™ implants into place, when there is substantial resistance to seating beneath the abutment head and decreased resistance at the mesial and distal ends of the implant. This also usually will result in opening of the middle Flexi-Cups. These implants will flex and lock in all directions into undisturbed alveolar bone. This results in immediate positive fixation.

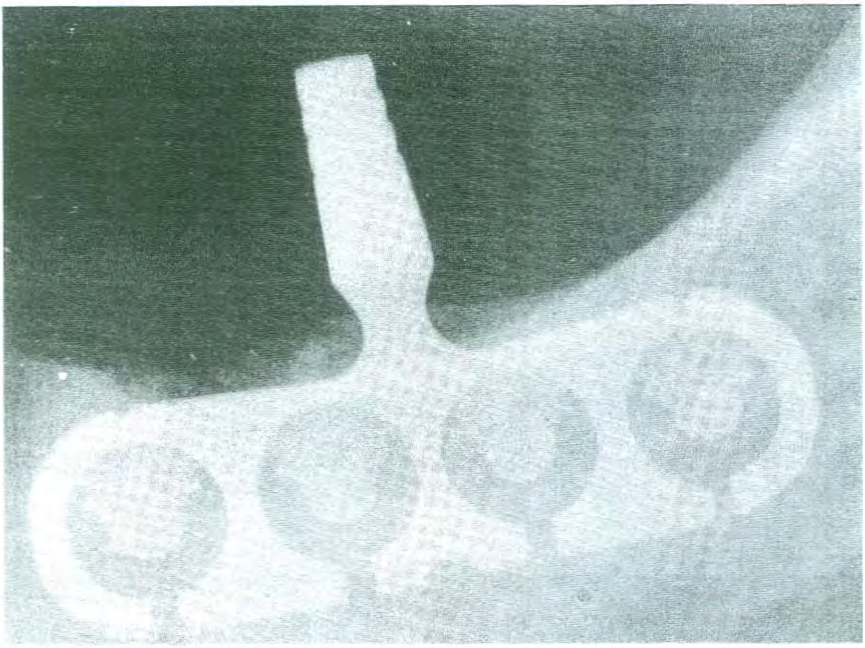

Figure 7. Using the Flexi-Cup Implant for thin ridges.

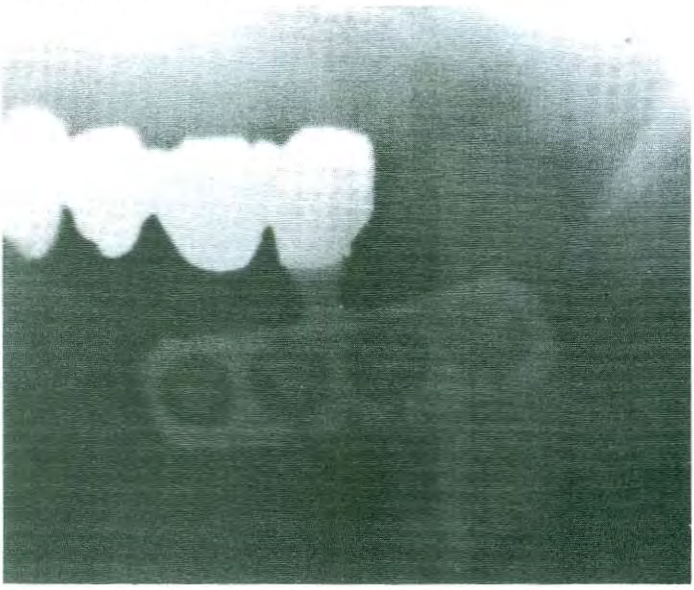

Figure 7a. Flexi-Cup™ implants can be utilized in a conventional manner with thin ridges without opening the buccal or lingual Flexi-Cups. As was stated above, a superior resistance to occlusal loading will still be achieved when compared to other blade implant designs. When utilized in this manner compression in five directions is still achieved (buccally, lingually, mesially, distally, and apically).

Farah[14] studied ten different implant designs. He concluded that No. 10 implant had the best design due to its rounded ends with additional fixed and rigid lateral supports, even though it did present a problem of initial stability and it required a greater removal of bone for insertion. According to his data all ten implants were axially loaded with a fifty pound force. An assumption was made that implant No. 1, a small "single tooth" design, would function under a force of fifty pounds. With normal conditions in the oral cavity, this is not the case. Average loading for the incisors is 22.5 pounds.[15] Implant No. 1 may very well function successfully in the anterior region. On the other hand implant No. 10 is primarily designed for the molar region, where the applied force may be as much as 195 pounds,[15] making Farah's conclusions questionable.

IMPLANT DESIGN AND ITS RELATIONSHIP TO BONE PHYSIOLOGY

Bones receive their strength from overall shape and by thickening of areas that receive greater stress.[9] Also, alveolar bone is deposited interiorly by distribution of stresses via the natural dentition. Tooth extraction leads to resorption of the alveolar crest,[10,11] as well as to a decrease in trabeculation of the whole ridge.[12]

The density of mandibular bone is different at various horizontal cross-sectional levels.[13] At various vertical cross-sections one can also demonstrate areas where cancellous portions vary considerably in relationship to the amount of marrow space to bone support. Specifically in the molar region there is an area of weakness which consists of very loosely arranged alveolar bone, mostly of "hemopoietic marrow."[9] (Fig. 8 and 8a)

