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The Influence of Mucosal Tissue Thickness on Crestal Bone Stability Around Dental Implants

Specialty – Prosthetic Dentistry

Promotion Paper

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ABBREVIATIONS

FPD – fixed partial denture

PES – pink esthetic score

BW – biologic width

JE – junctional epithelium

CT – connective tissue

SLA – sandblasted, large grit and acid-etched

RVG – radiovisiography

RBM – resolving blasting media

I-A – implant-abutment

RCT – randomized controlled trial

CI – control implants

TI – test implants

CIM – control implants mesial

CID – control implants distal

TIM – test implant mesial

TID – test implant distal

TI(a) – averidge measurement

1. INTRODUCTION

1.1. Significance of the study

The success of dental implants has been extensively documented and without question has changed the way dentistry is practiced today. However, long-term data show that marginal bone loss analogous to periodontal bone loss does occur, thus the longevity of implant treatment depends on integration between fixture and oral tissues.

It has been well described in the literature, that two-piece implants undergo crestal bone loss after the connection of the abutment and delivery of prosthesis in single tooth replacements [1;2], partial edentate [3;4] and complete edentulous patients [5;6]. First attempt to clarify crestal bone changes during the first year of implant-supported prosthesis function was performed by Adell et al [7]. Their study reported an average of 1.2 mm of bone loss from the first thread during first year of loading. Interestingly, further bone loss was recorded to be only 0.1 mm per year. Later on, this led to establishment of the success criteria for implant treatment that included up to 1.5 mm loss of crestal bone after 1 year of implant function, as it was proposed by Albrektsson et al [8]. This bone deterioration was defined as early crestal bone loss and was thought to be an inevitable result from surgical intervention.

Although later observations showed that early marginal bone loss did not affect implant stability and success rates [9;10], an important factor to consider may be the fact that the stability of peri-implant mucosa around implant is largely dependent on the level of the underlying bone. The consequence of marginal peri-implant mucosa migration apically may have a major implication in the aesthetics of the restoration particularly in the anterior area. Prospective follow-up studies by Bengazi et al [11] and Small et al [12] reported mean 0.4 mm of buccal recession after 6 months of prosthesis insertion, possibly due to early bone deterioration. This is with an agreement with retrospective studies of Grunder et al [13], who showed about 0.6 mm of soft tissue recession and Ekfeldt et al [14] reporting 0.8 mm soft tissue apical migration in the first year after crown placement. Consequently, the identification of the reasons for early bone loss seems to be very important.

During two decades of research many factors have been advanced as possible reasons for this phenomenon. Overload [15], microgap [16], polished implant neck [17] and others have been extensively discussed in literature, but the stability of the crestal bone still remains a controversial issue. Surgical trauma [18;19], peri-implantitis [20], prosthetic abutment material [21] and its manipulations [22] are additional causes, which are thought to have impact on bone level. Moreover, the influence of mucosal thickness and BW formation on crestal bone loss around implants has only recently been discussed in the scientific research and is not so meticulously analyzed, as other factors [23;24].

It has been proposed that a minimum 3 mm of peri-implant mucosa is required for the stable epithelial connective tissue attachment to form without bone loss [25]. This soft tissue extension is usually referred as a BW around implants and serves as a protective mechanism for underlying bone [26]. There are some suggestions that if minimal dimension of mucosal tissues is not available, bone loss may occur to ensure the proper development of BW [27]. These considerations could be compared to teeth-related studies, which showed that indeed an establishing of BW after tooth crown lengthening involved crestal bone loss [28].

