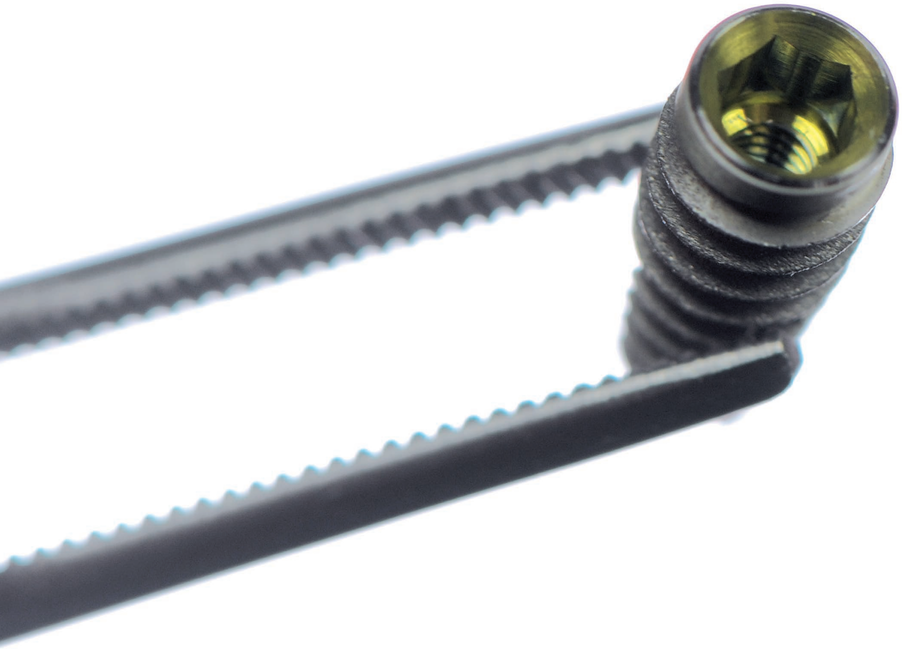

1

SURGICAL FACTORS FOR ESTABLISHING CRESTAL BONE STABILITY

Crestal Bone Loss

The importance of crestal bone stability around implants for the success and longevity of treatment cannot be overemphasized. The radiograph is the ultimate measurement of how well treatment has been performed. The radiographs in Fig 1-1 demonstrate an ideal treatment—the high quality of the treatment is clearly visible, and it must have been the result of good treatment decisions. It is well accepted by clinicians that stable bone with remodeling of less than 0.2 mm per year is one measure of successful long-term implant treatment, along with no bleeding on probing and a probing depth of no more than 5 to 7 mm.[1] On the other hand, a lack of stable bone may cause problems, leaving the clinician uncertain if the implant will remain stable for a longer period of time (Fig 1-2).

Crestal bone loss has accompanied implant treatment for so long that it has become the norm and has even been classified into different types. For example, *early crestal bone loss* is defined as bone resorption around the neck of the dental implant from placement to 1 year after loading. This definition is most likely based on the implant success criteria suggested by Albrektsson et al[2] in 1986, which state that 1.5 mm of bone loss within the

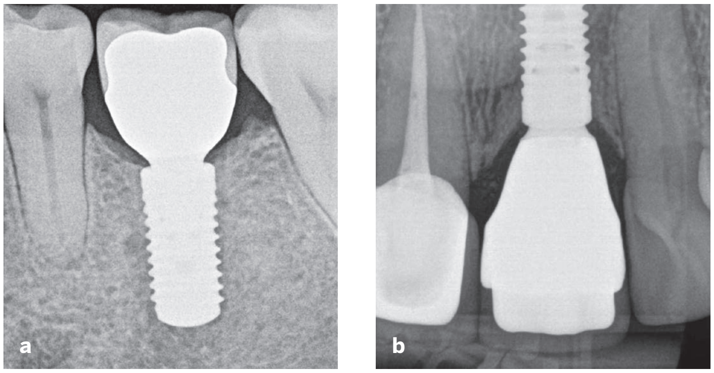

Fig 1-1 *(a and b)* Examples of crestal bone stability.

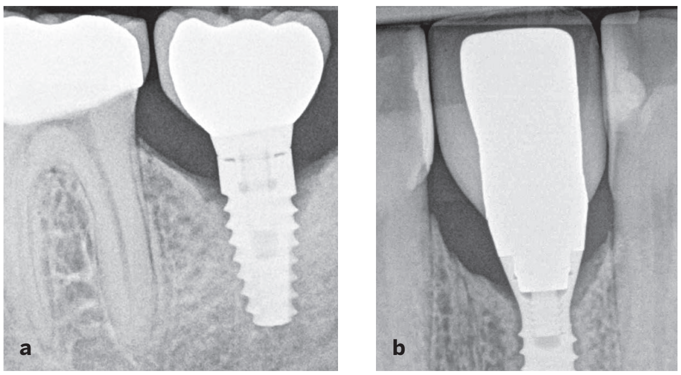

Fig 1-2 *(a and b)* Examples of crestal bone loss.

first year of loading can be considered a success if later bone loss does not exceed 0.2 mm annually. This concept was developed from observations of original Brånemark implants; however, implants used in contemporary dentistry have superior designs and surfaces that result in more success and bone stability. Therefore, some recent studies have questioned the accepted success criteria, stating that it is possible for implants to have lower amounts of bone loss after 1 year of function.[3,4] It was reported that implants with microthreads in the neck region and a conical implant-abutment interface may be expected to have only 0.33 to 0.56 mm of bone loss within 12 months of loading.

In the dental literature, early crestal bone loss is sometimes described as "saucer-shaped," "crater-like," or "ditch-like," as these descriptions indicate the typical pattern of bone loss seen on radiographs. This type of loss has historically been considered a natural and unavoidable result of biologic remodeling and a difference in bone stiffness. Occlusal trauma was suggested as a factor; however, if occlusal functioning causes constant overload at the implant neck area, it is unclear why bone loss ceases after some time rather than continuing until complete implant failure. To explain this phenomenon, it has been suggested that bone is less dense and more sensitive to stresses in the beginning of prosthetic loading, causing overloading and therefore resorption; however, within the first year of loading, bone matures and becomes denser, so the occlusal forces that initially cause crestal bone loss are not great enough to evoke further bone resorption. And yet, despite constant innovation and development of new effective techniques and materials, clinicians still face the problem of bone loss.

It is the author's belief that old standards in implant dentistry, where 1 mm of bone loss is thought to be normal, should no longer be considered valid. In fact, bone can have different reactions to the presence of implants, such as the following (Fig 1-3):

- Zero bone loss
- Stable remodeling
- Progressive bone loss

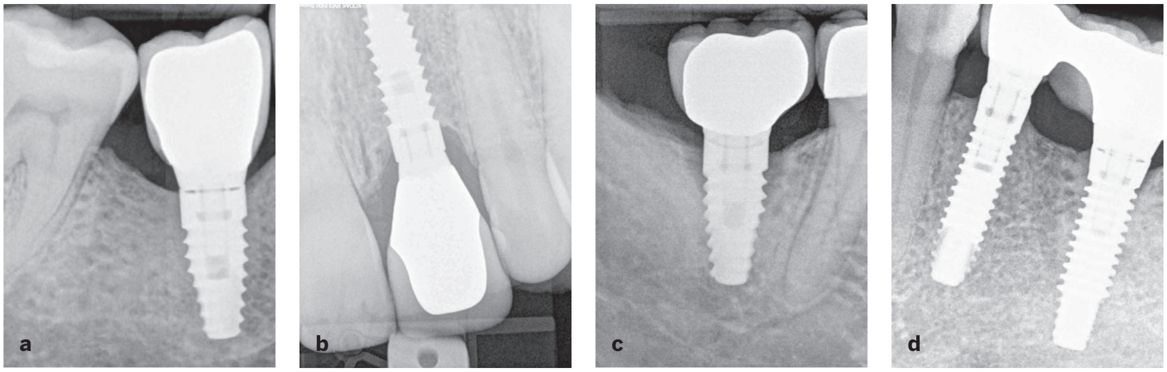

Fig 1-3 Different reactions of crestal bone level to dental implants. *(a)* Zero bone loss. *(b)* Stable remodeling. *(c)* Progressive bone loss. *(d)* Bone growth.

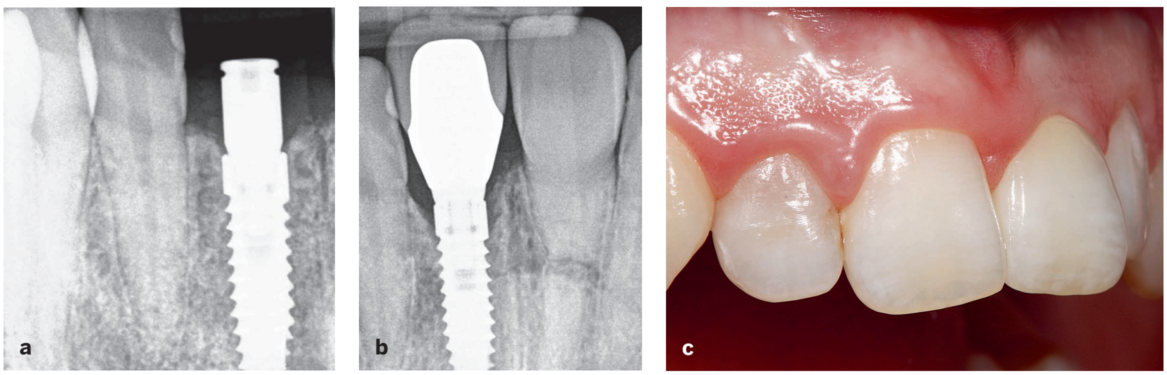

Fig 1-4 Example of stable crestal bone remodeling. *(a)* Bone level before development of biologic width. *(b)* Stable bone position exposing the implant neck without threat to implant survival. *(c)* In this case, there were no esthetic consequences of the stable bone remodeling.

- Bone demineralization and remineralization
- Corticalization
- Bone growth

Zero bone loss

Zero bone loss (a term introduced by the author), or crestal bone stability, is when the bone has not receded or been lost for any reason whatsoever. This term was chosen over an equivalent phrase like "no bone loss" as a challenge for clinicians to meet.

Stable remodeling

Stable remodeling refers to the presence of some bone loss that stops after some time and does not proceed further. It can be caused by biologic or mechanical factors. These implants are generally stable, and bone loss does not cause a threat to implant function (Fig 1-4). However, it would still be better to avoid this level if possible, especially considering that stable bone loss can be steady for some time, resulting in an anaerobic environment that is difficult to manage. If a patient suddenly has a periodontal infection or reduced oral hygiene capabilities, an implant with stable remodeling is more susceptible to further bone resorption than one with zero bone loss. In other words, bone around implants with stable remodeling is more prone to resorb unexpectedly in the future. This resorption cannot be restricted without intervention and therefore poses a threat to the overall outcome of treatment. When zero bone loss concepts are implemented, the chance to develop peri-implantitis is the lowest.

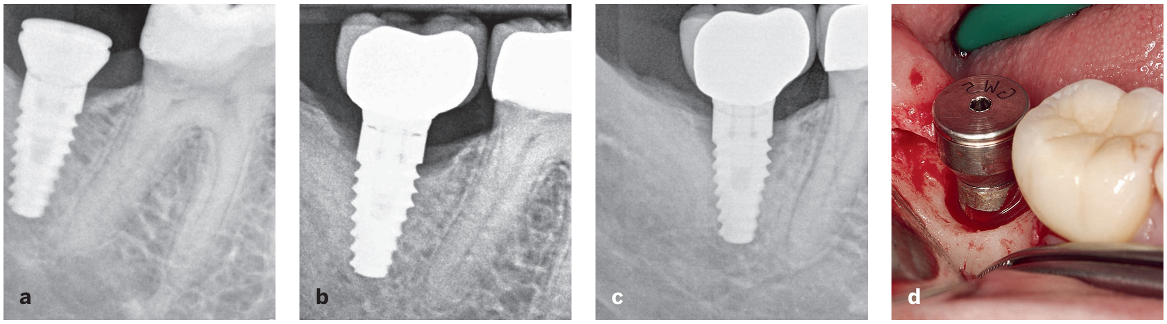

Fig 1-5 *(a)* Bone level after implant placement. *(b)* Bone position just after delivery of prosthesis. *(c)* At 1-year follow-up, half of the implant is no longer in the bone. *(d)* A crater has formed in the bone, so the implant must be removed.