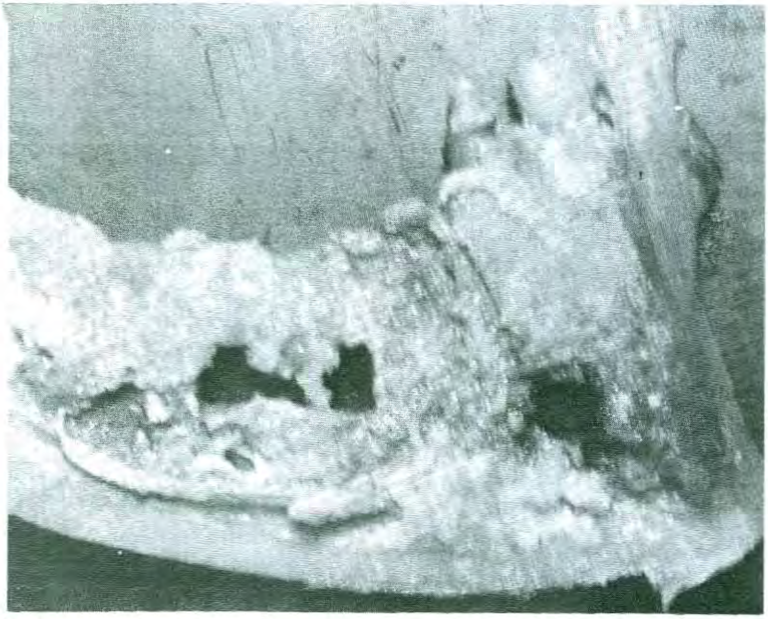

Figure 8.

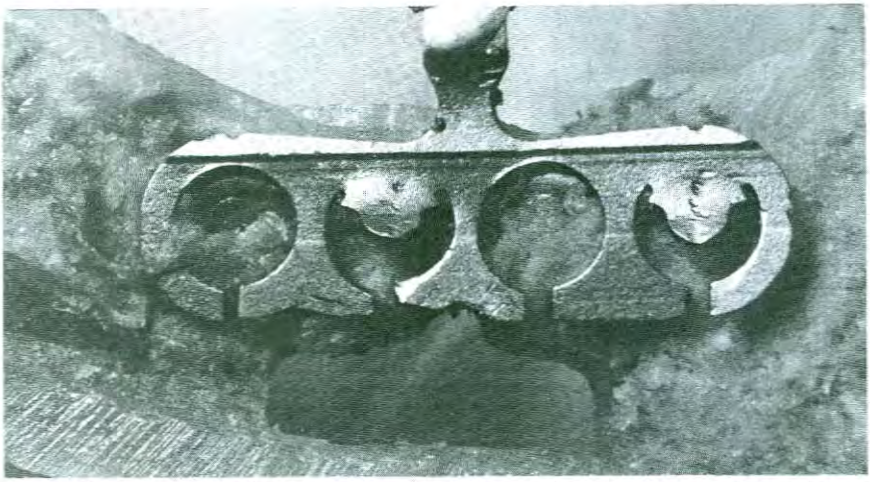

Figure 8a. In an area of no resistance, implant must be opened up to the maximum borders.

Historically, vents in implants of various dimensions were deemed necessary for success. After sufficient healing time elapsed bone formation hopefully would occur in the vents and act as a support mechanism.

Within the last few years, and on the basis of no research, certain authors have attached great importance to actual vent size and configuration.[16] Others have claimed that the success of certain implants was due to the geometric designs of their vents.[17,18]

Clinically, if an implant is not immediately and rigidly secured within the alveolar bone by three dimensional mechanical means (Figure 9), the relevance of vent size has no significant functional application. The implant will be loose from the outset. No significant bone formation will occur through the vents.

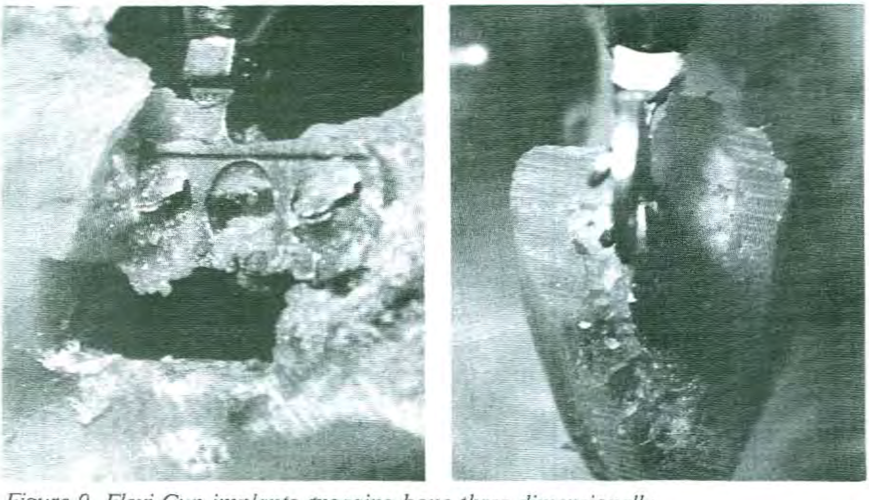

Figure 9. Flexi-Cup implants engaging bone three dimensionally.

When one dimensional cone or wedge shaped implants are placed in reasonably available alveolar bone, initial stabilization depends primarily on apical resistance and thickness of the ridge crest at the implant head site. With the classical thin ridge, where both cortical plates are in close approximation, there is almost no alveolar bone. Vascularily is compromised. An overstressed implant head, without any initial apical support, would automatically cause saucerization due to high concentration of loading in this area.

The density of alveolar bone, after tooth extraction, varies considerably.[9-13,19] Finite stress analysis, photo-elastic studies[14,20-30] and (M.T.S.) mechanical testing of dental implants in wet mandibles (Figure 10a, 10b) all demonstrate that implants work best under compression. Therefore, implants are compressive in nature, and none of them are physiological, i.e. toothlike.

