

The Biology of Implant Dentistry

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Historic Review

Success in the placement, hard tissue integration, and clinical use of endosseous iron alloy implants has been documented as far back as the first or second century AD.¹ However, in those days, the approach to implant dentistry was purely empirical and carried potential problems such as disease transmission, foreign body reaction, peri-implant inflammation, and fatigue fracture. Implant dentistry did not gain a scientific basis until the first third of the 20th century. Endosseous, root-form implants were introduced in the United States by Greenfield in 1913,² and subperiosteal implants were introduced in Sweden by Dahl in 1937.³⁻⁵ However, relatively high numbers of failures were reported using subperiosteal implants, which involved a relatively invasive approach.⁶ Removal necessitated by infection caused substantial defects in the residual alveolar bone. Since then, root-form, endosseous implants of varying shapes (cylinder, step cylinder, screw, and combinations thereof) have been used. As a result of an increased need for osteosynthesis after traumatic injury during World Wars I and II, it became evident that titanium, rather than stainless steel or other metals, was the most biocompatible material to use in the attempt to achieve fracture healing by primary intention or hard tissue integration.⁷⁻⁹

In the 1940s and 1950s, Bothe et al⁸ and Leventhal⁹ first described the biocompatibility of titanium for bone surgery. Later, Brånemark and his research group in Sweden defined such hard tissue integration around relatively smooth machined titanium implants as *osseointegration*.¹⁰ Schroeder and his team in Switzerland defined the hard tissue integration adjacent to a rough-surfaced, titanium plasma-sprayed (TPS) surface of implants as *functional ankylosis*.¹¹⁻¹³ Such a functional unit allows only limited movement of the endosseous implant compared with natural teeth, because there is no intervening tissue between the implant surface and the surrounding alveolar bone. The relationship between the endosseous dental implant and the bone tissue dominated the dental implant literature for many years. This was due to the fact that the direct contact of the implant with the bone was completely different from the natural tooth, which has an attachment apparatus between the tooth root and bone consisting of cementum and a periodontal ligament. The endosseous dental implant represented only one part of the dental restoration. It was equivalent to the tooth root, and the final restoration needed an equivalent component to the tooth crown. Consequently, the dental implant restoration, similar to the natural tooth, had to penetrate the oral integument; ie, the restoration also had to pass through the oral soft tissues that were comprised of epithelium and connective tissue. What was unknown was the relationship of the epithelium and connective tissue to the final implant restoration.

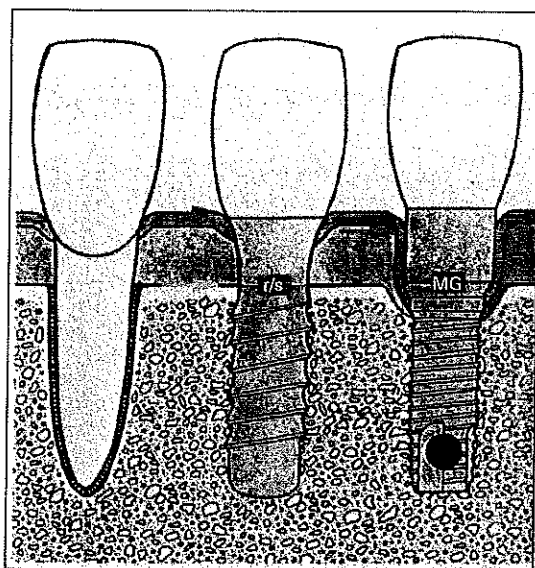


Fig 34-1 Schematic drawing comparing hard and soft tissue reactions around a natural tooth (*left*) with a loaded one-piece, non-submerged implant (*middle*) and a loaded two-piece, submerged implant (*right*). Note that one-piece implants, without a microgap, exhibit a rough/smooth (*r/s*) implant border at the bone crest level, while two-piece implants have a microgap (MG) at the level of the bone crest between the implant and the abutment. *Red arrows* indicate the level of the gingival margin; *yellow arrows* indicate the level of the first bone-to-implant contact. (Adapted from Cochran and Mahn,¹⁸ with permission.)