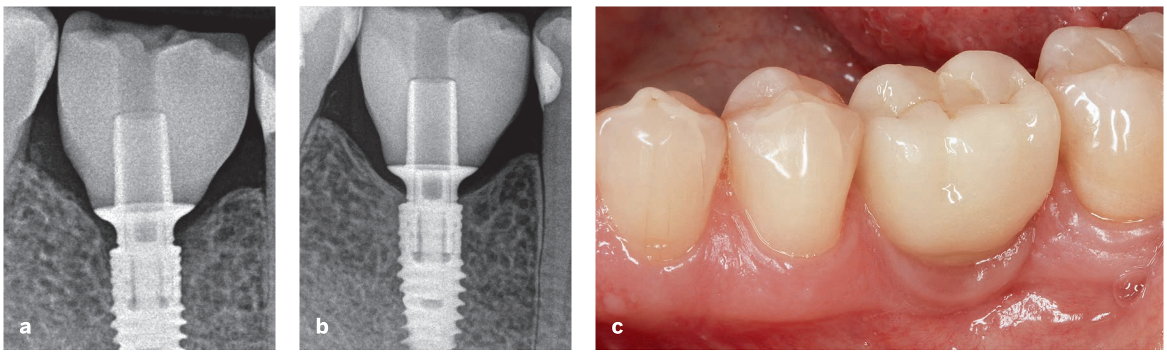

Fig 1-6 Remineralization of crestal bone around implants (V3, MIS). *(a)* Delivery day. *(b and c)* After 1 year.

Progressive bone loss

When stable bone remodeling becomes ongoing bone loss, it is referred to as *progressive bone loss*, a dangerous crestal bone condition that affects the functional and esthetic outcomes of treatment. It is impossible to predict whether remodeling will stop or continue, and if bone loss is not stopped, it can lead to extensive problems, including peri-implantitis or even loss of the implant (Fig 1-5).

Bone demineralization and remineralization

Crestal bone can behave differently at various levels of healing and development, and in some situations, bone remineralization or demineralization can occur (Fig 1-6). Bone can become more or less mineralized over time as minerals enter or leave the organic matrix of the bone. It is unknown exactly why this occurs. Therefore, crestal bone loss is not always true resorption of the bone tissue; sometimes it can be the demineralized organic matrix presenting as bone loss. The tool used to detect bone loss is a two-dimensional radiograph, on which demineralized bone appears as bone resorption. Cases of occlusal trauma around teeth with widening of the periodontal ligament are similar because they might look like bone loss at the crest. However, when the trauma is eliminated, periodontal ligament space is reduced to its normal dimensions.

This might be compared with remineralization of alveolar bone around the tooth, as demonstrated by Rosling et al,[5] who showed that bone regeneration occurs in infrabony pockets in patients who maintain an optimal standard of oral hygiene. When infection and irritants are removed, the organic bone matrix remineralizes. This may

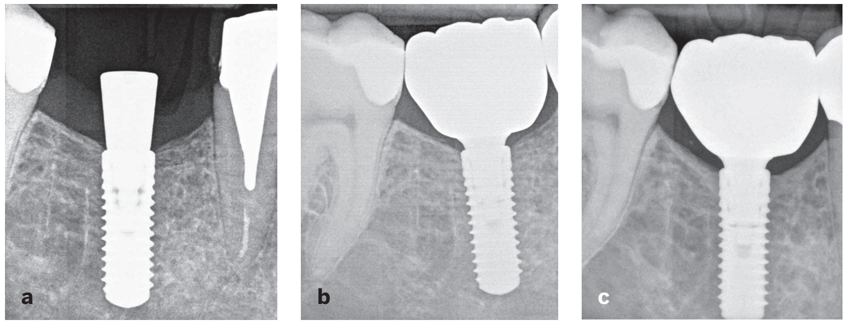

Fig 1-7 Corticalization process visible radiographically. *(a)* Normal cortical plate after implant placement. *(b)* The plate is getting thicker medially after loading. *(c)* Corticalization and thickening of the plate 3 years after loading.

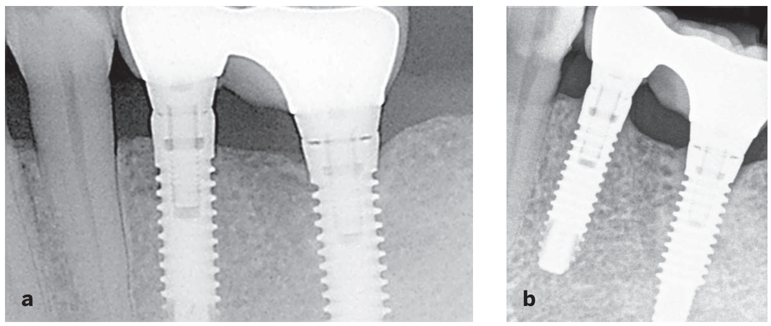

Fig 1-8 *(a and b)* Over time, bone has continued to grow around the crest of the implant. Although exactly what happens during this process is unknown, it is possible to observe vertical extension of the bone around the premolar implant mesiodistally and around the molar implant mesially.

happen around non-platform-switched implants as well. Clinical observations suggest that when the prosthetic phase of the treatment is over, and tissues are left undisturbed, a favorable environment for bone remineralization is created.[6]

Corticalization

Corticalization is a process that occurs when the cortical plate of alveolar bone becomes more dense, or mineralized. On the radiographs in Fig 1-7, it can be observed that the cortical plate becomes more intensely white and increases in height over time after loading. The reason for this is not clearly understood, but one proposed explanation is Frost's law, which states that mild overloading of the bone results in an increase in its mass. This process is similar to vertical bone growth, but it manifests as increasing and intensifying zones of mineralization cortically. It is also present when the cortex of the alveolar ridge is removed and an implant is placed into purely trabecular bone. This process does not pose any threat to implant integration; some say it is even beneficial because trabecular bone has more blood supply, and as the outer part of trabecular bone becomes mineralized, the desired corticalization results.

Bone growth

To date, there are no clinical studies demonstrating a predictable process for achieving bone growth after implant placement and restoration delivery. However, it has been hypothesized that the constant loading of the implant stimulates the growth of the bone, as the force is transmitted to the bone from the implant. The implant is mobile in the bone up to 10 µm, so micromovement stimulates the bone, possibly causing it to grow. Vertical growth could be explained by the ossification of the periosteum or connective tissue, which lays directly on the bone surface (Fig 1-8). The processes of bone remineralization and bone growth are encouraging because they indicate that some improvement can occur over time, even in cases of crestal bone loss.

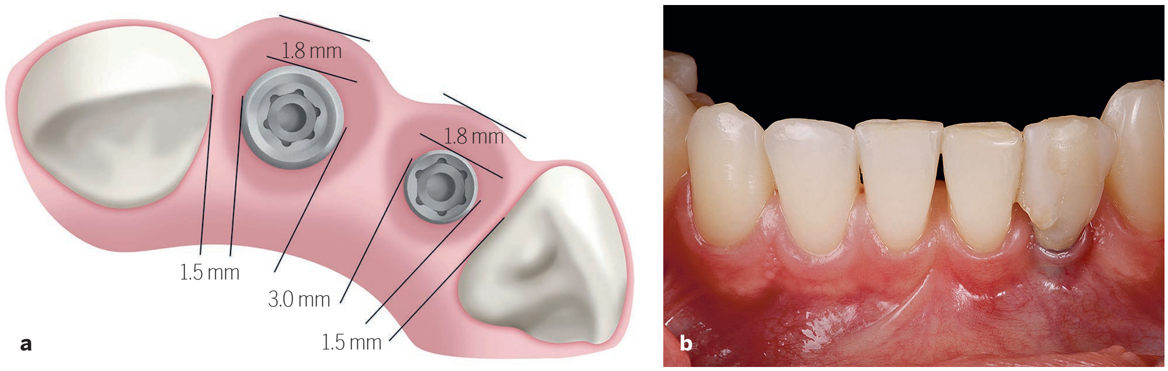

Fig 1-9 *(a)* Horizontal bone loss may have a vertical component if the bone width is thin, which results in vestibular tissue collapse. *(b)* Note the grayish appearance of the soft tissues around the restoration, indicating crestal bone loss and thinner tissues.

Importance of Stable Bone

Though some clinicians may find the importance of bone stability to be obvious, the reasoning for this is worth reviewing: Crestal bone stability is important because it guarantees implant function in the first place. Therefore, the goal should always be prevention of bone loss. As mentioned previously, peri-implant crestal bone stability reflects on the treatment skills and choices of the clinicians involved in both the placement and the restoration of the implants.

The literature reveals that early crestal bone loss usually does not threaten osseointegration of the implant; however, in some specific cases, such as those with thin peri-implant cortical bone, short implants, or high esthetic value, the presence or absence of crestal bone could significantly affect the survival and success of the implant.[7] Crestal bone plays a major role in primary (ie, short-term) and long-term implant stability. Primary stability is key to osseointegration, as it is well described and proved that primary stability ensures transition to secondary stability, which is characterized by biologic interlocking of the bone and the implant surface.[8] When the implant is restored and brought into function, presence of adequate crestal bone is also one of the major factors in securing long-term success. A number of finite element analysis studies have shown that when axial and lateral physiologic forces are applied to the implant, high peak stresses are generated in cortical bone.[9–12]

Although clinicians should strive for bone stability in all cases, there are two major situations that require bone levels to be as stable as possible: (1) implants in the esthetic zone and (2) the use of short implants.

Implants in the esthetic zone

The stability of the peri-implant mucosal level is largely dependent on the height of the underlying bone. The consequence of marginal peri-implant mucosal migration as a result of marginal bone loss has a major influence on the esthetics of the restoration, particularly in the anterior region. Peri-implant mucosal recession, which may follow crestal bone loss, results in crown margin exposure, soft tissue recession, and loss of the papilla.[13] This depends on the width of bone because as crestal bone resorbs horizontally, vertical height of bone may also be lost (Fig 1-9).

When there is vertical crestal bone resorption, the bone changes form a circular pattern around the implant. This results in facial bone changes during the process of bone remodeling. When there is greater bone width, a so-called crater forms around the implant, but the outer facial wall is unaffected; however, if the bone is thin, facial bone is lost as well.

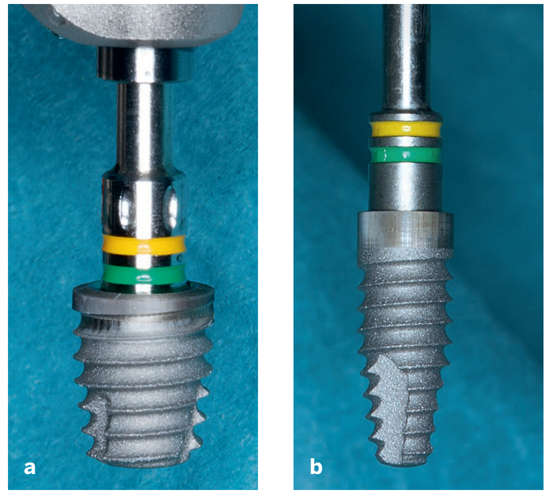

Fig 1-10 Crestal bone loss is more dangerous around short implants than longer ones because each millimeter lost is a greater percentage of BIC lost. When you compare the short implant *(a)* with the standard-length implant *(b)*, you can see the difference in potential BIC.

Crestal bone loss can influence the mesial and distal papillae positions, soft tissue level, and contour. These are all components of the pink esthetic score, which can be used to objectively evaluate the esthetic result of treatment. If this score is low, which can be expected in cases of bone loss, restorations cannot be deemed esthetic, and patient satisfaction may be lower.[14] Many authors reported mucosal retraction around implant-supported restorations within the first year of function, so it has been recommended to restore anterior implants with provisional crowns for at least 6 months.