The transition of alveolar mucosa to peri-implant soft tissues after implant installation is a complex process. Berglundh et al [29] described the morphogenesis of peri-implant mucosa, implying that the characteristics of mucosal tissues may be important in this process. However, the data regarding relationship among mucosal thickness and marginal bone loss around implants is sparse. Berglundh and Lindhe [30] reported that thin tissues can provoke crestal bone loss, during the formation of the peri-implant seal in an animal experiment. Observations in the other histological study showed that implants, surrounded by consistently thin mucosa, had angular bone defects, while at implant sites with even alveolar pattern, wide mucosa biotype was prevalent [31]. However, the evidence of well-designed and structured animal studies is limited reducing the generalizability of results to clinical samples [32]. In addition, the clinical research in examining the effects of tissue thicknesses on bone stability around implants is lacking. Consequently, the question remains whether mucosal tissue thickness plays a role in the etiology of early crestal bone loss.

This research project will investigate probable relationship between importance of mucosal tissue thickness and BW formation in crestal bone stability around dental implants.

1.2. The aim of the study

To determine the influence of mucosal tissue thickness prior implantation and methodology of implant placement on crestal bone changes around dental implants with regular horizontally matching and platform switching implant-abutment connections rehabilitated with different prosthetic restorations.

1.3. The Objectives of the study

1. To measure the bone loss around implants with regular implant-abutment connection, placed in mucosal tissues;
2. To offer the classification of mucosal tissue at edentulous alveolar crest thickness, according to bone loss around implants;
3. To measure the bone loss around implants with platform switching, placed in thin mucosal tissues;
4. To determine, if implant placement 2 mm above bone level can prevent or significantly reduce crestal bone loss around dental implants;
5. To determine, if there are possible differences between separate measurements on distal and mesial sites or combined measurement per implant;
6. To determine to influence of prosthetic configuration and jaw on bone loss around implant, positioned in thick or thin mucosal tissues.

1.4. Hypotheses to be defended

1. Thin mucosal tissues can cause crestal bone loss around dental implants with regular implant-abutment connection, during the process of biologic width formation;
2. If at a time of surgery, thin mucosal tissues were present positioning of implant 2 mm supracrestally does not prevent early crestal bone loss;

3. Implant placement 2 mm supracrestally can significantly reduce crestal bone loss, if, at a time of implant placement, thick mucosal tissue were present;
4. Thin mucosal tissues can cause crestal bone loss around dental implants with platform switching, during the process of BW formation;
5. Mucosal tissue thickness at the crest before implant placement can be classified as thin, medium or thick;
6. There is difference between separate measurements of distal and mesial sites of implant, compared with combined measurement;
7. Prosthetic configuration of implant-supported restorations (single crowns, splinted crowns, 3-unit fixed partial dentures (FPD)) do not influence the amount of crest bone loss around implants placed in thick or thin tissues.
8. Patient gender and jaw selection do not influence the amount of crest bone loss around implants placed in thick or thin tissues.

1.5. Relevance and novelty of the study

It is well acknowledged that stability of crestal bone around implants plays a major role in implant longevity and esthetic outcome of treatment. Early crestal bone loss may have serious consequences around implants, positioned in anterior regions and in areas with very limited bone height. Thus, even loss of 1.5 mm may result in poor esthetics or dramatically disturbed bone-to-implant contact of a short implant. Thus, many studies presently aim and surely will focus in the future on determination of the clinical and technical solutions, which must be undertaken to prevent recession of hard tissues. Anatomical properties of mucosal tissues will always be a factor to be considered by clinician before implant placement and its impact to overall treatment success is of utmost importance. There is a lack of research data regarding mucosal tissue influence on stability of crestal bone around implants. It appears that no clinical studies have been found in the literature on the topic and very few animal experiments evaluated this relationship. However, in light of evidence-based dentistry, results from animal studies cannot be directly attributed to clinical practice.

The following demonstrate the relevance of the study:

1) The mucosal tissue thickness is shown as a factor, responsible for crestal bone loss;
2) Classification of mucosal tissue thickness at the crest was proposed;
3) Crestal bone stability around implants with platform switching were evaluated in thin mucosal tissues;
4) This particular research protocol with different implant positions regarding bone level was applied in clinical study. Therefore this clinical investigation will add to existing knowledge in the field;
5) Method of presenting bone loss data (split or combined) is important for reliability.