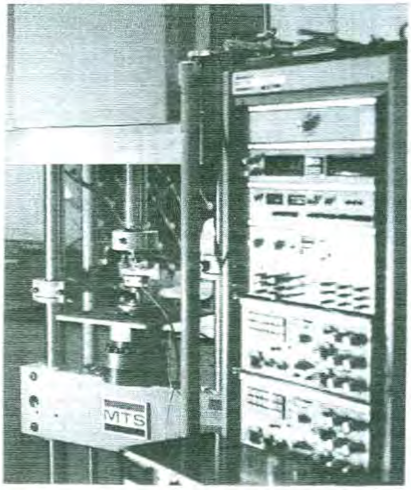

Figure 10a. Material Testing Systems (M.T.S.) at University of Medicine and Dentistry of New Jersey.

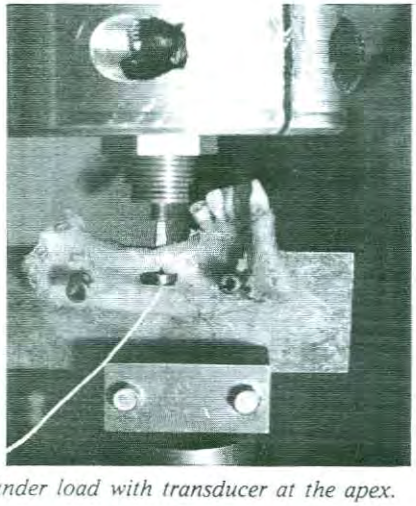

Figure 10b. Implant under load with transducer at the apex.

To graphically illustrate the above points, Martin and Valen undertook a study at the University of Medicine and Dentistry of New Jersey to compare relative resistance to loading of the Flexi-Cup™ implant and wedge type blade implants (Figure 10a, 10b). As a force was applied to the implants in wet mandibles (Figure 10a), transducers at the apex of each implant (Figure 10b) recorded the resulting force in the bone. Futhermore, a comparison was made between the two implant types as occlusal loading increased.

Figure 11 demonstrates settling of wedge type implant as loading increased from 0 to 100 pounds at different time intervals. Note the first line of the graph and the distance of lapse time to the second recording line (arrow). This lapse time shows the amount of settling within the bone or an implant's inability to resist deformation of the bone. Furthermore, each time occlusal loading is instituted there is an additional increment of settling with wedge type blade implants.

Figure 12 demonstrates the function of the Flexi-Cup™ implant under the same continuous loading conditions. No significant settling is exhibited between lines one and two. Thereafter, all other loadings are within the same linear slope.