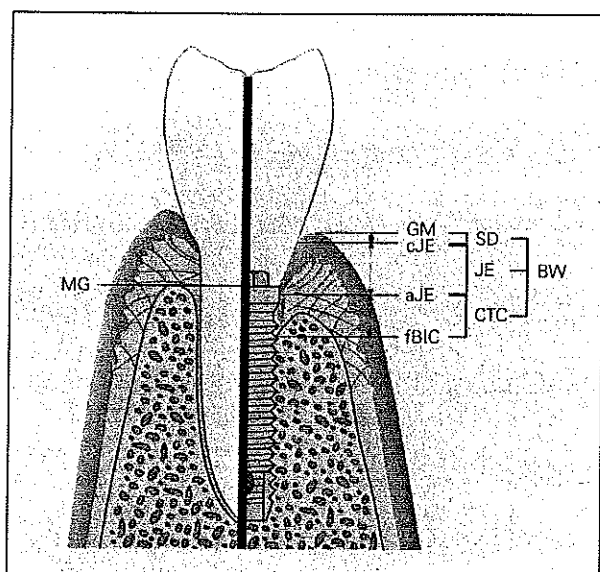


Fig 34-2a Schematic drawing (true to scale) comparing periodontal and peri-implant vertical soft tissue dimensions around a natural tooth¹⁹ and a two-piece, submerged implant,²⁰ respectively. MG = microgap; GM = gingival margin; cJE = most coronal cell of junctional epithelium; aJE = most apical cell of junctional epithelium; fBIC = first bone-to-implant contact; SD = sulcus depth (distance from GM to cJE); JE = junctional epithelium (distance from cJE to aJE); CTC = connective tissue contact (distance from aJE to fBIC); BW = biologic width (SD + JE + CTC).

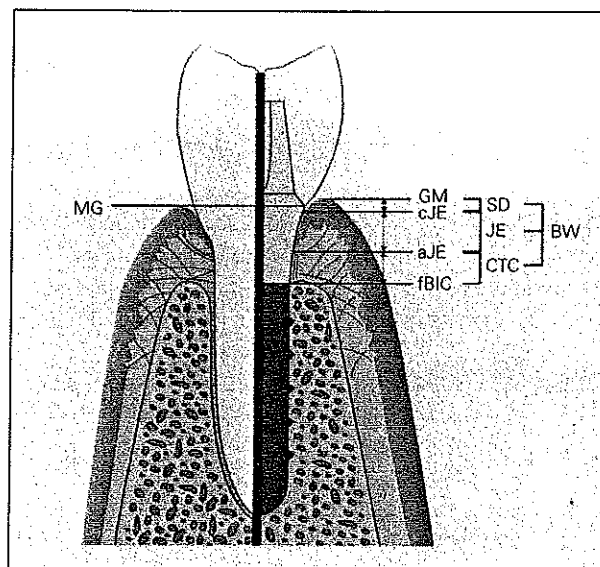


Fig 34-2b Schematic drawing (true to scale) comparing periodontal and peri-implant vertical soft tissue dimensions around a natural tooth¹⁹ and a one-piece, non-submerged implant,²¹ respectively. Note that both the gingival margin (GM) and the first bone-to-implant contact (fBIC) are located significantly more coronal ($P < 0.05^{20}$) as compared with those in Fig 34-2a.

Structural Biology: Natural Tooth Versus Endosseous Implant

In 1921, Gottlieb initially described the epithelial attachment around a natural tooth as epithelial tissue covering distinct areas of the enamel surface or the cementum, not as merely an attachment to the cements/enamel junction (see chapter 3).¹⁴ These findings were confirmed later,¹⁵ and the gingival crevice, or sulcus, was defined. Subsequently, Feneis¹⁶ showed that connective tissue consisted of three-dimensionally oriented fibers firmly connecting tooth structures to the surrounding gingiva. Thus, it became clear that both epithelial and connective tissue attachment contribute to a "protective structure" in an area where the natural tooth penetrates the gingival tissue of the body. Sicher confirmed these findings in 1959 and called this functional unit the *dentogingival junction*.¹⁷

Both natural teeth and endosseous implants represent a significant challenge for the human body as the only structures piercing the soft tissues of the body (Fig 34-1). However, it has been well documented that few bacteria are found beyond the sulcular area in either healthy periodontal or peri-implant tissues, which fulfill the function of creating a seal around teeth and implants. This "sealing apparatus" between a natural tooth or an endosseous implant and surrounding tissues comprises both hard and soft tissues—namely, hard connective tissue (alveolar bone), soft connective tissue, and junctional epithelium (Fig 34-2). In some cases of long-standing bacterial periodontal or peri-implant colonization of marginal soft tissues, however, soft and hard tissue breakdown can occur, resulting in significant attachment loss.²²⁻²⁷