2. REVIEW OF LITERATURE

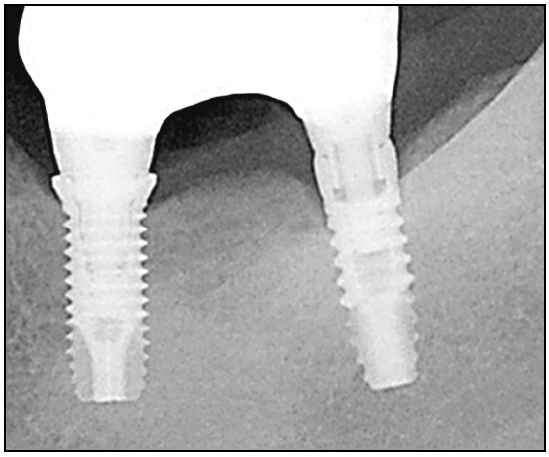
2.1. Early crestal bone loss

Early crestal bone loss could be defined as bone resorption around neck of dental implant from placement to 1-year post-loading [33]. This definition is probably based on implant success criteria, suggested by Albrektsson et al in 1986, which state, that until 1.5 mm of bone loss within the first year of loading can be considered as a success, if later bone loss does not exceed 0.2 mm annually [8]. This concept was developed from observational material of original Brånemark implants; however, implants used in conventional dentistry have superior design and surfaces, which seem to be more capable in keeping bone stable. Therefore, recently some studies have questioned the accepted success criteria, stating, that implants can have reduced amounts of bone loss after 1-year of function. It was reported that implants with micro threads in the neck region and conical implant-abutment interface may have 0.33 – 0.56 mm of bone loss within 12 months of loading [34;35].

In the dental literature early crestal bone loss sometimes is described as “saucer-shape”, “crater-like” or “ditch-like”, as it indicates the typical pattern of bone loss seen on radiographic image (Fig. 1).

Crestal bone, which is composed of cortical pattern, may play the major role in primary and long-term implant stability. Primary stability is a key to osseointegration, as it is well described and proved that it ensures transition to secondary stability, which already is characterized by biological interlock of bone and implant surface. When implant is restored and brought into function, crestal bone is also one of the major factors to secure enduring success.

Fig. 1. Typical crestal bone loss radiographic evidence.



A number of finite element analysis studies showed, that when axial and lateral physiologic forces are applied to the implant, high peak stresses are generated in cortical bone [36-38]. Other in vitro studies show, that loss or absence of cortical bone results in stress transfer to cancellous bone, whose stiffness is 10 times lower, than cortical bone and may not be able to withstand the stresses subjected to the implant, resulting in implant destabilization and subsequent loss [39]. However, clinical data shows different results, as usually bone loss stabilizes after 1 year of loading, thus early crestal bone loss, if not extents more in apical direction, generally shows no threat to osseointegration and implant long-term survival whatsoever. It has been proposed that an implant should be considered failed when the marginal bone loss has reached the apical 1/3 of the implant and that never happens during early crestal bone loss [40].

It is more important that the stability of peri-implant mucosa level around the implant is largely dependent on the height of the underlying bone. The consequence of marginal peri-implant mucosa migration, as a result of early marginal bone loss, has a major