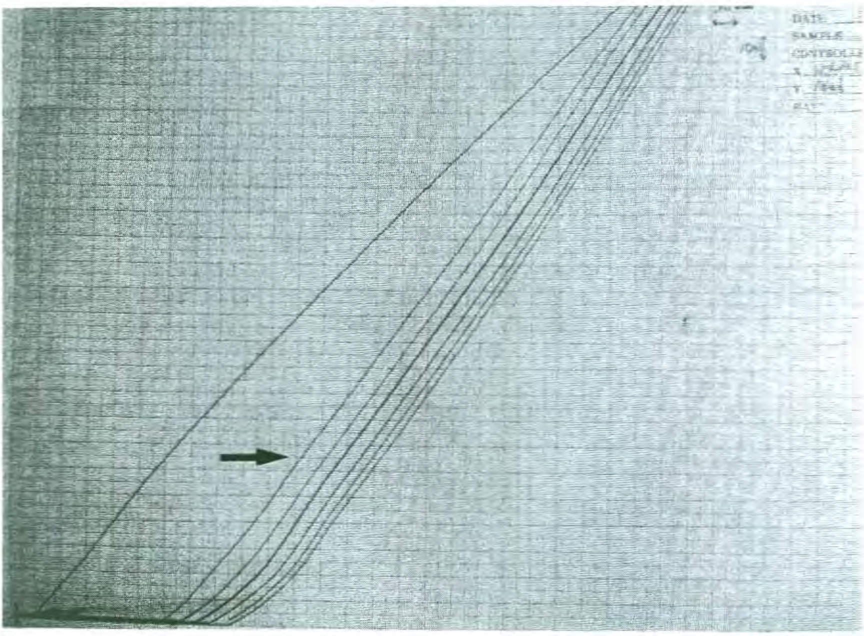

Figure 11

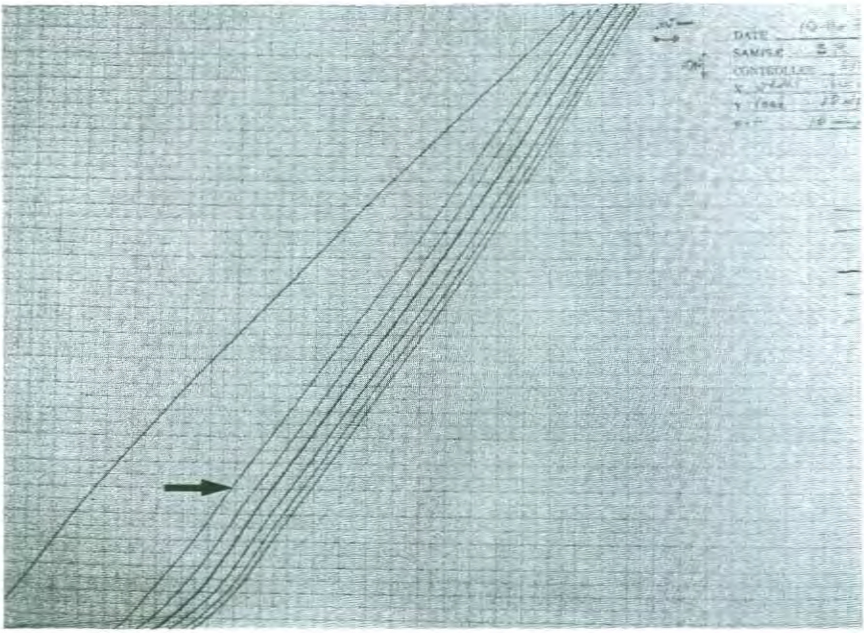

Figure 11a

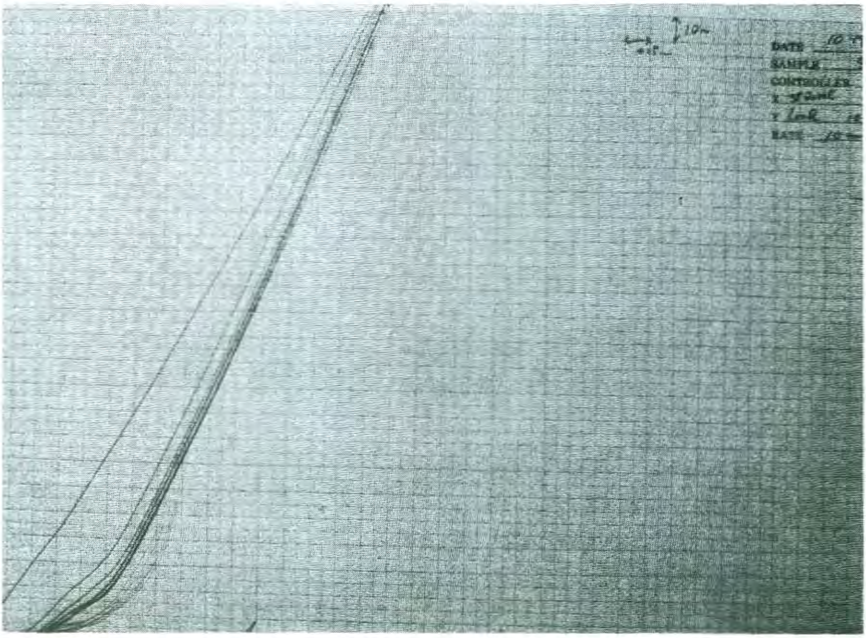

Figure 12

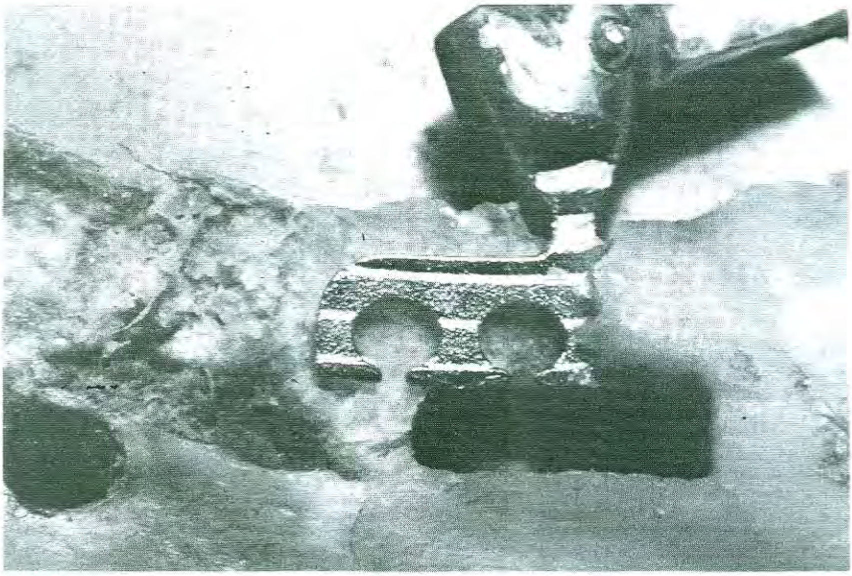

Figure 13. An "improved" wedge blade implant. Slippage is more likely to occur with a wedge blade at the interface.

PHOTOELASTIC ANALYSIS OF BLADES

When comparing the ability of implants to withstand occlusal loads, they should all basically be the same size. The author commissioned Dr. Hamdi Mohammed, from the University of Florida, to determine load concentration via fringe patterns in a photoelastic study utilizing the polarscope.

Early conventional wedge shaped implants which were sharp at the apex and had smooth tissue interfaces exhibited high stress concentration at the apex, in the order of 7.5 fringe patterns. (Figure 14)

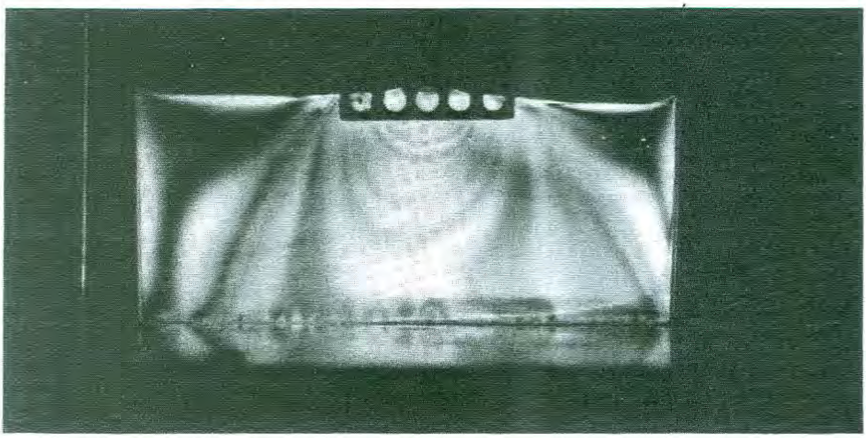

Figure 14. Early wedge type implant. 7.5 fringe patterns.