The most coronal connection between tooth surfaces (enamel and cementum) and periodontal soft tissues is provided by the junctional epithelium.^{14,28} However, the substance mediating the attachment between the "cuff" of the junctional epithelium and the tooth surface was first described by Schroeder in 1969 as hemidesmosomes attached via the internal basal lamina to the tooth surface.²⁹ The connective tissue compartment around natural teeth has been shown to consist of intertwined, three-dimensionally and functionally oriented collagen fibers anchored in the cementum, thus firmly connecting tooth structures to the surrounding gingiva.¹⁶ Within the bony housing, natural teeth are anchored via connective tissue fibers inserting into the alveolar bone on one side and into the cementum of the tooth on the other side, forming the

periodontal ligament space. Such a functional unit allows movement of the natural tooth within the alveolar socket. In 1961, Gargiulo and coworkers demonstrated that the vertical dimension of the dentogingival junction—composed of sulcus depth, the junctional epithelium, and connective tissue attachment—was stable at about 3.0 mm; they subsequently called it the biologic width (see Fig 34-2). In addition, this constant unit was dependent on the location of the crest of the alveolar bone.¹⁹

Two major clinical procedures have been derived from these findings and are widely used today: surgical crown lengthening³⁰ and forced eruption.³¹ Both procedures are based on the understanding that changing the level of the alveolar bone will predictably move the complete dentogingival junction as a unit in the same direction (apically or coronally). These procedures have a great impact on the location of the gingival margin and the tip of the papilla, and therefore they provide an important tool to achieve stable and esthetic gingival harmony around a healthy natural crown or a tooth-borne restoration (see chapters 23 and 33).

In 1974, James and Kelln realized that a healthy epithelial attachment around endosseous implants made from a cobalt-chromium alloy successfully prevents an apical migration of bacteria along the implant surface.²⁴ This finding suggested that a functional seal might exist around implants similar to that which was found around the natural tooth. Following this report, this research group and others showed at the electron microscopic level that a hemidesmosomal attachment occurred on cobalt-chromium alloy implants^{32,33} and on titanium surfaces,^{34,35} as it does on natural teeth. In addition, Buser and coworkers demonstrated an intimate contact between the basal epithelial cell layer and a relatively smooth titanium surface at the light microscopic level.³⁶ Thus, it can be concluded that the epithelial attachment of a natural tooth and that of an endosseous implant share many similarities.

The connective tissue adjacent to implants has different anatomic structures compared with that adjacent to teeth in the direct vicinity (50 to 100 μ m) of a relatively smooth titanium surface. One difference is that the connective tissue fibers run parallel to the implant long axis.³⁶⁻³⁹ In addition, almost no neural or vascular structures can be found adjacent to the implant surface; therefore, this tissue compartment resembles a scarlike connective tissue and is different from the periodontal connective tissue attachment apparatus connecting the tooth root to the alveolar bone. Thus, although the epithelium around implants is similar to the epithelium around teeth, the morphology of the connective tissue surrounding teeth and implants is different.

Submerged Versus Nonsubmerged Implant Placement

In the 1960s, as noted above, a Swedish research team led by Brånemark described the concept of osseointegration: the potential of screw-shaped machined titanium endosseous implants to integrate with bone.¹⁰ This research group recommended a submerged approach when placing such endosseous implants, meaning that the screw-shaped implants were placed with their tops at the level of the alveolar bone crest during a first surgical procedure.^{40,41} After a submerged healing period under the oral epithelium and connective tissue (3 to 9 months depending on the quality of the bone), a second surgery was carried out, in which the top of the implant was exposed and a secondary implant component (the abutment) was connected to the implant body. This procedure created an implant emerging through the soft tissues, resulting in a two-component transgingival device. This two-piece implant approach results in an interface, or *microgap* (see Fig 34-1), between the implant and abutment within peri-implant soft or hard tissues. The consequences of the interface between the two implant components was originally not known. Subsequent research has indicated that the interface between these implant components has an influence on bacterial accumulation, recruitment of inflammatory cells, and soft and hard tissue dimensions around the implant. For example, some studies have demonstrated that the interface provides space for bacterial colonization.^{42,43}