implication in the aesthetics of the restoration particularly in the anterior area. Peri-implant mucosa recession, which may follow crestal bone loss, results in crown margin exposure and loss of the papilla [41]. The pink esthetic score (PES) is used to objectively evaluate peri-implant soft tissues around implant crowns [42]. The PES is based on seven variables: mesial papilla, distal papilla, soft-tissue level, soft tissue contour, alveolar process deficiency, soft-tissue color and texture. Each variable is usually assessed with a 2-1-0 score, with 2 being the best and 0 being the poorest. It has been suggested that PES is reliable and reproducable tool to asses peri-implant tissues in esthetic zone [43]. Other authors have developed Implant Crown Aesthetic Index to evaluate soft tissue apperance around implant-supported restorations, which takes into consideration prosthetic work as well [44]. Thus crestal bone loss can influence position of mesial and distal papillea, soft tissue level and countour. If esthetic scores are low, what can be expected in case of bone loss, restorations cannot be related as esthetic and patient satisfaction is may be lower [45]. As many authors reported retraction of mucosa around implant-supported restorations after delivery with in the first year of function, it was recommended to restore anterior implants with provisional crowns for at least 6 months. It was suggested to restrain delivering permanent prosthetic solution, as soft tissue recession is likely to happen [46].

There is no agreement between researches why crestal bone tends to resolve more during first year of loading than following years, but it is clear that the process of bone loss is dependant on the etiologic factor. Wiskott and Belser have proposed that this “saucer-shape” bone loss may be self-limiting, as the tendency to stop after reaching first thread of implant is obvious [47]. However, “bone loss till first thread” can be challenged by serious critique, as bone loss depends on initial position of the implant [48]. Original Brånemark protocol included implant countersinking below the crest to minimize the risk of implant interface movement and to prevent undesirable implant exposure. Consequently, after uncovering during second stage surgery due to various reasons bone migrates about 1.5 mm in apical direction and stops around the region of first thread. However, if implant is placed at or even above the bone level, the number of thread, which bone loss reaches, may differ. Thus crestal bone loss is not thread related, rather dependant on implant placement level.

Early bone loss, which stabilizes without leading to failure, is distinct from late bone loss, which is another type of bone resorption. Esposito et al has defined late bone loss as failure to maintain the achieved osseointegration [49]. It is usually associated with peri-implantitis development, undetected cement remaining after prosthetic treatment or lack of attached peri-implant mucosa. Late bone resorption does not pose ability to restrict itself without intervention, thus poses a real threat to outcome of all treatment.

Many possible explanations for the phenomenon of early crestal bone loss have been proposed to consider. Occlusal overload, microgap, surgical intervention, polished implant neck, prosthetic abutment material, its manipulations and others are advanced as possible reasons [15-22].

Surgical trauma was perhaps the first factor to be discussed as a cause of early crestal bone loss [50]. It was suggested that the raising of periosteum flaps and marginal bone preparation at high speed can result subsequent bone loss after tissue healing. This assumption is probably partly based on classical study by Wilderman et al, who showed that horizontal bone remodeling after surgery with mucoperiosteal flap elevation can reach up to 0.8 mm [51]. Although the pattern of bone loss around implants differs from teeth, as vertical bone “saucerization” is more implant-related feature, compared to horizontal resorption around teeth, recent animal study by You et al [52] showed that flapless implant placement resulted in significantly lower amounts of marginal bone loss. Animal experiment studied 12 implants, placed in 6 mongrel dogs and half of the fixtures were installed in flapless approach and the other part secured in bone after traditional flap elevation. Radiographic evaluation showed 0.0 mm of bone loss in flapless group and 0.2-0.3 mm in conventional implant placement group.

For a long time occlusal overload was considered the main reason, since crestal bone was observed after implants received loading. Miyata et al [53;54] and Isidor [55;56] have demonstrated in animal experiments with monkeys that excessive occlusal loading can cause bone loss or even implant disintegration. The background for occlusal overload as a factor for crestal bone loss is based on studies by Frost [57;58], which analyzed the influence of loading on behavior of bone. Author proposed 5 types of strain levels interrelated with different load levels in bone: 1) disuse – bone resorption; 2) normal load – homeostasis; 3) mild overload – bone mass increase; 4) pathologic overload –

irreversible bone damage; 5) fracture. Normal load and mild overload were considered optimal conditions for bone status. Roberts et al [59] suggested that crestal regions around implant neck are constantly challenged by high stresses and that extreme loading can cause local "microfractures" of bone and result in resorption. Based on these assumptions, occlusal overloading was regarded as undesirable factor in crestal bone loss etiology. Misch has speculated that stresses at implant neck region can be sufficient to cause local overload and microfractures of bone, thus leading to early crestal bone loss [60].