All of this goes to show that bone stability was and still is key to a good esthetic outcome. However, it is important to note that correct three-dimensional (3D) implant position is as important as crestal bone stability for excellent esthetic outcomes.[15]

Use of short implants

The second situation in which crestal bone stability is especially important is when short implants are used. Short implants (ie, implants with a length of 4.0 to 7.5 mm) appear to provide favorable survival rates of 98.3% after 5 to 10 years and therefore can be predictably employed for simplification of implant therapy in situations of reduced alveolar height in posterior areas.[16] Short implants are designed with a wider diameter to compensate for the reduction in implant surface area.

Although short implants do not tend to lose more bone than standard-length implants, they tend to lose a higher percentage of bone-to-implant contact (BIC) compared with standard-length implants, which can affect long-term results[17] (Fig 1-10). For example, if a 4-mm implant loses 1.5 mm of bone, although it would fulfill the previously defined success criteria, the implant would be losing almost 50% of its integrated surface and probably be considered a failure. Therefore, while short implants are not more susceptible to crestal bone loss, bone loss appears to be more dangerous to short implants because bone resorption results in a greater loss of BIC.

Furthermore, even if the implant does not completely detach from the bone in the previous example, the crown-to-implant ratio becomes greater than 2:1, which can lead to increased prosthetic and biologic complications (Fig 1-11). Crown-to-implant ratio is not as important as crown-to-root ratio, but if it exceeds certain logical numbers, mechanical complications (eg, screw loosening) can be expected. Eventually, crestal bone loss can cause the short implant to fracture out of the bone. This is a classic example of how crestal bone loss may dramatically change crown-to-implant ratio, creating a greater risk of complications compared with a longer implant, where bone loss does not change the situation so drastically.

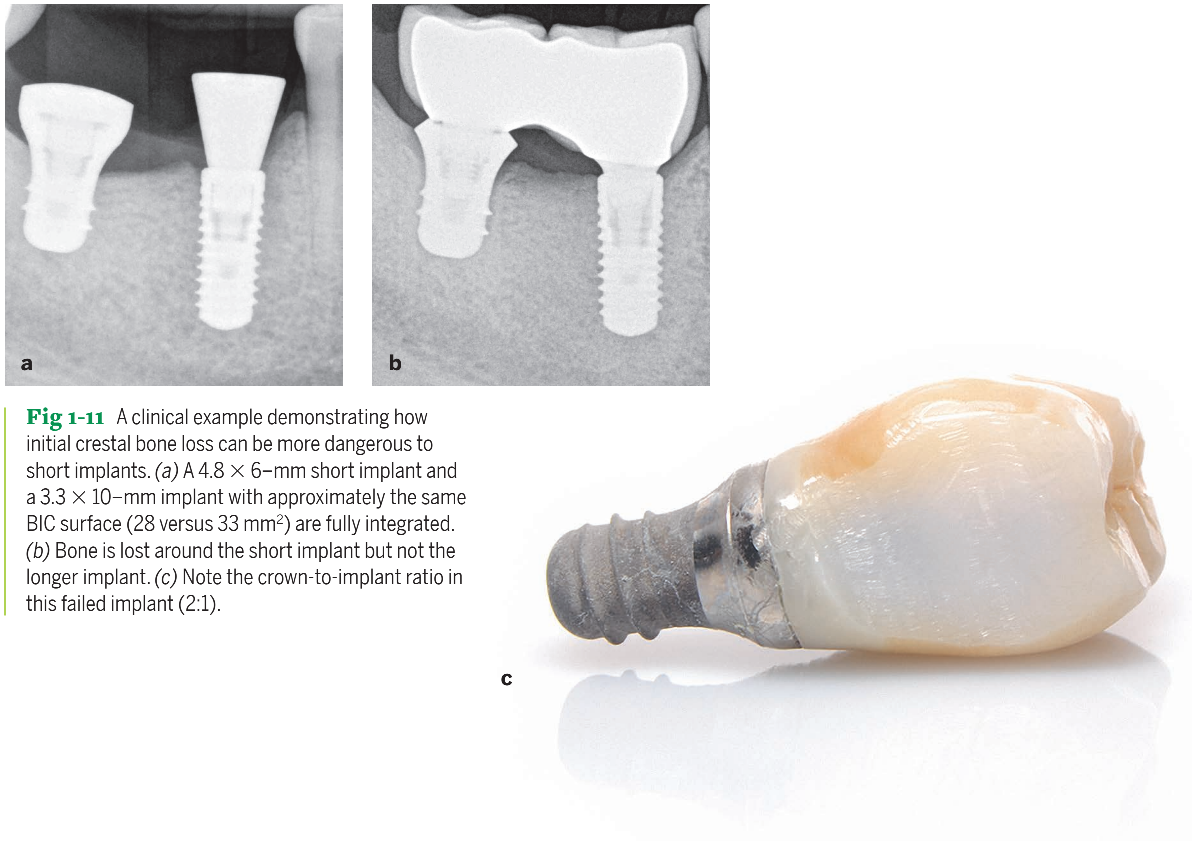

Fig 1-11 A clinical example demonstrating how initial crestal bone loss can be more dangerous to short implants. *(a)* A 4.8 × 6–mm short implant and a 3.3 × 10–mm implant with approximately the same BIC surface (28 versus 33 mm^2) are fully integrated. *(b)* Bone is lost around the short implant but not the longer implant. *(c)* Note the crown-to-implant ratio in this failed implant (2:1).

Factors Causing Crestal Bone Loss

From a scientific point of view, it is important to understand the pathogenic mechanisms of crestal bone loss. Many possible explanations for the phenomenon of early crestal bone loss have been proposed, including overload, microgap, polished implant neck, and others.[6,16,17] However, the stability of crestal bone remains a controversial issue. A discussion of all of the factors causing bone loss exceeds the scope of this book; instead, the focus is on exploring the factors that are most important to achieve the status of zero bone loss. All factors can be divided into the following categories:

- Operator-dependent factors
- Misdiagnosis or lack of diagnosis factors
- Zero bone loss factors

Operator-dependent factors

Operator factors or skills are important because if clinicians fail to perform procedures correctly (eg, bad implant position, surgical trauma, exposure of the implant, poor interimplant distance), bone loss will result (Box 1-1 and Fig 1-12). Even in an ideal clinical situation, mishandling of the processes can cause unfavorable outcomes. Fortunately, operator-dependent bone loss is usually reduced with time as the experience of the operator increases.

This group of factors includes the operator's proficiency in using the chosen implant system; for example, bone compression usually results when an implant system is used for the first time. Bone compression during implant placement is still considered one of the major factors for early bone loss. The idea is that during seating of the implant, if the bone is very stiff (type 1) and heat is

Box 1-1 **Operator-dependent factors that can affect bone stability or loss**

- Implant angulation
- Thin bone
- Augmentation complications
- Surgical trauma
- Interimplant distance
- Loading protocol
- Torque
- Trauma
- Overloading
- Poor implant-tooth distance
- Inadequate drilling
- Suturing
- Immobile flaps
- Buccal position

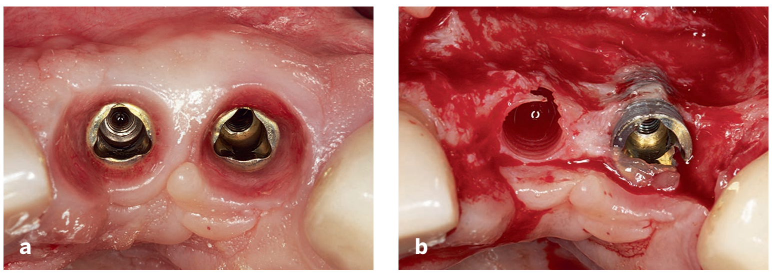

Fig 1-12 Poor 3D position of the implant. *(a)* The overly buccal position of the implants is masked by soft tissues. *(b)* The implant is exposed buccally.

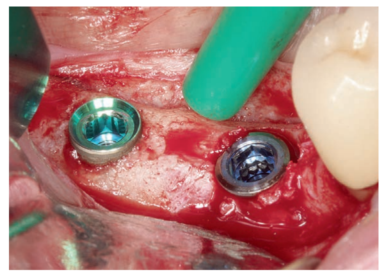

Fig 1-13 Surgical bone compression in the mesial implant may cause bone loss. The shape of the implant neck is flaring and therefore highly compressive.

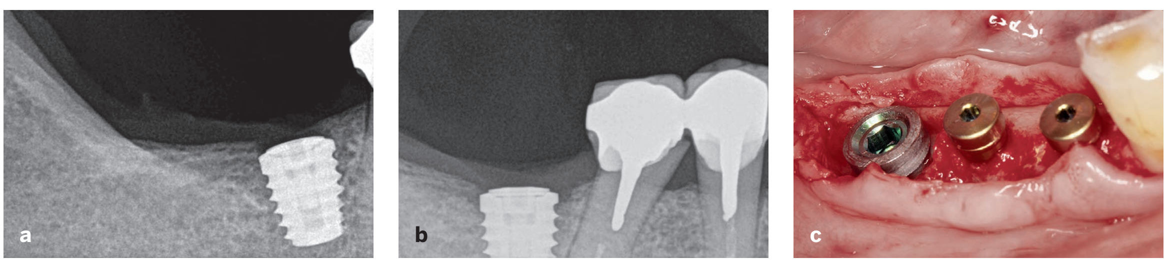

Fig 1-14 A classic example of compression-related bone loss. *(a)* The implant is placed in the mandible with cover screw in place. *(b)* After 2 months of healing, before the implant uncovering, crestal bone loss is already present. *(c)* There is a great amount of bone loss by the second stage of surgery.

generated, substantial bone loss will result. This bone loss needs to be distinguished from other types of bone resorption because it is present before the healing abutment is connected. For example, if the implant is placed with too much torque, resulting in bone compression, bone will resorb after implant placement even though the implant is covered with soft tissues and not exposed (Figs 1-13 and 1-14).

Misdiagnosis factors

Another group of factors influencing crestal bone stability are misdiagnosis factors. If patients have certain conditions that are not resolved or addressed, the end result will be bone resorption around implants. The skills of the doctor can be very good, but poor outcomes will still result from the unresolved patient condition. This group of

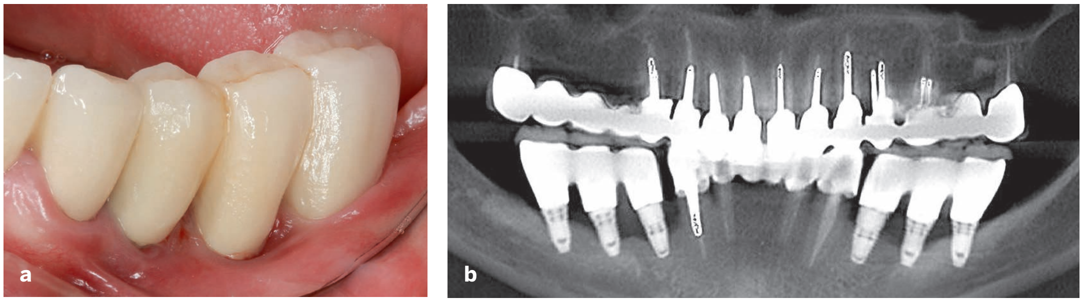

Fig 1-15 *(a)* Lack of attached gingiva around implants causes peri-implant tissue mobility. *(b)* This leads to bone loss.

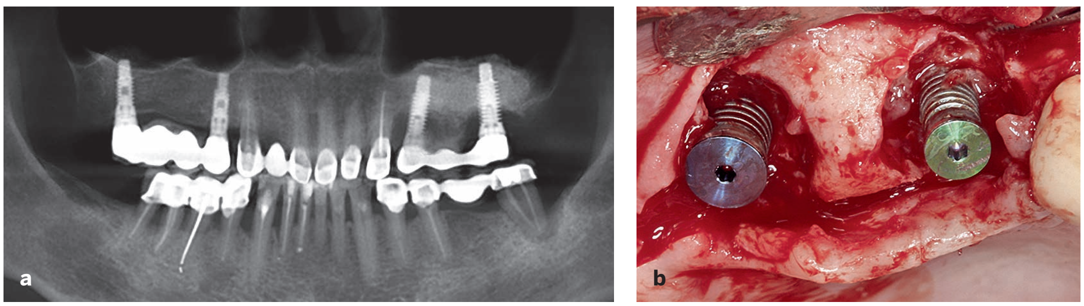

Fig 1-16 *(a and b)* Untreated periodontitis predisposes the sites to extensive crestal bone loss regardless of other factors related to bone remodeling.

factors includes the periodontal status of the patient, insufficient bone width, and lack of attached soft tissues (Fig 1-15). For example, periodontitis requires attention before any implant therapy commences. If implants are placed in a patient with untreated periodontitis, there will be early or delayed crestal bone loss due to infection (Fig 1-16).