Another approach to placing endosseous dental implants was developed in Switzerland at about the same time. This work, by Schroeder and coworkers,¹¹⁻¹³ was based on extensive research in the field of orthopedic surgery. These implants were either screw-shaped or cylindrical in shape, but rather than having a relatively smooth machined surface, they had a rough surface created by adding titanium by a process using a plasma spray (hence the term *titanium plasma sprayed*). Another major difference with this approach was that the implant extended above the bone level by about 3 mm, which meant that the implant passed through the epithelium and connective tissue. This so-called transgingival top part of the implant had a smooth machined titanium surface and was supracrestal, ie, above the bone crest, at the time of implant placement. This configuration was therefore a one-piece implant that had no interface or microgap and passed from inside the body to outside the body, similar to the natural tooth. More recently, another rough surface has been introduced on the endosseous portion of the implant. This titanium surface is sandblasted with a large grit

and acid attacked (SLA). This SLA surface has been shown to result in a greater amount of bone-to-implant contact and to have a firmer bonding to the bone as determined by higher removal torque values compared with some other implant surfaces, including machined and TPS surfaces.^{44,45} Such improvements in surface technology have resulted in earlier loading of the implants with the crown, a large benefit for the patient.⁴⁶

With this one-piece implant, only one surgical procedure is required for implant placement compared to two surgical procedures for the two-piece implant systems. At surgical placement of the one-piece implant, the rough/smooth border at the top portion of the implant is placed level with the bone crest. This results in the top of the implant being immediately exposed to the oral cavity and is called a *nonsubmerged* placement. As is the case with the submerged two-piece implants, the proof of bony integration of the implant (or functional ankylosis) was provided at the light microscopic level. Additionally and importantly, because nonsubmerged implants have only one piece, there is no space between implant components located at the bone level and thus, no potential for bacterial colonization and subsequent inflammatory response within peri-implant soft and hard tissues.

Other implant systems with various surfaces and designs are available, and most companies have a nonsubmerged, one-piece (also known as single-stage) implant design. The biologic consequences of the differences between one-piece and two-piece (nonsubmerged and submerged) implants is not known. Cochran and coworkers have begun a series of systematic experimental studies to evaluate the consequences of these two implant designs on the soft and hard (crestal bone) tissues.

Crestal Bone Loss Around Titanium Implants

One consequence of the difference between one-piece (nonsubmerged) and two-piece (submerged) implant designs is the effect on the level of the crestal bone around the implants. In 1981, Adell and coworkers described some crestal bone loss around two-stage implants that had been loaded for approximately 1 year,⁴⁰ with minimal crestal bone loss occurring the following years. The initial bone loss averaged 1.5 mm, resulting in a first bone-to-implant contact at approximately the level of the first or second thread of the machined implant (see Fig 34-2a), with a 0.56-mm interthread distance (pitch). Subsequently, such crestal bone changes were defined as one criterion of success when placing two-stage titanium implants.⁴⁷ In these studies, radiographic controls were first taken at the

time of crown placement (loading), because it was believed that diagnostic radiography might interfere with osseous healing around the implant.^{40,48,49} Thus, the protocol did not allow the detection of early crestal bone changes during the initial phases of healing.

In the early 1980s, no similar data existed for one-piece implants. In addition, no data were available to help researchers understand changes in the level of the crest of the bone. Subsequently, crestal bone loss for one-stage, nonsubmerged implants was found to be less than 1 mm in a 1-year prospective study.^{50,51} This study used a dual-surfaced, one-piece implant^{11-13,52,53} with the rough/smooth implant border placed at the bone crest level. In addition, data from an 8-year prospective human radiographic study showed that crestal bone levels, on average, were stable over the entire study period, demonstrating an overall annual crestal bone loss of 0.1 mm⁵⁴ 8 year