However, it is not clear why bone loss does not continue until complete implant failure, if occlusal functioning is likely to cause constant overload at implant neck area. It was suggested bone is less dense and more sensitive to stresses in the beginning of prosthetic loading, thus bone is overloaded and links to resorption. Therefore, within first year of loading bone matures, becomes more dense and occlusal forces, that initially causes crestal bone loss, is not great enough to evoke further bone resorption [61].

In contrast recent studies have questioned the role of loading in etiology of early crestal bone loss [62-64]. In addition Heitz-Mayfield et al [65] in experimental study with dogs created overload by raising the bite with prosthesis nearly by 3 mm for 8 months. Outcome of the study did not find additional bone loss around test implants, compared with control group. Furthermore, clinical trials, which studied bone levels around cantilever prostheses [66-68], restorations, receiving non-axial loads [3], angled abutments [69-71] and other situations, with enlarged loading did not show additional risk for bone loss and implant failure. Some studies have shown that bone loss around implants can occur even before loading, thus not supporting the role of loading in bone resorption, observed during the first year of function [72]. Therefore, it can be concluded that osseointegration can be disturbed by occlusal overload under experimental conditions, however it is very hard or even impossible to directly relate occlusal overload and bone loss in humans.

Another factor broadly discussed in implant literature as a cause of marginal bone resorption is implant-abutment interface – microgap. Microgap is the special feature of two-piece implants, which forms, when prosthetic abutment is connected to implant body and it's been related to crestal bone loss. Laboratory experiments show that the size of

microgap may be different between implant systems and prosthetic abutments. Kano et al [73] reported that horizontal misfit of implant-abutment interface can range from 89 to 13 μm, depending on type of abutment, while vertical misfit was recorded to be smaller, from 5 to 11 μm. Dibart et al determined only 0.5 μm microgap in the locking taper system implants, which were regarded having "bacteria free" connection, as microorganisms are larger in diameter than 0.5 μm [74]. The size of microgap must be important, as in vitro studies have shown that due to implant-abutment interface there is a microbiological contamination along all the system [75;76]. Three reasons are advanced as explanations of the presence of bacteria at the implant/abutment interface: 1) leakage; 2) contamination during prosthetic phase; 3) loosening of abutment after some time of function. Piattelli et al in 2001 supported the idea of leakage, showing the penetration of oral fluids and bacteria occur through occlusal access opening for the screw-retained implant-abutment connection, which may also occur if the central screw becomes loose [77]. In contrast, cement retained implant crowns showed no internal microbial contamination. The contamination during prosthetic phase of treatment is another possible reason for bacteria to be present in internal implant parts. Before permanent placement, the abutment should be cleaned in ultrasonic bath or even autoclaved, as proposed by some authors in order to clean all debris and microorganisms [78].
This leakage is responsible for abutment-related inflammatory cell infiltrate formation in soft tissues adjacent to microgap, as described in numerous histological animal studies [79-81]. Ericsson et al [82] termed it "abutment - infiltrated connective tissue" and suggested that its presence shows the reaction of host to the bacterial contamination of inner abutment components. It was stressed, that abutment-related lesion has no relationship with plaque-associated infiltrate lateral to peri-implant sulcus and junctional epithelium. The formation of infiltrate may be a host mechanism of protecting the peri-implant bone. In contrast one-piece implants, which bypass the effect of microgap, do not show the development of specific inflammatory cell infiltrate at the bone crest [83;84]. Hermann and collaborates in a series of animal experiments did prove that placement of implant-abutment interface at the level of bone or more apically may result in significant marginal bone reduction [85;86]. The pathogenesis of microgap-related bone loss was described by Broginni et al [87]. It was observed that 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 osteoclasts formation and draw, which may result in alveolar bone loss. This hypothesis was confirmed in a later experiment which showed the capacity of deeper-placed implants to accumulate more neutrophils, more inflammation, and thereby cause more bone loss [88]. Generally, it was concluded that bone may recede up to 2 mm to maintain appropriate distance from the source of infection. This can be considered similar to alveolar bone loss around crowned teeth if BW is invaded by prosthesis margin [89] or distance between infection and a healthy attachment in periodontally involved teeth, as it was observed by Waerhaugh [90]. Therefore, the recommendations to position implants supracrestally for microgap distraction may be considered justifiable [91;92]. Todescan et al [93] also reported stable bone recession from implant-abutment interface apically, however did not confirm the direct correlation between the depth of implant placement and the severity of bone loss. In fact, the implants which remained 1 mm above the bone crest had the lowest bone level, compared to crestally or 1 mm more apically countersunk implants. However, it must be noted that the measurements were performed 3 months after implantation, which can be considered as early or even premature. The most appropriate time for assessment of early crestal bone loss is after 1 year of service, as it was proposed by Albrektsson et al [8]. Consequently, Pontes and co-authors, whose study had at least 7 months of follow-up, did notice the significant relationship between the implant insertion depth and the extent of bone loss [94]. The importance of the time factor in evaluation is obvious in the Assenza et al study, which reported 1.32 mm marginal bone loss after 6 months and 2.21 mm after 1 year due to microgap. The present study had follow-up of 1 year, which can be considered a fully-satisfactory period for reliable evaluation of crestal bone changes [67].