Zero bone loss factors

This third group of factors comes into play during ideal clinical situations. These are the factors that cause bone loss that may not be clear to the clinician. For example, there may be an ideal clinical situation—sufficient bone height and width, 2 mm or more of attached tissues, and implant placement in the correct 3D position—but crestal bone loss still occurs (Fig 1-17). It is not a good situation to be in when the first follow-up appointment demonstrates a degree of failure. The clinician may explain to the patient that bone often adapts and resorption will stop, but this is not always what happens. There have been demonstrated cases where initial bone remodeling continued and caused the implant to fail. A preferred situation would obviously be a follow-up appointment demonstrating uncompromised bone stability, in which there is not cause for concern on the part of the clinician or the patient. Clearly, the desired clinical situation is one similar to that shown in Fig 1-18. As in the previous example, the initial conditions are perfect for developing bone stability: bone width greater than 7 mm, leaving at least 1.5 mm of bone beyond the implant buccolingually; adequate attached tissues; an implant with platform switching and a conical connection; and a screw-retained restoration. This time, the bone stability is great! Why is this?

Two major groups of factors responsible for crestal bone loss stand out in this particular case and in general: implant design factors and biologic factors. Implant design factors are (1) implant-

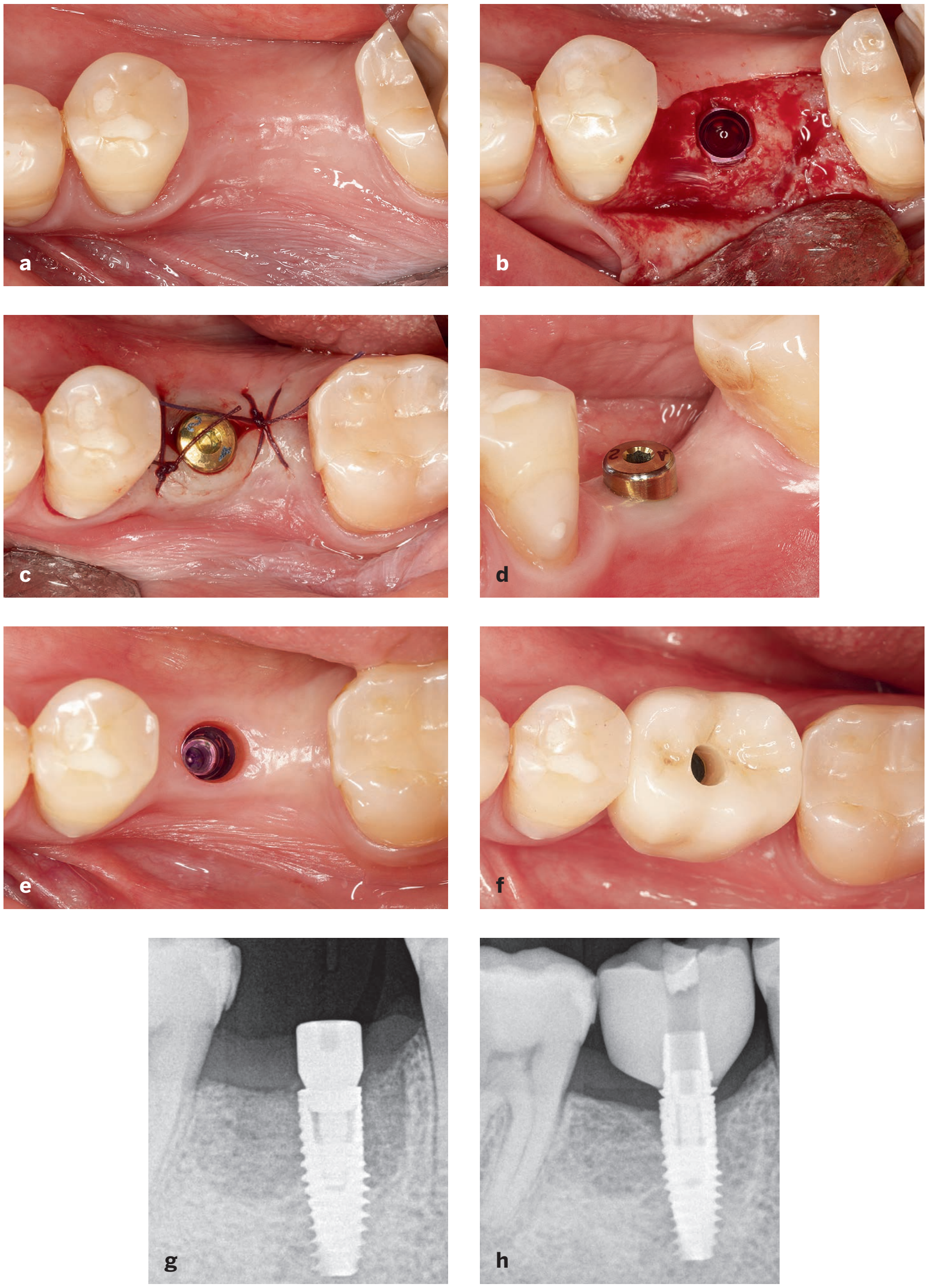

Fig 1-17 *(a to h)* This case demonstrated an ideal initial clinical situation: wide bone, sufficient attached tissues, correct apicocoronal position of the implant, and a screw-retained restoration. However, the radiograph taken on delivery of the prosthesis (part *h*) shows crestal bone loss already occurring. How could this have been avoided?

abutment connection with microgap and (2) polished implant neck. The biologic factors are (1) vertical soft tissue thickness and (2) attached tissues. These factors are the topics of subsequent chapters in this first section of the book.

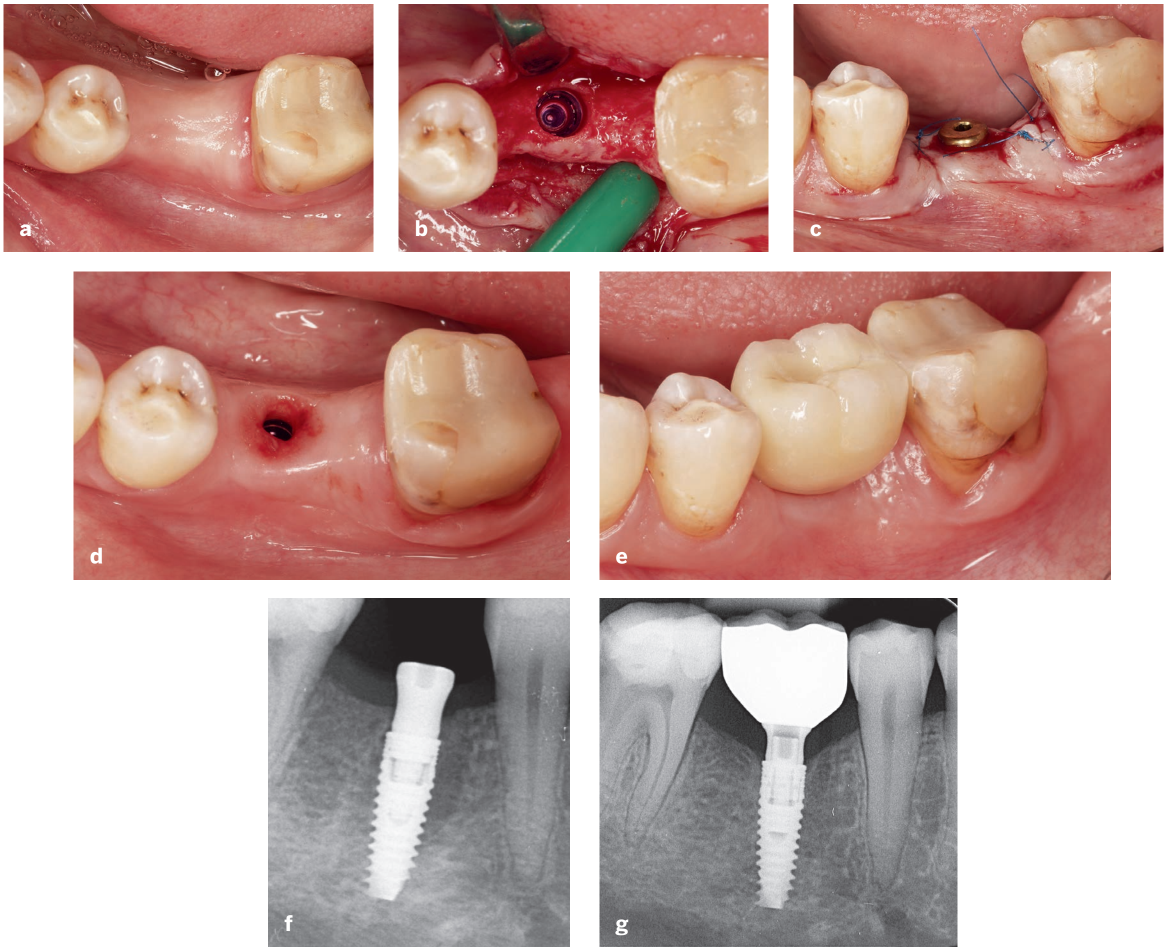

Fig 1-18 *(a)* Initial clinical situation. *(b)* Osteotomy with the implant in place. *(c)* Single-stage surgery with healing abutment in place. *(d)* Perfect healing before prosthetic treatment. *(e)* Definitive zirconia-based screw-retained crown. *(f)* Radiograph after implant placement. *(g)* Radiograph after restoration showing no bone loss.

Conclusion

The most important message of this book can be best described using a metaphor. Imagine a basket of apples. Each apple represents a separate factor that influences crestal bone stability. The purpose of research is to take one apple out of the basket and study it alone, eliminating other confounding factors. Clinical studies must be designed so that the factor in question, the single apple, can be studied as objectively as possible. The difficult part is that after research is complete the apple must be returned to the basket, meaning that in clinical reality all factors operate simultaneously. For example, perhaps a study proved that implants with platform switching work better at maintaining crestal bone stability than implants with a matching connection. That does not mean that every implant with platform switching will perform better than every implant without platform switching. It is not absolute dogma because other factors are present as well. For example, if there is no attached immobile gingiva, bone will likely still resorb even if platform switching is used.

Zero bone loss concepts involve balancing all of these factors, which requires understanding each individual factor and how it correlates with the others. The biggest strength of this multifactorial understanding is that clinicians will be able to achieve success and understand why there were unexplained failures experienced in the past. The understanding will allow the clinician to avoid repeating the same mistakes again. Everybody makes mistakes, but the true error is knowingly doing the same thing again and not correcting it.

Take-Home Messages

Crestal bone loss is a multifactorial issue with no single most important factor.

Important implant design factors include the presence or absence of a polished implant neck and the implant-abutment connection.

Biologic factors include vertical soft tissue thickness and attached gingiva.

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2

2

IMPLANT DESIGN FACTORS

When people ask which implant type works the best, it is always difficult to answer. However, it is quite clear that how the implant is made affects how it performs, like the construction of a car influences how it drives. There are many implant design factors that can influence the performance of the implant. For example, implant thread design can increase or decrease primary stability of the implant, the implant alloy can increase or decrease the possibility of implant osseointegration, and the shape and length of the abutment connection can make the implant-abutment junction less or more prosthetically friendly. This chapter specifically examines those factors that have a direct correlation with the stability of crestal bone after the implant has integrated.

The research has identified two major implant design factors that are important in the development of zero bone loss concepts: (1) presence or absence of a polished implant neck and (2) the implant-abutment connection or microgap. These design factors have been selected as most important for implant survival and crestal bone stability through a combination of clinical research and everyday practice. Every two-piece implant has these features; therefore, they are relevant for every clinical case. This is important because understanding how these factors influence bone loss or bone stability makes an impact on implant choice.