Based on the early studies and on clinical findings, several experimental studies have been carried out comparing the changes in crestal bone in one- versus two-piece implants placed with submerged and nonsubmerged surgical approaches.⁵⁵⁻⁵⁸ As time has passed, many clinicians have realized that submerging the dental implant (two-piece) was not required for successful osseointegration. This was due to the success of the one-piece, nonsubmerged implant and the desire to perform only one surgical procedure on the patient. Clinicians then began to surgically place the two-piece implants using a nonsubmerged technique, whereby they connected the abutment to the implant at the time of the so-called first-stage surgery. This essentially resulted in a two-piece implant (with a microgap or interface at the bone crest level) that was nonsubmerged. Alternatively, some clinicians began to place the one-piece implant more apically into the bone and cover (submerge) the implant under the soft tissues. All these possibilities made the nomenclature difficult. For this reason, the authors have chosen to separate the surgical technique from the implant configuration. Thus, *submerged* and *nonsubmerged* are only used to reflect the surgical technique utilized at the time of implant placement. Similarly, *one-piece* and *two-piece* are utilized to reflect only the implant configuration, ie, how many components are required to reach the oral cavity. Thus a one-piece implant reflects the original nonsubmerged or one-stage technique, and a two-piece implant reflects the original submerged or two-stage technique in which the implant stops at the bone crest and a secondary implant component, such as an abutment or crown, is then connected, resulting in an interface at the bone crest. Presently then, the one-piece implant can be placed in a nonsubmerged or a submerged surgical technique, and the two-piece implant can be submerged (still usually without an abutment) or the implant and abutment can be

connected and placed in a nonsubmerged surgical approach.

All of these implant configurations and surgical approaches have been examined in relation to crestal bone changes.⁵⁵⁻⁵⁸ It was found that in one-piece, nonsubmerged implants, crestal bone levels rapidly remodeled to the level of the rough/smooth implant border, originally being located at approximately the alveolar crest (Fig 34-3). In two-piece implant/abutment configurations, approximately 2 mm of crestal bone loss rapidly occurred (Fig 34-4). Importantly, this remodeling was dependent on the location of the microgap in relation to the crest of the bone at the time of implant placement. Furthermore, crestal bone loss around two-piece implant/abutment configurations was independent of whether implants had been placed using a submerged or nonsubmerged surgical technique. These changes occurred relatively rapidly (within 1 month) after implant placement (first-stage surgery) for unloaded one- and two-piece, nonsubmerged implants, whereas crestal bone loss around unloaded two-piece, submerged implants was identified within 1 month after abutment connection (second-stage surgery) when an interface (microgap) was created. Finally, the effect of the microgap was observed to be greater than the effect of the rough/smooth implant border.

Biologic Width Around Titanium Implants

Another difference between one-piece (nonsubmerged) and two-piece (submerged) implant designs is their effects on the linear dimensions (biologic width) of the epithelium and connective tissues around the implant. Initially, the vertical dimension of the soft tissues around dental implants was not well described, because the emphasis was on bone-to-implant contact. In 1991, Berglundh and collaborators³⁷ presented experimental data on peri-implant soft tissue integration around two-piece, submerged implants. Cochran and collaborators, however, were the first to discuss the biologic width dimensions around endosseous implants.^{20,21,59,60} In the case of one-piece, nonsubmerged implants, biologic width was found to be approximately 3.0 mm around both unloaded and loaded implants^{20,21,59,60} and therefore was very similar to the dimensions found around natural teeth.^{19,61} Hermann et al confirmed that these dimensions are not only physiologically formed but also stable over time.⁶⁰ Subsequently, the same research group found that significantly increased amounts of crestal bone loss around two-piece implants, also means that the gingival margin is significantly more apical (see Figs 34-6a and 34-6b) around the two-piece