Later wedge shaped blade implants (Figure 15) with additional step-like configurations at the interface exhibited lower stress concentration, in order of 6.5 fringes. Unfortunately, the step-like configuration faces upwards and this does not provide proper implant support in a compressive mode.

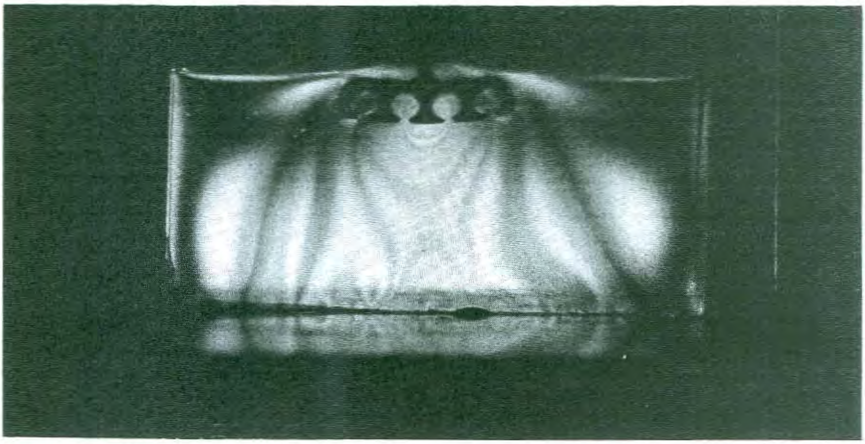

Figure 15. "Improved" Wedge type implant. 6.5 fringe patterns.

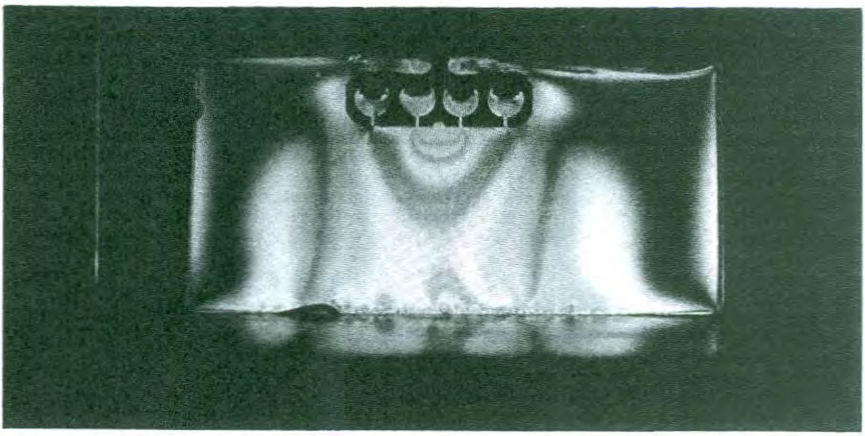

Figure 16. Flexi-Cup™ implant. 4 fringe patterns.

On the other hand, the Flexi-Cup™ implant (Figure 16), under the same photoelastic conditions, exhibited a much lower stress concentration at the apex, in the order of 4 fringe patterns.

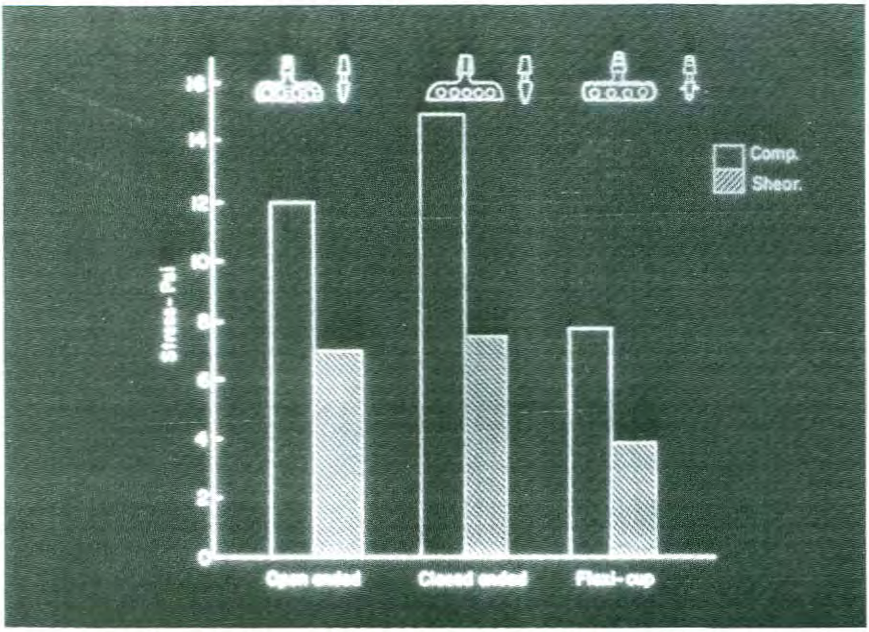

Figure 17. Comparative results of photoelastic testing of 3 implants in compressive and shear modes.