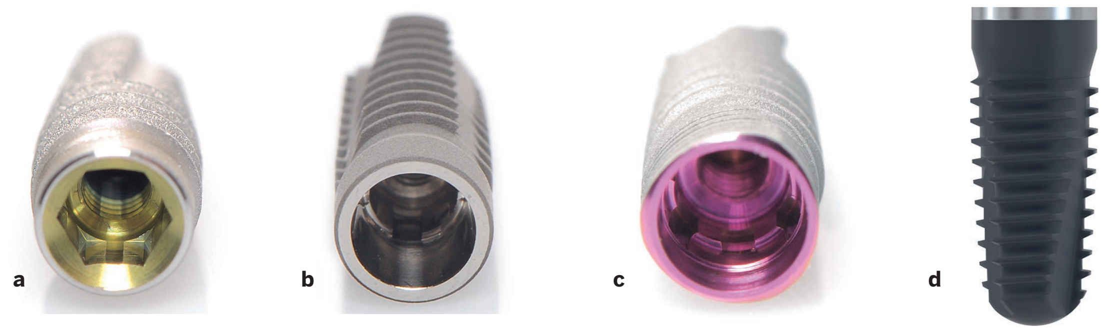


Fig 2-1 Different implant designs with different sizes of polished collars and types of implant-abutment connections. *(a)* Internal 45-degree connection (BioHorizons). *(b)* Conical connection with horizontal polished portion (Conelog). *(c)* Implant with a 12-degree conical connection (MIS). *(d)* Implant with a polished neck (Camlog).

Familiarity with Implant System

Crestal bone stability requires the clinician to truly know and understand the type of implant being used. Half the cases that result in bone loss would not have had this outcome if the implant had been placed correctly in the bone. For this to be possible, the clinician must know the system well. For example, if the system uses platform switching, what is the difference in diameter between the abutment and the implant platform? This should be at least 0.4 mm, according to a study by Canullo et al.[1] If it is any less, then bacterial infiltration is not shifted away from the bone, meaning that the implant actually works like a standard implant despite being branded and sold as having platform switching. There certainly are implants on the market that have this discrepancy. As another example, is there a rule for how to place a bone-level implant without platform switching? The phrase *bone-level* dictates that it should be placed crestally, but then the implant microgap will be at bone level, which means bacteria can reside in the implant, which is not ideal.

So the depth of every implant strictly depends on its design factors combined with the level of knowledge of the clinician who places it. Differences in design begin with the implant neck and the implant-abutment connection (Fig 2-1). The next questions to ask are the following: Do these implant designs differ in effectiveness? What will be their influence on crestal bone stability immediately and over time?

Polished Collar

The polished implant neck is a definite factor in the etiology of early crestal bone loss. Historically, the implant neck was manufactured with a polished surface to reduce plaque accumulation if the implant became exposed to the oral environment as a consequence of alveolar bone loss. However, clinical trials studying bone levels around implants with polished collars have shown the tendency for resorption of hard tissue in contact with machined surfaces.[2] Hämmerle et al[3] reported that ITI Dental Implant System implants, which have a polished surface, did not maintain bone when the implant was restored, despite countersinking. Shin et al[4] found similar results, concluding that implants with rough necks experienced less bone loss compared with those with polished necks (Fig 2-2).

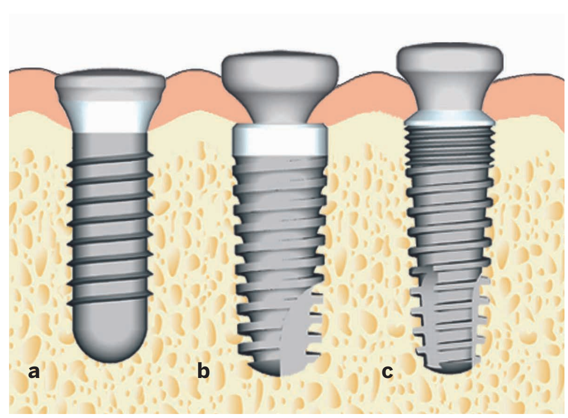
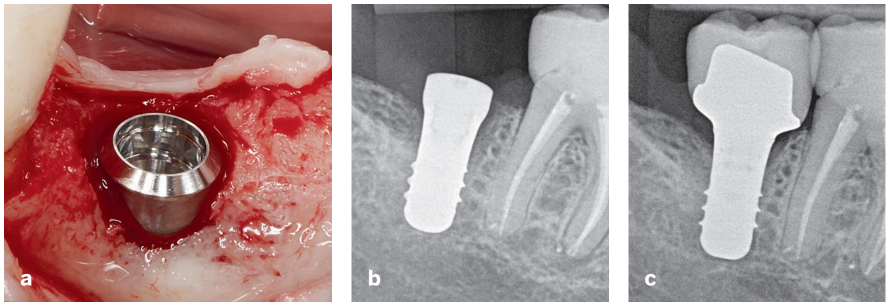


Fig 2-2 A study compared three implant neck types: *(a)* rough-surfaced, *(b)* polished, and *(c)* microthreaded. The polished neck was associated with the most bone loss, and the microthreaded neck with the least bone loss. (Reprinted with permission from Shin et al.[4])

Fig 2-3 *(a)* The polished collar of a tissue-level implant placed too deep in the bone results in bone loss *(b)* after 2 months of healing and *(c)* at the 1-year follow-up.



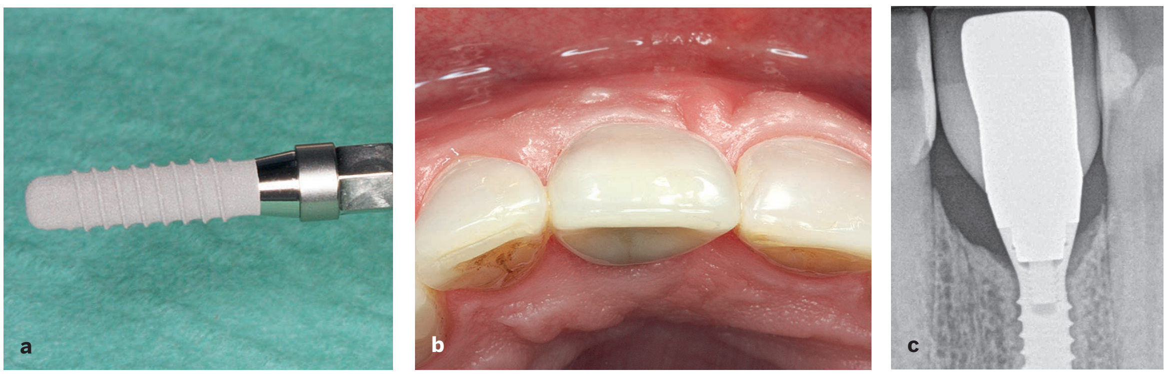
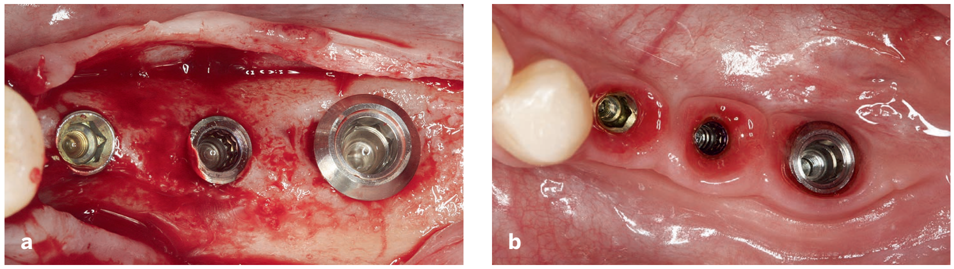


Fig 2-4 *(a)* Implant with a polished neck. *(b and c)* Bone loss from the smooth surface can clearly be seen. In this case, there was no esthetic problem because of crestal bone loss or exposure of the polished collar; however, this implant is meant to be placed in nonesthetic zones.

Hänggi et al[5] reported that implant designs with a shorter smooth coronal collar may help to reduce the risk of an exposed metal implant margin in areas of esthetic concern because these implants had no additional bone loss. These conclusions were confirmed in a recent study by Peñarrocha-Diago et al,[6] in which bone loss after 6 and 12 months proved statistically significantly different between two groups, with comparatively greater loss associated with implants with machined-surface necks, without microthreads, and with an external connection versus implants with a treated surface, microthreads, an internal connection, and platform switching.

The pathogenesis of bone loss related to a polished surface is described in a review article by Wiskott and Belser.[7] It was hypothesized that machined implant surfaces cannot effectively distribute the occlusal stress between bone and the smooth titanium surface; instead, *stress shielding* is created, which results in bone loss. It was observed that bone grows over submerged implants, as can be noted during stage-two surgery, but after prosthetic loading, the bone resorbs to the first thread of the implant.[8,9] Thus bone loss from a polished collar can be described as nonfunctional bone resorption because the resorption occurs without distribution of stress to the bone. However, one can then ask how stress was distributed in the original Brånemark implants, which were all polished. If polished titanium cannot deliver occlusal stress to the bone and stimulate it to remain in place, then why did these implants osseointegrate? The answer is that although the implants were polished (machined, to be precise), the portion of the implant that resided in bone featured threads that were able to distribute the stress to the bone.

Further proof of bone resorption associated with polished surfaces was provided by Jung et al,[10] who demonstrated extensive bone loss around implants with 3-mm-long polished necks. In addition, studies of single-piece implants, which bypass the effect of a microgap, found that bone level was established at the smooth-rough surface border regardless of the depth of implant positioning.[10,11] Thus, it can be concluded that a polished implant neck is a valid etiologic factor in the pathogenesis of crestal bone loss (Figs 2-3 and 2-4). This does



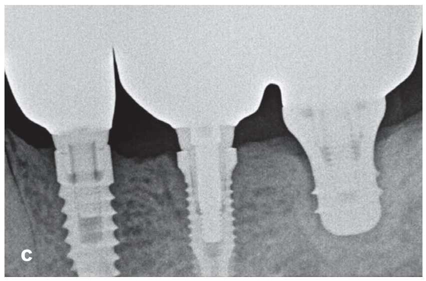


Fig 2-5 Different reactions of bone to implants with different designs. *(a)* A tissue-level implant with a polished neck is placed too deep in the bone *(left)*, an implant with platform switching is placed at the bone level *(center)*, and a bone-level implant with a matching connection is placed supracrestally *(right)*. *(b)* Peri-implant soft tissues appear very healthy. *(c)* Because the polished part of the tissue-level implant was placed incorrectly *(right)*, this led to extreme bone loss and eventually implant failure. The other two implants show stable bone—they do not have a polished portion of the surface.

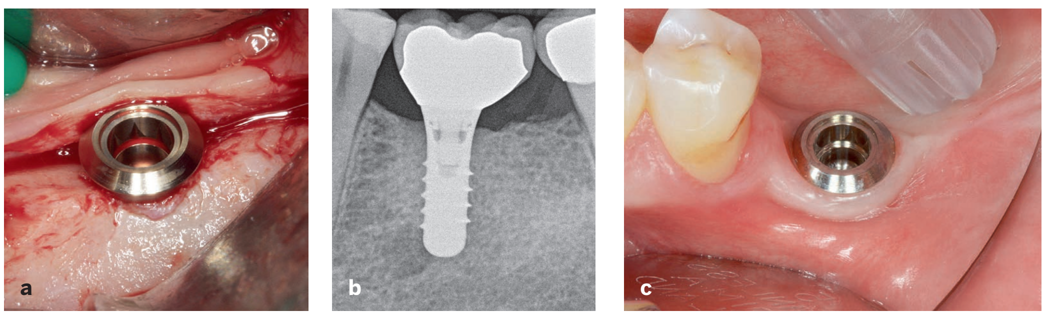


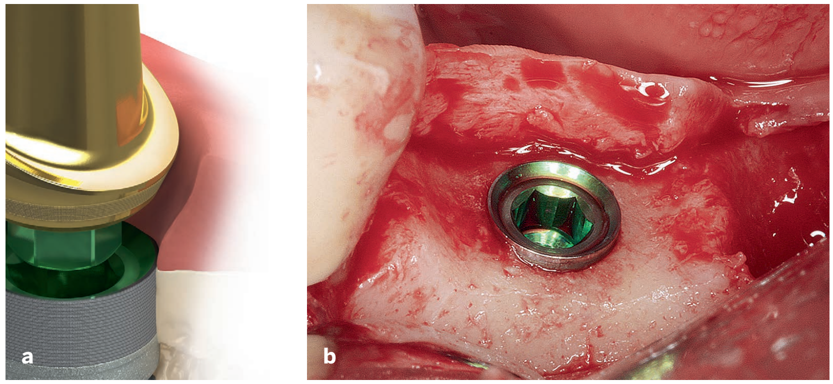
Fig 2-6 *(a)* This tissue-level implant is placed correctly, with the polished neck positioned supracrestally. *(b and c)* This positioning technique frequently results in crestal bone stability and healthy peri-implant tissue.