Piattelli and co-workers reported no bone resorption if microgap was located 1.0 – 2.0 mm above the alveolar crest, and a loss of 2.1 mm if microgap was present at the level of the alveolar crest [95]. However, all the above-mentioned studies are animal experiments, which do not occupy the highest position in the hierarchy of evidence [96]. Interestingly, some clinical reports provide a different perspective of the subject. The findings of several successive clinical studies by Heijndrijk and co-workers, which claimed microgap

to be no threat to bone stability around osseointegrated implants [97-99]. A possible explanation for this variation may lie in different follow-up periods, diverse implant designs and other, still not identified reasons.

In contrast, Vela-Neblot et al used crestally placed implants as a control group in a clinical study comparing different implant-abutment connections and obtained constant bone loss around implants in control group [100]. In the light of this study, microgap remains a significant threat to bone stability. Another article dealing with clinical performance of implant-abutment interface in close proximity to bone was published by Norton [101]. The retrospective analysis revealed that two-piece implants underwent only minimal marginal bone loss or even bone gain during 3-year follow-up.

Hermann and co-workers have proposed another implant-abutment connection related factor in etiology of early marginal bone loss [102]. In animal experiment 60 implants were placed in 5 hounds. Two-piece implants had microgap size of approximately 10μm, 50 μm and 100 μm and one part of the implants were laser-welded together, not allowing any movement between implant body and abutment. The other part of tested fixtures had the same size of microgap, but abutments holding connected to implants only by prosthetic screws. Results showed that all implants in non-welded group had significantly increased amounts of crestal bone loss, compared to implants with laser-welded abutments. Therefore, it was concluded that micromovments between implant and prosthetic abutment can be more important for bone loss than size of microgap itself. Similarly, King et al [103] in subsequent experiment have confirmed conclusions of prior study stating that the stability of implant-abutment connection is very important feature in prevention of marginal bone loss.

The importance of implant-abutment interface instability to bone loss is usually two-fold. First, it was proposed that when occlusal forces are applied to implant due to abutment connection instability, a pumping effect maintains constant flow of bacteria form implant interior through microgap to peri-implant tissues [104]. Such action contributes to formation of inflammatory cell infiltrate formation, which constitutes the basis for microgap-related bone loss. Second theory states that abutment micromovments itself can cause resorption of crestal bone situated in close proximity.