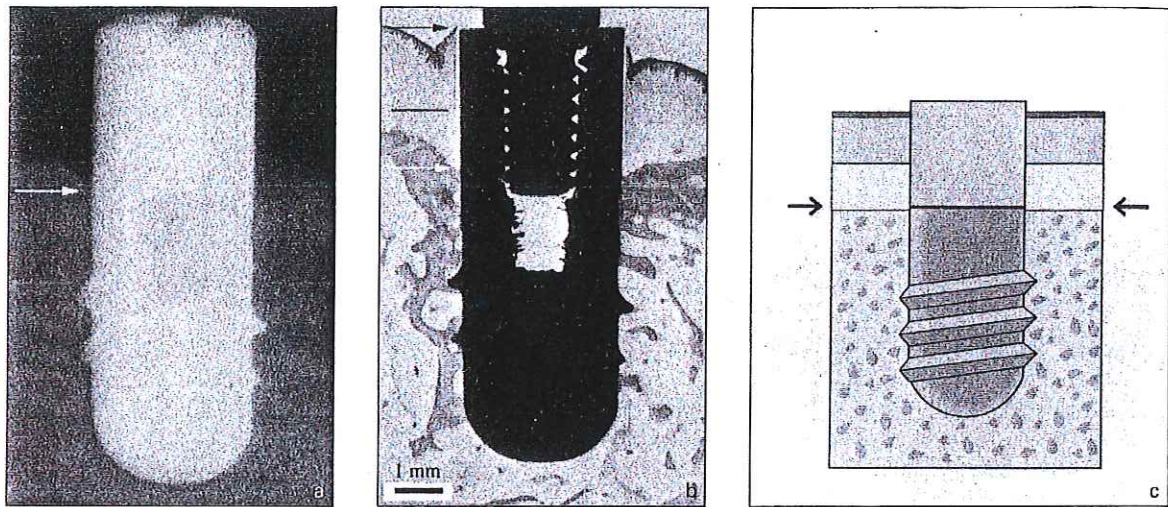


Fig 34-3a A standardized periapical radiograph of a one-piece, nonsubmerged implant after 6 months of unloaded healing and remodeling. The *arrow* indicates the level of the first bone-to-implant contact.

Fig 34-3b A mesiodistal histologic section of a one-piece, nonsubmerged implant. The *white arrow* indicates the level of the first bone-to-implant contact (fBIC), while the *black arrow* indicates the level of the gingival margin (GM). The vertical dimension between the GM and the fBIC is the biologic width. The *black bar* reveals the level of the most apical cell of the junctional epithelium (aJE). The area between the aJE and the fBIC represents the connective tissue contact compartment. Overall, minimal to no signs of peri-implant inflammation (degree of round cell infiltrate) are visible within peri-implant soft tissues. Apical to the fBIC, there is evidence of an intimate hard tissue integration. (Toluidine blue and basic fuchsin stain; original magnification $\times 2.5$).⁵⁵⁻⁵⁷ (Modified from Hermann et al,⁵⁶ with permission.)

Fig 34-3c Schematic drawing of soft and hard tissue dimensions around a one-piece, nonsubmerged implant placed according to standard surgical procedure after 6 months of unloaded healing and remodeling in relation to the rough/smooth implant border (*arrows*). The red compartment represents the vertical dimension of the sulcus depth, the pink compartment indicates the junctional epithelium, and the yellow compartment represents the connective tissue contact. The sum of these three dimensions equals the biologic width. *Arrows* indicate the level of the crest of the bone at the time of implant placement.

implants compared to one-piece implants. This finding has potentially important implications for final tissue contours in the field of esthetic implant dentistry.²⁰

Inflammation Around Titanium Implants

It has been shown that peri-implant inflammatory infiltration is limited around one-piece, nonsubmerged implants having no microgap. This is in contrast to two-piece implants, where moderate to severe degrees of peri-implant inflammation have been observed (compare Figs 34-3b and 34-4b).⁶² This inflammation occurred regardless of whether two-piece implants were initially submerged and the abutment attached at a second surgical appointment, or whether an abutment was placed at initial surgery in a two-piece, nonsubmerged implant approach. In addition, the severity of inflammation increased the more apical the

location of the microgap between implant and abutment. This inflammation was likely due to bacterial colonization of the interface, as has been described.^{42,43}

Tissue Implications for Dental Implants

Based on findings that a biologic width forms around non-submerged, one-piece endosseous implants similar to that around natural dentition,²¹ it appears that the oral tissue components are physiologically established with relative dimensions.⁶⁰ Results from these and other experimental studies suggest that for tissues around dental implants, (1) the level of bone,^{55,56} (2) the dimensions of the soft tissues,^{20,21,60} and (3) the degree of inflammation⁶² are all important for the final restoration. Pathological changes result in altered tissue relationships, similar to what occurs around teeth, compromising the final restorative outcome.