Fig 2-7 Some implants (eg, T6, NucleOSS) have a polished internal connection or are polished at the horizontal plane. This polished area is shielded from the bone and therefore poses no threat to bone stability.

not necessarily mean that the implant will be lost because of bone resorption around a polished neck, but this resorption is still worth avoiding whenever possible. Furthermore, it was reported that tissue-level implants, which usually have polished areas ranging from 1.8 to 2.8 mm, had only 1.5% early implant failures prior to loading and 2.0% late implant loss in a 9-year follow-up.[12] Therefore, it is recommended that the polished implant neck be positioned at the level of the bone, because if it is placed deeper, bone will eventually resorb to the smooth-rough surface border, regardless of the depth of implant placement (Figs 2-5 to 2-7).

To summarize, the first lesson in establishing zero bone loss concepts is to not place implants with a polished collar below bone level, because the bone in the region of the collar will be lost.

Fig 2-8 *(a)* The microgap—the connection between implant and abutment—is one of the most important implant design features. *(b)* The relationship between the microgap and the bone level is very important. In this example, it is supracrestal.



Microgap

Although not all implants have a polished neck, all two-piece implants have a *microgap*, or a junction where the implant meets the abutment. This is a critical part of implant design that makes a difference in bone stability. There are those who prefer the use of single-piece implants, which bypass the effect of the microgap. In theory, this single-piece implant should have no crestal bone loss related to the effects of the implant-abutment connection. However, single-piece implants do not show lower levels of bone loss, and their design harbors a critical flaw in that only cemented restorations can be placed on them. Furthermore, all single-piece implants have an undercut, which precludes the removal of excess cement after cementation. This issue is discussed in detail in chapter 12.

The microgap has been associated with crestal bone loss, and all modern implants have a micro-gap, because the two-piece design allows flexibility during restorative treatment, providing the prosthetic freedom to restore the implant however the restorative dentist requires. Also, using two-piece implants allows for the correction of surgical mistakes, such as the position or angulation of the implant. Therefore, implant-abutment connection and the subsequent microgap are necessary features for contemporary implants.

This factor in crestal bone stability is probably the most discussed throughout the implant literature. There are numerous animal studies and clinical papers that analyze the effect of this microgap on the bone, proving great scientific and clinical interest in the subject matter. What is the relationship between the implant-abutment connection and crestal bone stability? To answer this question, the microgap must be viewed from two points of view: as a source of bacterial contamination and as a source of micromovement (Fig 2-8).

Bacterial contamination

How do bacteria infiltrate an implant, considering that an implant is produced sterile? Two-piece implants inevitably have internal contamination, and there are several opportunities for this contamination to occur: (*1*) during implant placement; (*2*) during the prosthetic phase; and (*3*) during loosening of the abutment after some time of function.

It has been documented that implants harbor contamination that forms during implant placement, as small amounts of saliva or blood get inside the implant and later cannot be removed by regular cleaning procedures. Cleaning the inside of the implant or use of chlorhexidine gel might be recommended after implant placement, when the cover screw is connected in submerged surgery, or when the healing abutment is connected during uncovering or nonsubmerged implant placement (Fig 2-9).

Microgap size

A important factor is the size of the microgap. Laboratory experiments have demonstrated that the size of microgap may differ between implant systems and prosthetic abutments. Kano et al[13] reported that horizontal misfit of the implant-

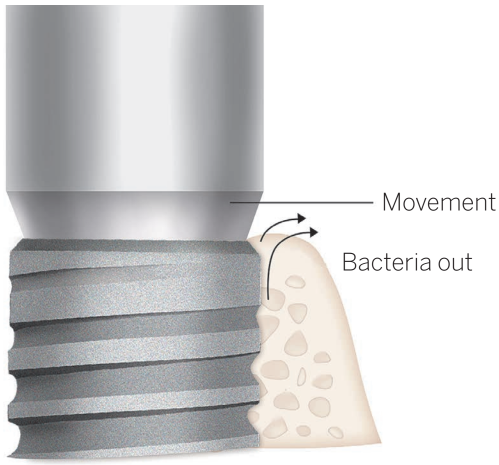


Fig 2-9 If the implant-abutment connection (ie, microgap) is contaminated and located at bone level, bone loss occurs as bacteria inside the implant infiltrate the bone. The factors responsible for this include the size of the microgap and the stability of the connection.

abutment interface can range from 75 to 103 µm, depending on the type of abutment, while vertical misfit was recorded to be smaller, from 0 to 11 µm. Dibart et al[14] found a microgap of only 0.5 µm in locking taper implant systems, which were regarded as having a "bacteria-free" connection because microorganisms are larger in diameter than 0.5 µm. The importance of the size of the microgap has been proven by in vitro studies that have shown microbiologic contamination of the entire implant system due to leakage at the implant-abutment interface.[15,16] The microgap thus can be considered a "gate" through which bacteria can potentially escape.

Stability

Stability of the implant-abutment connection is another factor that can affect bacterial contamination because movement allows bacteria to escape and damage the bone; however, the movement itself also might be detrimental to the crestal bone. There are different connection types, including external, flat, and internal connections, but a conical connection seems to provide the best stability.[17] Using a conical connection is always recommended, but the connection stability is even more important when the implant is placed subcrestally (Figs 2-10 and 2-11).

Hermann et al performed a study related to implant-abutment connection and the etiology of early marginal bone loss.[18] In this animal experiment, 60 implants were placed in five hounds. The two-piece implants had microgap sizes of approximately 10, 50, and 100 µm, and one group of implants was laser-welded together, preventing any movement between the implant body and the abutment. The other group of tested implants had the same microgap sizes, but the abutments were only connected by prosthetic screws. The results showed that all implants in the nonwelded group had significantly increased amounts of crestal bone loss compared with implants with laser-welded abutments. Therefore, it was concluded that micromovements between the implant and the prosthetic abutment can be more important for bone loss than the size of the microgap.

In a subsequent experiment, King et al[19] confirmed the conclusions of the prior study, stating that the stability of the implant-abutment connection is a very important feature in prevention of marginal bone loss. The affect of instability of the implant-abutment interface on bone loss is thought to be twofold. First, it has been proposed that when occlusal forces are applied to an implant with an unstable abutment connection, a pumping effect maintains a constant flow of bacteria from inside the implant through the microgap to the peri-implant tissues.[20] Such action contributes to formation of inflammatory cell infiltrate, which constitutes the basis for microgap-related bone loss. A second theory states that abutment micromovement itself can cause resorption of crestal bone situated in close proximity.

Thus, bacteria inside the implant and micromovements create microbial leakage at the implant-abutment interface. This leakage is responsible for inflammatory cell infiltrate formation in soft tissues adjacent to the microgap, as described in numerous histologic animal studies.[11,21,22] Ericsson et al[21] termed it *abutment-infiltrated connective tissue* and suggested that its presence shows the reaction of the host to bacterial contamination by inner abutment components.

The formation of infiltrate may be a host mechanism to protect the peri-implant bone. In a series of animal experiments, Hermann et al[23,24] confirmed that placement of the implant-

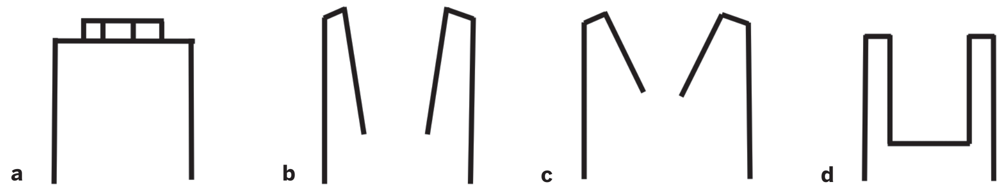


Fig 2-10 Different types of implant-abutment connection offer different levels of stability. It is generally accepted that a conical connection provides the best stability; however, the level of implant placement depth is important as well. *(a)* External connection. *(b)* Conical connection from 5 to 6 degrees. *(c)* Conical connection from 8 to 20 degrees. *(d)* Internal connection.

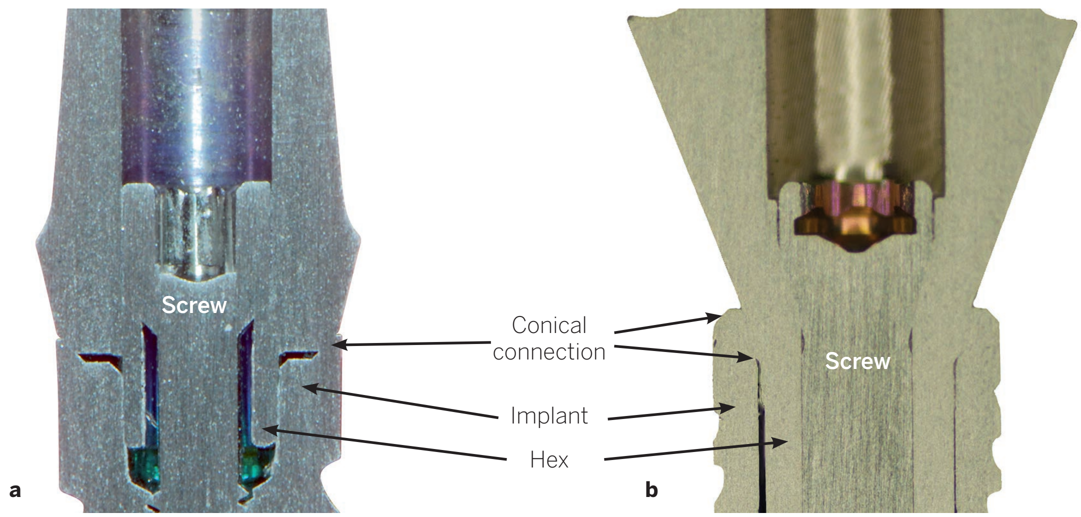
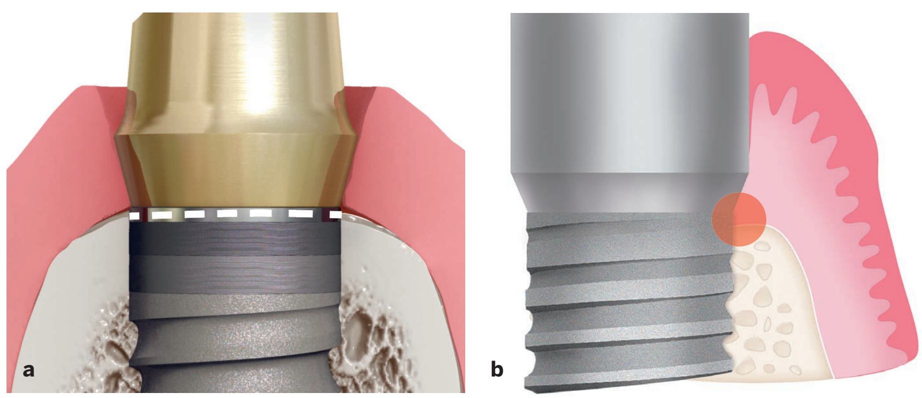


Fig 2-11 Cross-section of different implant-abutment connections. *(a)* Implant with internal and smaller conical connection of 45 degrees (BioHorizons). *(b)* Implant with conical connection of 15 degrees (Straumann Bone Level implant). Note that the conical connection is the only place where the abutment is contacting the implant and stress is distributed. (Courtesy of Dr Uğur Ergin, Istanbul, Turkey.)