Polished implant neck is advanced as another factor, playing role in early crestal bone loss etiology. Historically implant neck was manufactured with polished surface to reduce plaque accumulation, if implant becomes exposed to oral environment, as a consequence of alveolar bone loss. However, clinical trials, which studied bone levels around implants with polished collars, have shown the tendency for hard tissue resorption in contact with machined surface. Hammerle et al reported that ITI implants did not maintain bone, when implant was restored, despite countersinking [105]. Recent study by Shin et al concluded similar results that implants with rough neck experienced less bone loss, compared to polished neck fixtures [106]. Hanggi et al reported that implant design with the shorter smooth coronal collar may help to reduce the risk of an exposed metal implant margin in areas of esthetic concern, as implants had no additional bone loss [107]. The pathogenesis of polished surface related bone loss is described in review article by Wiskot and Belser [17]. It was hypothesized that machined implant surface cannot effectively distribute occlusal stress between bone and smooth titanium surface; "stress shielding" is created and results in bone loss. It was observed that bone grows over submerged implant, as it can be noted during second stage surgery, but after prosthetic loading bone goes down to first thread of the implant [108;109]. Jung et al. have demonstrated extensive bone loss around implants with 3 mm long polished neck part [110]. In studies with one-piece implants, which bypass the effect of microgap, bone level was found to establish at the border of smooth-rough surface, regardless the deepness of implant positioning [79]. Thus it can be concluded that polished implant neck is a valid etiologic factor in crestal bone loss pathogenesis.

It was suggested that prosthetic phase of treatment may also influence crestal bone level around implants. Abutment disconnection and subsequent reconnections, abutment materials and dimensions may disturb the peri-implant tissue seal, which in turn may affect the crestal bone level.

Abrahamsson et al in 1997 reported the recession of peri-implant mucosa and bone resorption after the dis/reconnection of titanium abutment 5 times, in that way simulating procedures of prosthetic treatment. Test implants showed significantly higher reduction of bone height than control implants - 1.49 mm and 0.78 mm respectively. Clinically, the bleeding and ulceration of soft peri-implant tissues after the disconnection of the

abutment was observed [111]. It was concluded that the mechanical disruption of the mucosal barrier might be recognized as an open wound of connective tissue with subsequent epithelial proliferation to cover the open connective tissue. This change in peri-implant tissues may result in crestal bone resorption in order for the connective tissue to regain its normal dimension. It was shown that epithelium starts to migrate within few hours after the creation of wound [112], but it takes about 1-2 weeks for connective tissue to re-establish its contact with abutment. This discrepancy in time favors the down-growth of epithelium.

In a later study in 6 dogs and 36 implants, Abrahammson et al [79] found that single disconnection of healing abutment to prosthetic abutment did not cause any additional bone loss. Watson et al [113] in retrospective clinical study evaluated soft tissue condition and crestal bone loss around implants which had earlier healing abutments placed after second stage surgery. After a 3-year follow-up, it was concluded that there was no evidence to suggest that abutment exchange adversely affects the outcome of implant treatment. The shift from healing abutment to prosthetic analogue neither affected the survival rates of implants nor increased the marginal bone loss.

It was suggested that abutment material characteristics may influence the capability of soft tissue integration and subsequently, the stability of crestal bone loss around implants [114]. Titanium, gold, base metals, and zirconium or aluminum oxide ceramics are available for prosthetic abutment fabrication. Biologic reliability of these materials has been analyzed in various experiments, ranging form in vivo tests to randomized clinical trials. Chemical composition of materials has shown to have an impact on various cell adhesion, migration and proliferation in laboratory environment [115-119]. However, in vitro experiments have limited clinical relevance and stronger evidence should be retracted from animal, human or clinical studies [120]. The ability of prosthetic abutment material to influence peri-implant tissues can be characterized by two parameters, namely presence or absence of bones loss and mucosal recession. Classical animal study by Abrahamsson et al showed that titanium and aluminum oxide ceramic abutments can develop stable bone level. Soft tissues adjacent to gold and porcelain-fused-to metal abutments showed recession and significant crestal bone loss occurred; therefore it was concluded that their biocompatibility could be questioned [121]. In contrast, a later study