ILLUSTRATED INSERTION OF FLEXI-CUP™ IMPLANTS

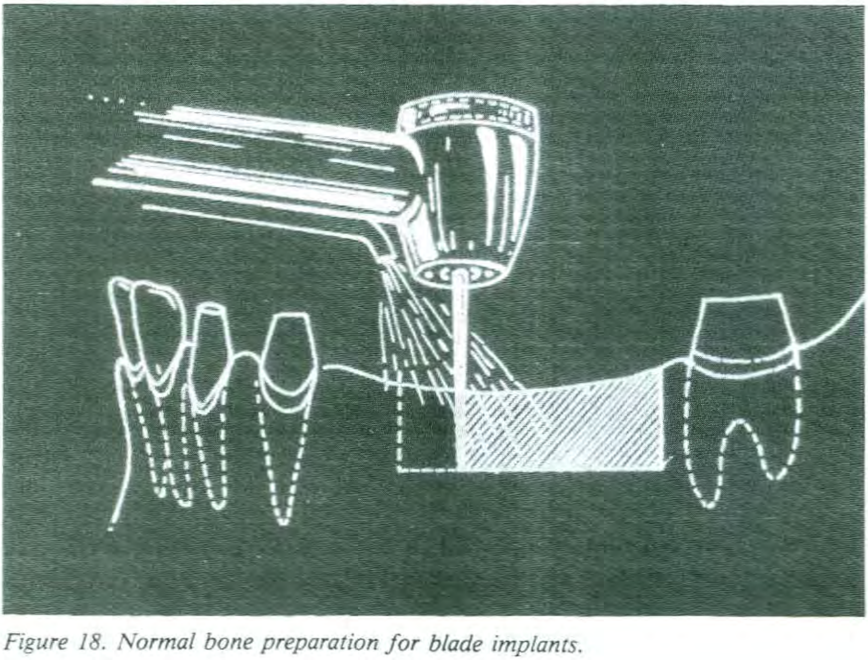

Figure 18. Normal bone preparation for blade implants.

Figure 18a. Clinical illustration of prepared implant channel.

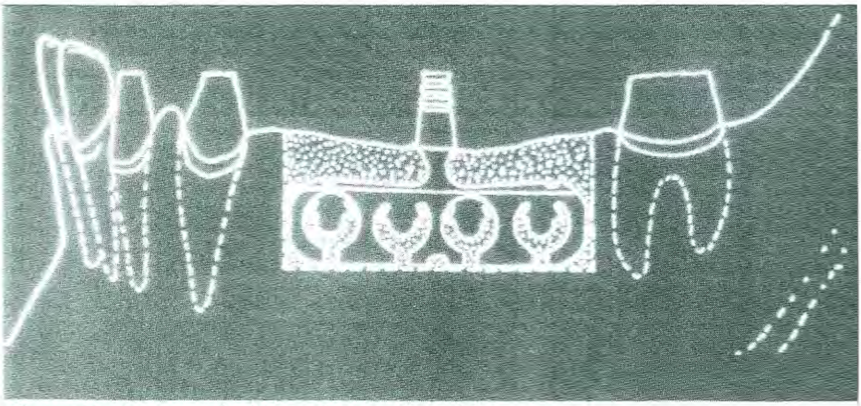

Figure 19. Schematiclly illustrating passive trial.

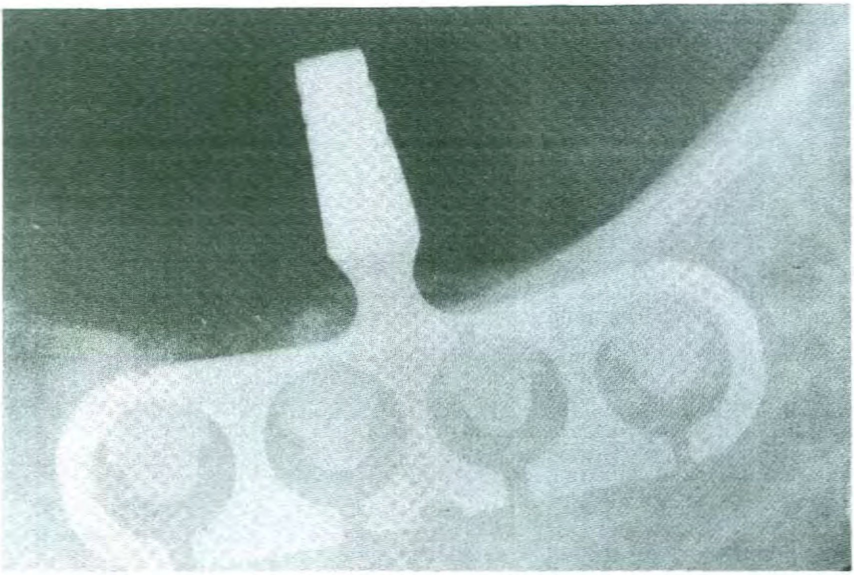

Figure 19a. Passive trial insertion. Probably the most important step and the simplest for the Flexi-Cup™, is the passive trial. A channel must be produced equivalent to the depth of the selected implant. The implant should fit passively in place with gentle tapping or finger pressure for the final vertical placing. Up to this point the bone is being compressed vertically in one dimension. After this step the implant is removed.