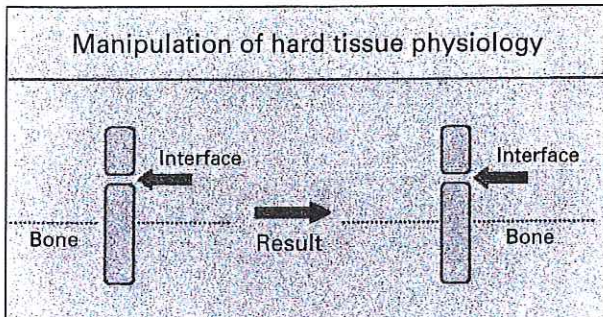


Fig 34-5a Schematic diagram demonstrating the lack of change in alveolar crestal bone when the top of the implant (one piece, nonsubmerged) is located significantly above the original bone crest.

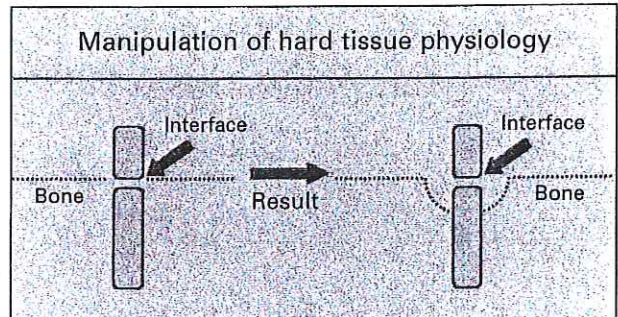


Fig 34-5b Schematic diagram demonstrating the apical movement of alveolar crestal bone when the top of the implant (two piece, submerged) is located at or below the original bone crest. Significant crestal bone loss occurs after abutment placement.

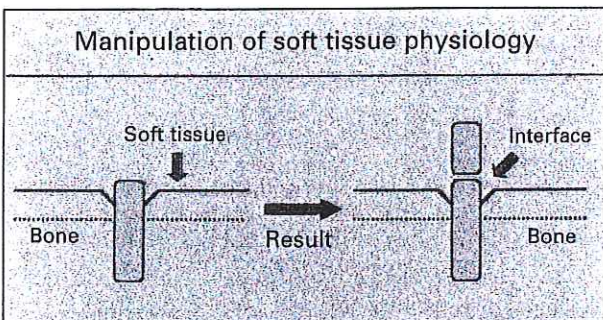


Fig 34-6a Schematic diagram demonstrating the soft tissue location around an implant (one piece, nonsubmerged) placed so the top of the implant is located significantly above the original bone crest. Minimal changes occur in the soft tissues.

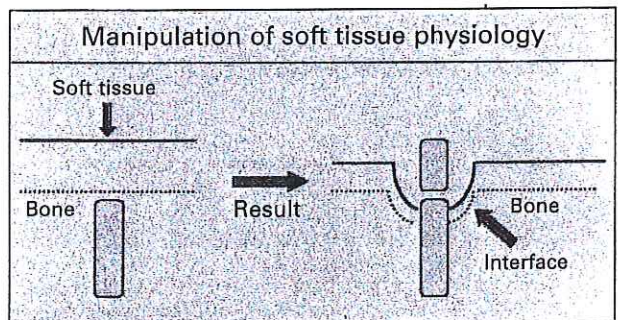


Fig 34-6b Schematic diagram demonstrating the soft tissue changes around an implant and abutment (two piece, submerged and nonsubmerged) when an implant is placed so the top of the implant is located at or below the original bone crest. The peri-implant soft tissues are significantly more apical than when the implant is placed above the soft tissues.

Summary

Replacing missing teeth and roots with artificial devices was first attempted almost 2,000 years ago. Two different surgical approaches and implant configurations have evolved, and both achieve high levels of clinical success. The major difference between these two approaches (the submerged and the nonsubmerged approaches) is the implant configuration, not the surgical technique. The presence of an interface between the implant and abutment, as well as the location of the interface in relation to the alveolar crest, is critical and has significant biologic implications. These implications include the location and di-

mensions of the soft and hard tissues and the inflammatory response in the adjacent peri-implant soft tissues. A histologic comparison of soft and hard tissue attachment between teeth and implants reveals similar epithelial attachment mechanisms and structures. However, differences are found between teeth and implants in regard to connective tissues and bony integration, because implants do not have cementum or periodontal ligament structures.

The biology associated with implants suggests that they be positioned within the bony housing based on a tissue-driven implant placement technique rather than a restoration-driven technique. With such placement, dental implants can achieve biologically based, physiologic (and therefore natural) tissue relationships.