Fig 2-12 Incorrect position of an implant without platform switching. *(a)* The microgap is placed even with the bone. *(b)* In this situation, micromovements and bacterial contamination will create inflammatory infiltrate, which will lead to bone loss.



abutment interface at the level of bone or more apically may result in significant marginal bone reduction (Fig 2-12). The pathogenesis of microgap-related bone loss was described by Broggini et al.[25] The pattern of peri-implant neutrophil accumulation suggests that a chemotactic stimulus originating at or near the microgap of two-piece implants initiates and sustains recruitment of inflammatory cells. These cells promote osteoclast formation, which may result in alveolar bone loss. This hypothesis was confirmed in a later experiment that showed the capacity of

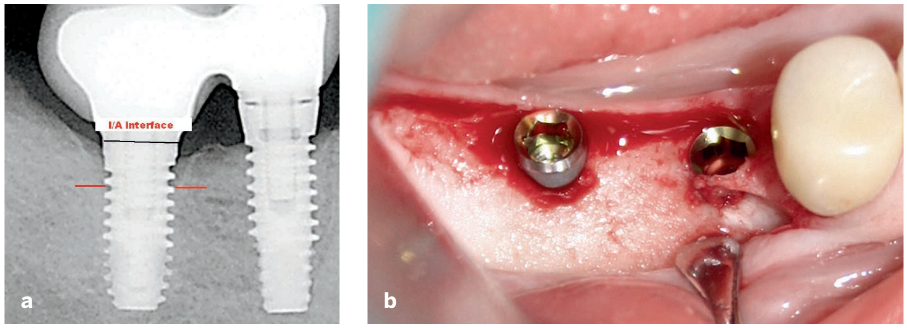


Fig 2-13 *(a)* Crestal bone loss around control *(left)* and test *(right)* implants. *(b)* Position of test implant *(left)* and control *(right)*. The control implant was placed at the bone level, meaning that the microgap was located at the bone crest. After a 1-year follow-up, 1.68 mm of bone loss was registered around implants placed at the bone level, indicating that the microgap is an important factor in crestal bone stability. (Reprinted with permission from Linkevičius et al.[28])

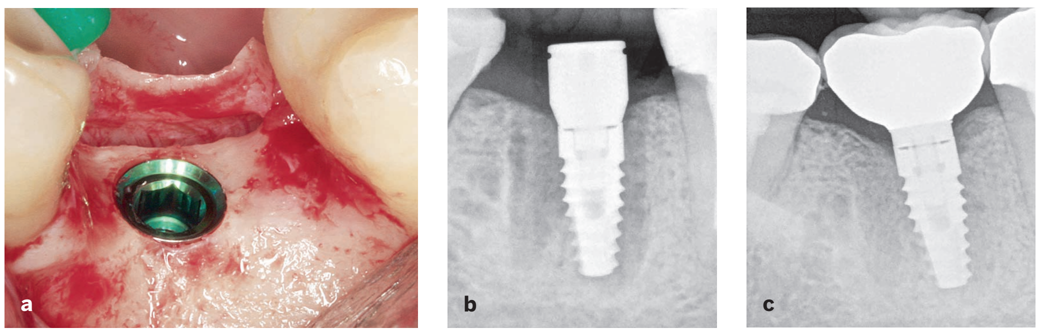


Fig 2-14 *(a to c)* A microgap between the implant and the abutment causes bone resorption because it is placed too deep in the bone. Bacteria are in direct contact with the bone, and there are micromovements at the micrograp that also cause bone loss.

more apically placed implants to accumulate more neutrophils and more inflammation and thereby cause more bone loss.[26] Generally, it was concluded that bone may recede up to 2 mm to maintain an appropriate distance from the source of infection.

Location of microgap

Piattelli et al reported no bone resorption if the microgap was located 1.0 to 2.0 mm above the alveolar crest and a loss of 2.1 mm if the microgap was at the level of the alveolar crest.[27] However, all the previously mentioned studies are animal experiments, which do not have a very high position in the hierarchy of evidence (see the Introduction). Clinical studies have confirmed that implants with a microgap that do not have a stable implant-abutment connection will lose crestal bone if they are placed at bone level. Linkevičius et al[28] performed a controlled clinical study in which two implants with matching implant-abutment connections were placed adjacent to each other. The test implant was placed about 2 mm supracrestally, and a control implant was positioned at the crestal level. The placement of implants at bone level is a standard protocol that is recommended by a majority of manufacturers and studies. Prosthetic procedures with porcelain-fused-to-metal fixed restorations were initiated following a healing period of 2 months in the mandible and 4 months in the maxilla. Results showed that after 1 year of function, the control implants (ie, with the microgap placed at the bone level) experienced 1.68 mm of bone loss (Fig 2-13). If an implant is placed too deep in the bone, bone loss will occur after restoration even before 1 year of follow-up (Fig 2-14).

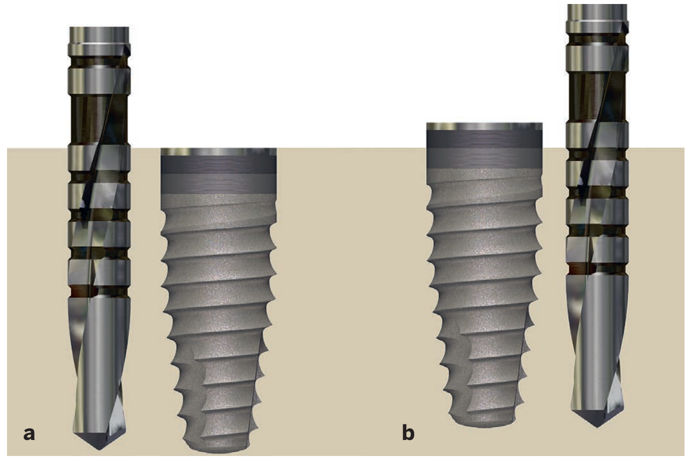


Fig 2-15 *(a)* When the implant without platform switching is placed at or below the bone crest, the microgap is located in the bone, allowing for micro-movement and bacterial contamination. *(b)* Placing the implant supracrestally reduces the damaging effect of these factors.

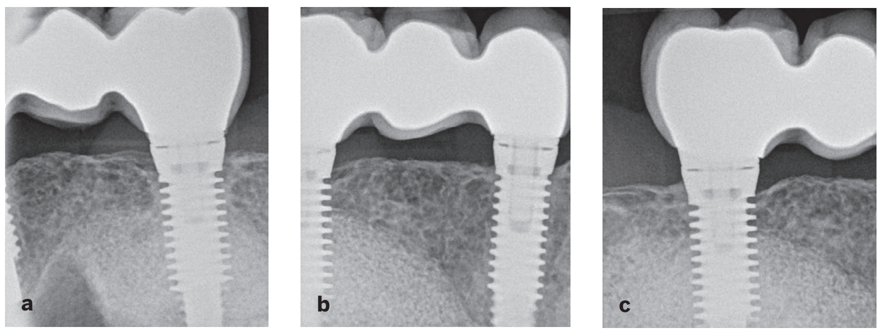


Fig 2-16 *(a to c)* The bone reacts well to supracrestal implant placement even after 10 years in function. This position can be recommended only for implants without platform switching.

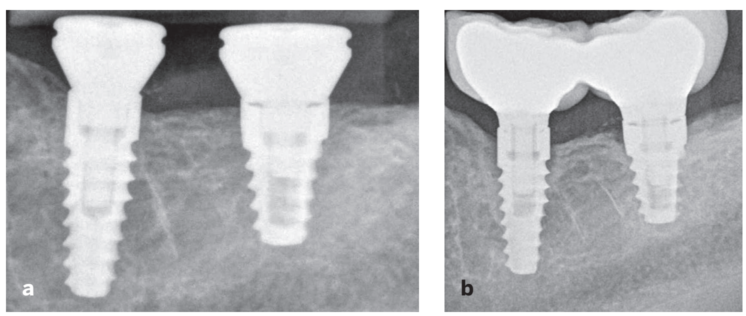


Fig 2-17 In some cases, supracrestally positioned implants with a matching implant-abutment connection have bone loss. The microgap was isolated, but bone loss can be observed between placement *(a)* and the 1-year follow-up *(b)*.

Supracrestal placement with matching connection

Two solutions are recommended to avoid microgap-related crestal bone loss, depending on the implant design. First, it may be reasonable to position an implant with a matching, non-conical connection supracrestally[29,30] (Fig 2-15). Todescan et al[31] suggested supracrestal positioning of implants with matching connection to distance the microgap away from the bone and reduce crestal bone resorption. Linkevičius et al[28] showed that supracrestally positioned implants in a thick tissue biotype had 0.68 mm of bone loss, which is lower than the same implants placed crestally. In fact, clinical experience shows stable bone around supracrestally positioned implants after 10 years of follow-up (Fig 2-16).

However, 0.68 mm is still a substantial amount of bone resorption. One possible reason that bone loss still occurs is that supracrestal placement of the implant may cause exposure of the rough surface of the implant, which is meant to be placed in bone. A rough surface poses a significant risk of plaque infiltration and adherence, which may cause inflammation of the tissues and lead to bone loss (Fig 2-17). For this reason, it must be stressed

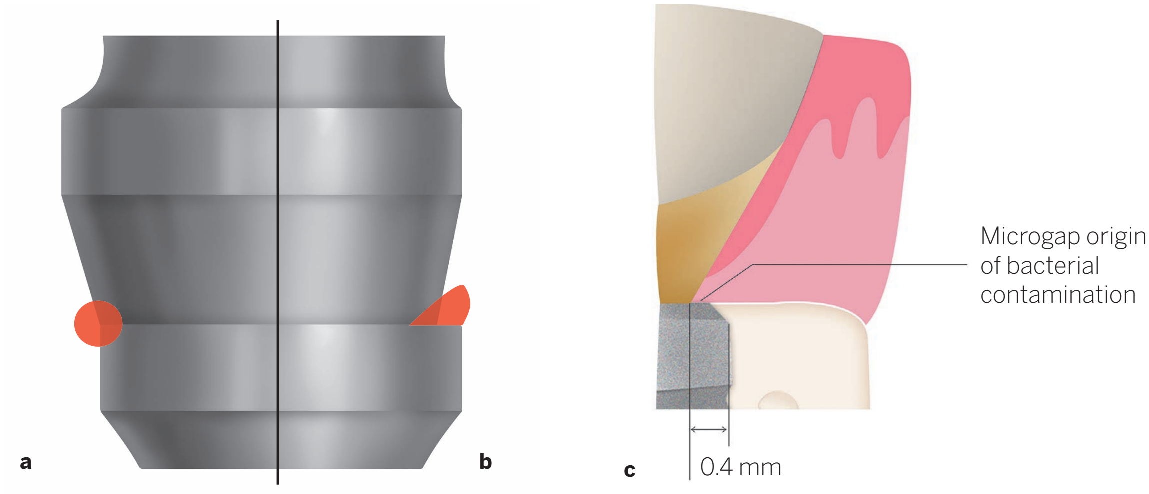


Fig 2-18 *(a)* Without platform switching, bacteria leak from the microgap directly into the bone tissue. *(b)* Platform switching offers an advantage in that bacteria are moved inward and away from bone. *(c)* The extent of platform switching is also important; at least 0.4 mm is required to be effective.

that supracrestally positioned implants without platform switching should have a polished neck of 0.5 to 1 mm.

Platform switching

The most significant implant design feature that has been introduced to the market has been platform switching. Proponents of platform switching claim that this implant design feature is the most important factor in preventing bone loss and that implants with platform switching will have no bone loss. Platform switching allows for the movement of bacteria away from the bone tissue in a horizontal direction, toward the implant (Figs 2-18 and 2-19). Its effects are similar to the proposition to place implants without platform switching about 1 mm supracrestally to isolate the microgap, but in this case isolation of the microgap is in a horizontal direction.

The concept of platform switching involves an abutment or suprastructure with a diameter that is smaller than the implant diameter at the implant-

Fig 2-19 This implant with platform switching clearly demonstrates how the implant-abutment connection is moved toward the center. It is also important that the area of the horizontal shift is polished because this is where soft tissue ingrowth is expected.