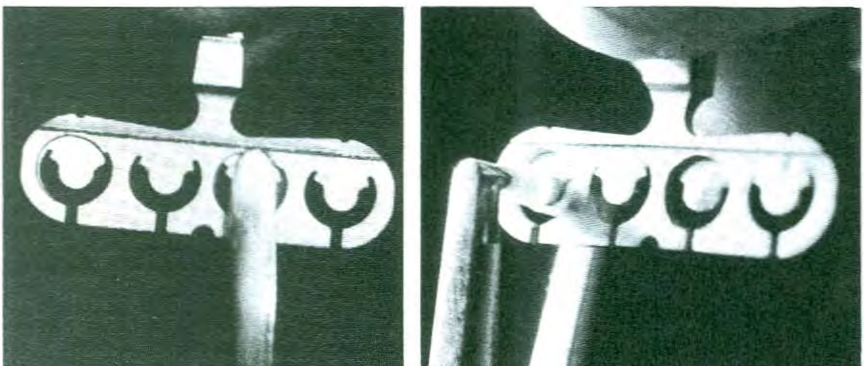

Figure 20. After removal of the implant from the bone channel, special pliers are utilized in order to bend the flexible cups buccally and lingually. Each cup is made to bend only one way to their respective sides.

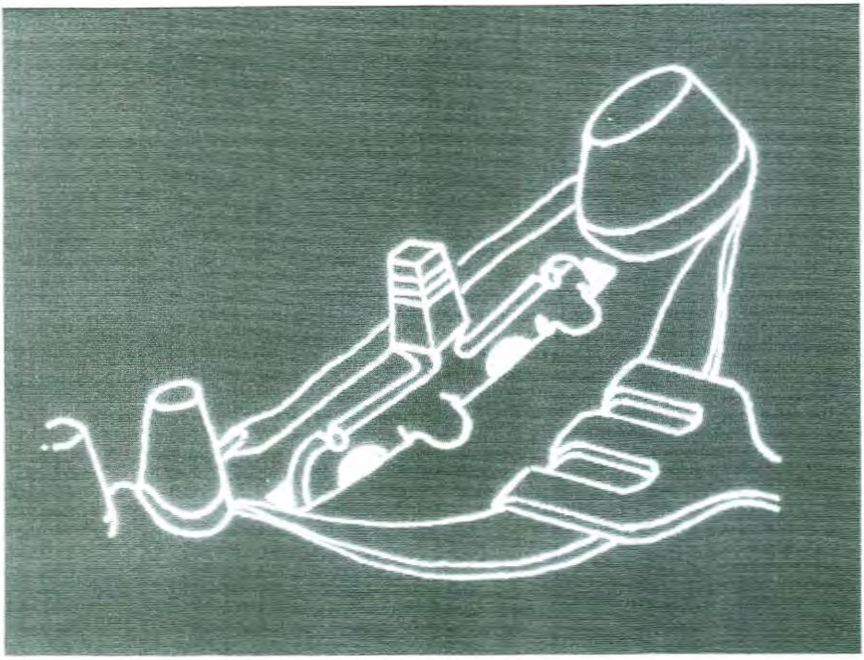

Figure 21. Re-entry into the original channel. Please note at this stage the flexible cups will sit on the crestal cortical bone. Final seating will not be possible.

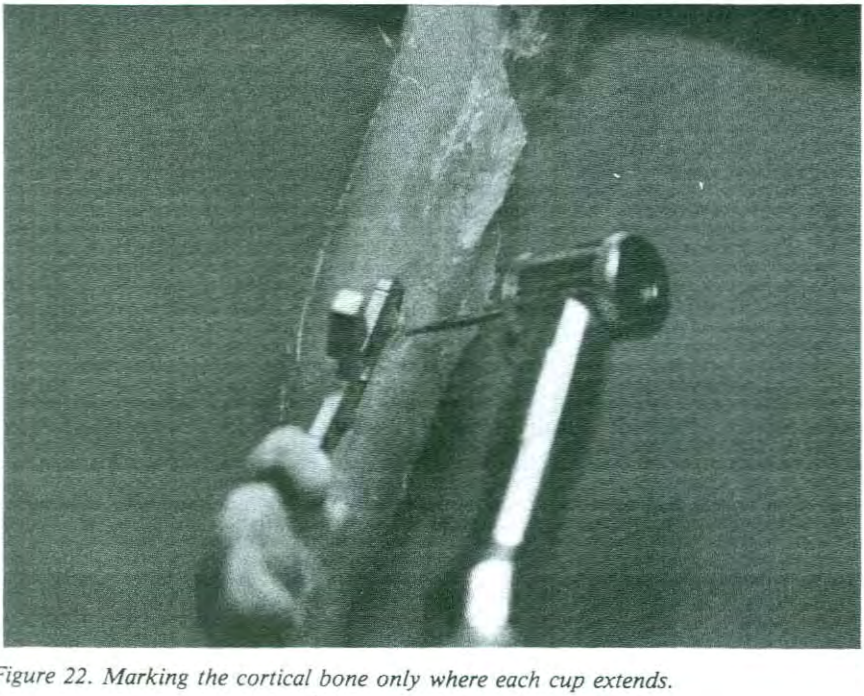

Figure 22. Marking the cortical bone only where each cup extends.