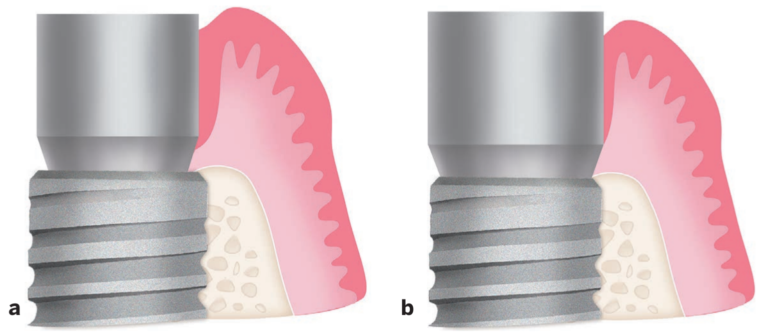


Fig 2-20 The size of the mismatch, ie, the extent of platform switching, is important for bone stability. An implant with a larger mismatch *(a)* will have less bone loss compared with an implant with less platform switching *(b)*.

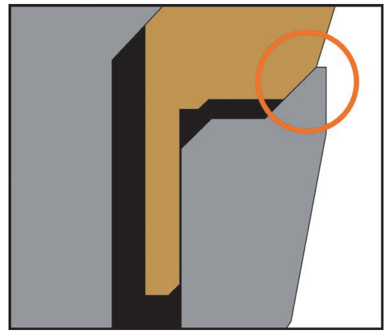


Fig 2-21 Internal connection showing a closed biologic seal at the outer level *(circle)*.

platform level. This configuration results in a circumferential horizontal step, which enables horizontal extension of the biologic width. The rationale for platform switching is to locate the micrograp of the implant-abutment connection away from the vertical bone-to-implant contact area. Compared with the conventional restorative procedure of using matching implant and suprastructure diameters, platform switching is suggested to prevent or reduce crestal bone loss.[26,32–34]

Many clinical studies have reported the positive impact of platform switching on crestal bone stability. The reduction in bone loss appears to be correlated with the size of the step between implant and abutment. In a prospective clinical study involving 69 implants in 31 patients, Canullo et al found bone loss of 1.49 mm at implants with matching abutments, 0.99 mm at implants with a 0.2-mm step, 0.82 mm with a 0.5-mm step, and 0.56 mm with a 0.85-mm step. Thus, the mean positive impact on bone resorption 33 months after implant surgery was greater when the step of platform switching was larger[1] (Fig 2-20).

Data from laboratory, animal, or human histologic and clinical studies confirm the important role of the microgap between the implant and abutment in the remodeling of the peri-implant crestal bone. Vela-Nebot et al[35] studied crestal bone stability around 30 implants with platform switching of 0.45 and 0.5 mm (test) and 30 implants with regular connection (control). The 1-year follow-up radiographic examination revealed that mean mesial bone loss was 2.53 mm for the control group and 0.76 mm for the test group. The mean value of bone resorption observed distally was 2.56 mm for the control group and 0.77 mm for the test group. The authors concluded that implants with platform switching had a significant reduction in bone loss compared with the control group.[35]

Micromovement

Preventing bacteria from contaminating the bone is only one factor in crestal bone stability. The other significant factor is reducing micromovements. Logically, a stable connection between the implant and abutment is required to reduce micromovements, but how is that achieved? The simplest solution is to choose the best type of connection. There are different connection types depending on the angulation and the length of the internal conical portion of the implant.

It is generally accepted that the smaller the angle of the inclination, the more stable and less resistant to lateral movements the connection will be (see Fig 2-10). The Morse taper connection has 2 to 4 degrees of angulation. The best-known implant brands that take advantage of this connection are Ankylos and Bicon, and other systems use them as well. The second type of conical connection is a wide conical connection with angulation from 5 to 20 degrees, which is used in Straumann, Nobel, MIS, and other implant brands. The third group features angulation of more than 20 degrees, which in fact is not referred to as a conical connection but rather as an internal or flat connection (Fig 2-21).

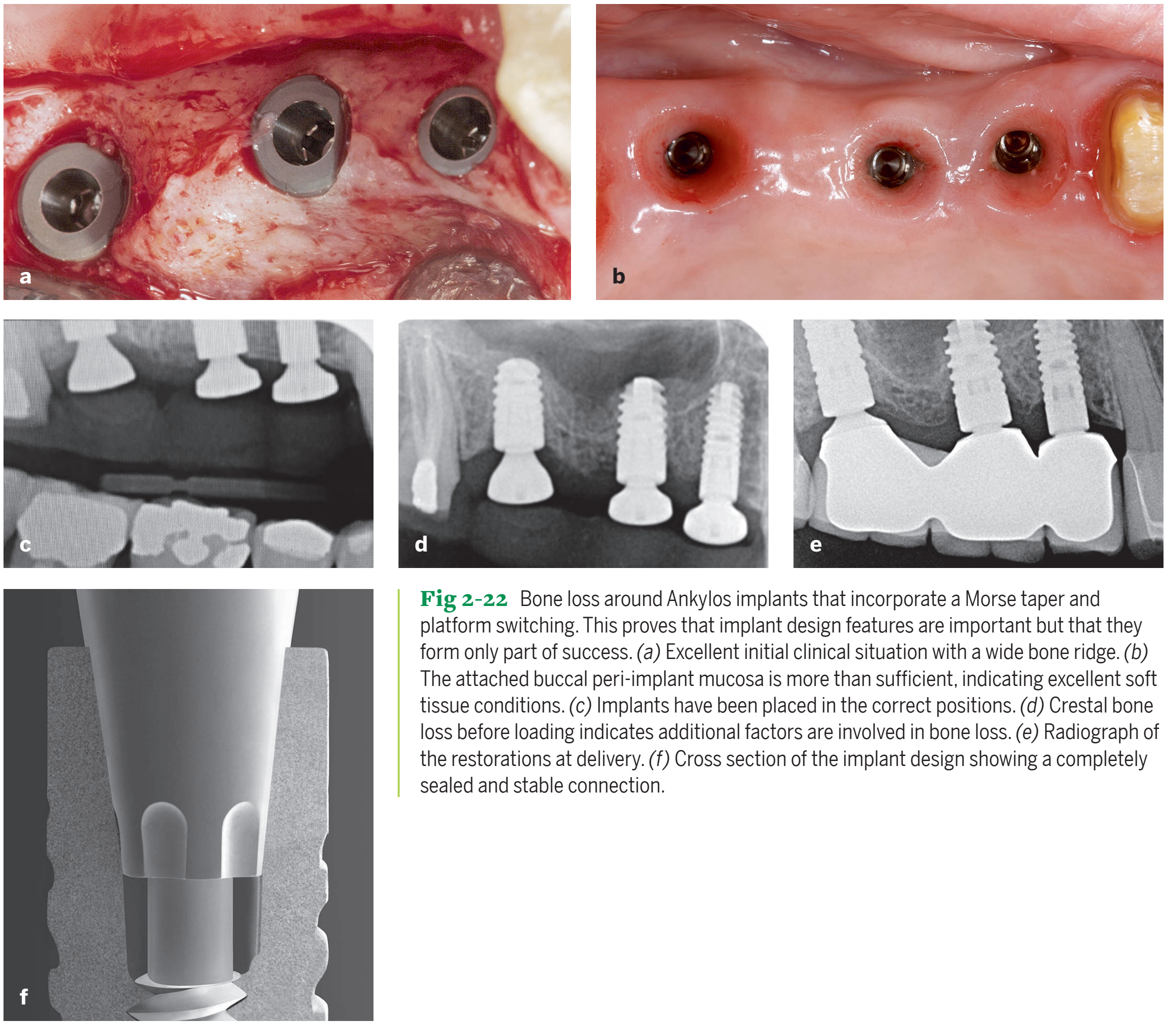


Fig 2-22 Bone loss around Ankylos implants that incorporate a Morse taper and platform switching. This proves that implant design features are important but that they form only part of success. *(a)* Excellent initial clinical situation with a wide bone ridge. *(b)* The attached buccal peri-implant mucosa is more than sufficient, indicating excellent soft tissue conditions. *(c)* Implants have been placed in the correct positions. *(d)* Crestal bone loss before loading indicates additional factors are involved in bone loss. *(e)* Radiograph of the restorations at delivery. *(f)* Cross section of the implant design showing a completely sealed and stable connection.

A famous study by Zipprich et al[17] found that the steeper the angulation, the less abutment movement. In addition, conical connection implants were advocated, stating that stability of connection is the most important factor in having no bone loss. Movement at the junction between implant and abutment creates a pump-like effect, forcing bacteria out and causing bone loss. In addition, the movement itself is damaging to the bone, so the negative reaction is doubled. When there is less movement at the implant-abutment connection, fewer bacteria escape the implant, and less inflammation results. On the other hand, a steep conical connection precludes splinting restorations, which is a disadvantage (see chapter 14).

Conclusion

A mechanical approach to bone stability through implant design suggests that platform switching and a conical connection at the implant-abutment junction are the most important factors in keeping bone stable. Of course, there is no doubt that these factors are important, but to claim that mechanical issues are the only relevant factors is simply not seeing the full picture. There is a lot of evidence of bone stability associated with implants with matching abutments and a simple internal connection.

Figure 2-22 shows a clinical case illustrating that mechanical implant design factors are not the only

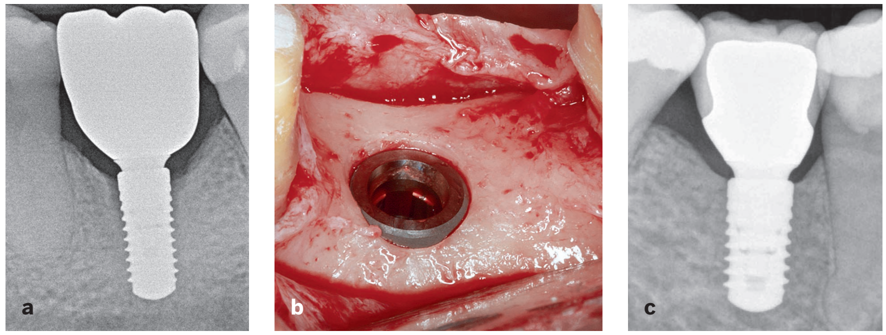


Fig 2-23 Implants with platform switching and a conical connection can show different outcomes. *(a)* Evident bone resorption. *(b)* Implant with platform switching placed at the bone level. *(c)* Excellent bone stability.

important factors in bone stability. This case uses platform-switched implants with a Morse taper connection, which is considered to be very stable, resembling "cold welding." Implants were placed in an ideal clinical situation: a wide alveolar ridge, more than 2 mm of attached gingiva, and a slightly subcrestal implant position. Ankylos implants offer substantial platform switching, so the effect of keeping bacteria away from the bone should be evident. A Morse taper connection should limit any movements and preclude any bone remodeling due to the size of the microgap. A radiograph at the time of placement shows stable bone around the seated implants; however, bone resorption occurred after 2 months. This shows that mechanical implant design factors are not all that matter, because bone was lost despite the ideal connection. In addition, this loss cannot be attributed to a poor anatomical situation because the bone ridge was so wide. Further, the radiograph taken at delivery shows a massive amount of crestal bone loss, which cannot be explained if only implant design factors are considered relevant.

So what was missed in this case? The answer is biology. Upcoming chapters discuss these hidden biologic factors, such as vertical soft tissue thickness, and how they influence bone stability. For example, the case in Fig 2-23 demonstrates a situation with platform-switched implants with a conical connection. The implant is placed at the bone level in both situations; however, one resulted in perfect stability of the bone, while the other resulted in bone loss. This is why it is necessary to consider the entire clinical picture.

Take-Home Messages

The polished collar of an implant neck does not osseointegrate and will cause bone loss if positioned below the bone level.

The microgap is detrimental to bone because of bacterial leakage and micromovements of the abutment inside the implant.

Platform switching shifts the microgap inward in a horizontal direction, keeping bacterial leakage away from the bone.

A conical connection provides stability of the implant-abutment junction, but this stability alone does not guarantee that there will be no bone loss.

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