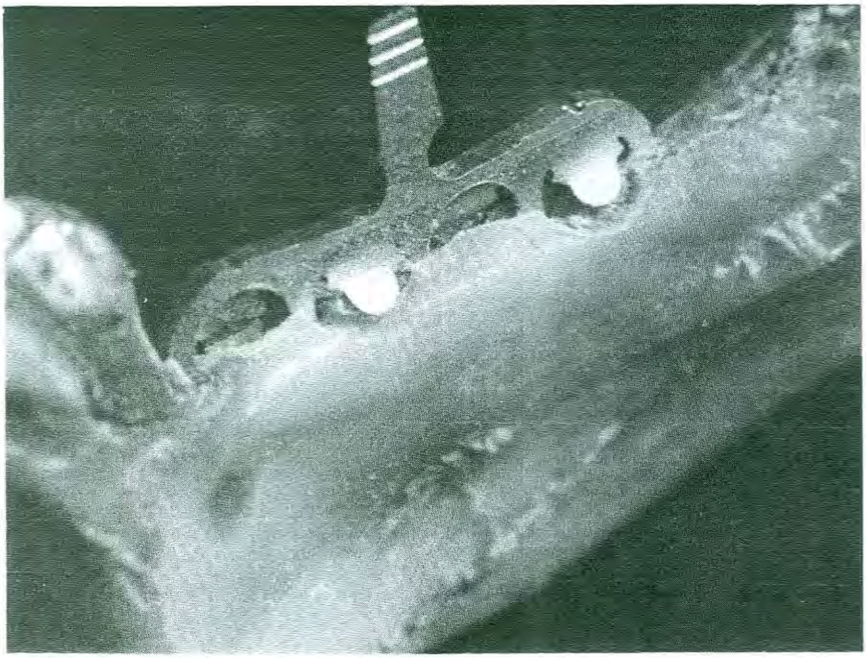

Figure 23. Proper cutting of the cortical bone at the ridge crest.

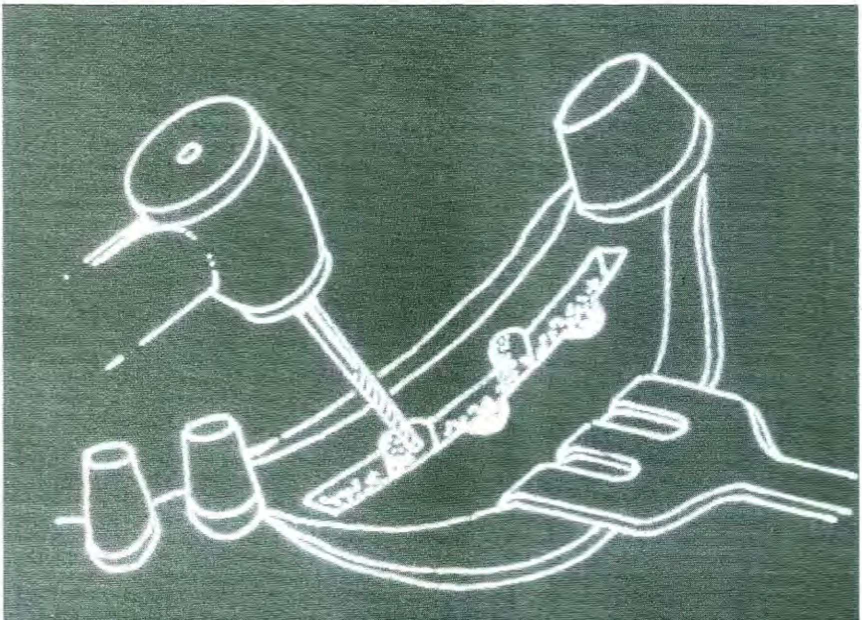

Figure 24. Remove the implant and cut the outlined cortical bone as previously marked. (DO NOT CARRY NOTCHES DOWN INTO THE ALVEOLAR PROCESS).

Figure 25. The notched ridge ready to receive a Flexi-Cup™ implant.

Figure 26. The implant is firmly seated in place by tapping.

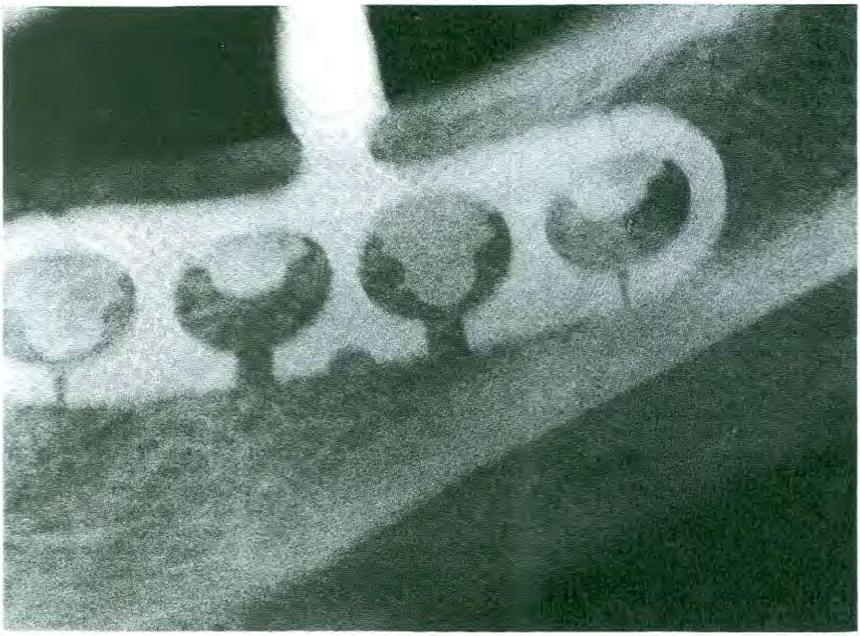

Figure 26a. Note spreading of the cups and compression of the mesial and distal legs.

CONCLUSION:

Alveolar bone is three dimensional in nature. In order to maximally resist applied occlusal stresses, implant designs and materials should be utilized to totally engage the supporting alveolar bone in five directions. Early wedge type implants failed to do this and only succeeded clinically under minimum stress conditions. For long term success and maximum resistance to occlusal loading the author recommends the principles of the three dimensional Flexi-Cup™ blade implant and related devices.

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ADDITIONAL LITERATURE AND INSTRUCTIONAL MATERIAL AVAILABLE UPON REQUEST

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