by Abrahamsson and Cardarpoli [122] showed no difference between soft and hard tissue integration around gold alloy and titanium one-piece implants. One-piece implants have abutment incorporated into the implant body, thus this experiment can also be treated as a titanium and gold alloy abutment assessment. The differences between two studies could be explained in terms of methodological disparity. The first study used two-piece implants of the Brånemark System (Nobel Biocare AB, Göteborg, Sweden). Methods included abutment disconnection and second stage surgery. The other experiment used custom made one-piece implants (Straumann, AG, Waldenburg, Switzerland); therefore neither abutment disconnection nor second stage surgery were carried out. In addition one-piece implants bypassed the possible effect implant/abutment interface. It was stated earlier that abutment disconnection [22], second stage surgery with flap elevation [123] and microgap [81] could cause crestal bone loss and/or soft tissue recession.

Kohal et al conducted animal study to compare titanium and zirconium abutments [124]. The experiment showed that zirconium oxide integrated into peri-implant tissues no worse than titanium. Bone apposition did not differ statistically between compared specimens. These findings indicate the equal biocompatibility between zirconium oxide and titanium. However, as the study did not evaluate crestal bone changes, it can be perceived as a descriptive experiment. It should be noted that non-human primates used in the experiment resemble human oral anatomy and histology more than any other animals [125], ensuring reliability of the study.

To date, there are three published prospective randomized controlled clinical trials [126-128] showing stable soft and hard tissues around aluminum oxide abutments. Bone loss did occur, but was not statistically different from control titanium abutments for which biocompatibility was already proven decades ago [129]. Nevertheless, it can be stated that aluminum oxide abutments indeed can develop a stable marginal bone in a clinical situation.

Tooth-controlled experiment and uncontrolled prospective studies show that aluminum oxide abutments can develop stable peri-implant tissues similarly to titanium abutments [130]. Interesting conclusions came from the Vigolo et al [131] experiment which examined gold alloy and titanium abutments. There were no significant differences found between the two materials in terms of crestal bone stability. These findings could

potentially change the prevailing opinion that gold as an abutment material is responsible for crestal bone loss. This coincides with conclusions of recent systematic review about the influence of prosthetic abutment material on soft peri-implant tissues and bone published by Linkevicius and Apse [132]. Interestingly, zirconium oxide abutments were not compared to titanium abutments in any clinical trial, hence no considerations about superiority or inferiority of zirconium over titanium as abutment material could be made, at least in clinical level. However, there is some reliable data from tooth-controlled investigations. In a 4-year study Glauser et al provided clear evidence demonstrating that zirconium oxide abutments caused favorable reaction of peri-implant bone[133].

In conclusion, it can be stated that currently there is no sufficient evidence to state that titanium abutments perform better in maintaining stable peri-implant tissues, compared to gold, aluminum and zirconium oxide abutments.

Peri-implantitis can be also considered as a factor in bone loss etiology. This disease is described as inflammatory lesion of peri-implant mucosa, including loss of supporting bone. It is characterized by radiographic evidence vertical destruction of crestal bone, formation of peri-implant pocket in association with bone loss, bleeding on probing, suppuration, redness and swelling of peri-implant mucosa, typically no pain. The causes for peri-implantitis development were related to presence of specific bacteria *Aggregatibacter actinomycetemcomitans, Prevotella intermedia, Porphyromonas mucosalis* and *Treponema denticola* [134]. Karousis et al in systematic reviews and clinical studies has indicated that patients with history of periodontitis have increased risk to develop peri-implantitis related bone loss [135-137]. In contrast, Yi et al [138] demonstrated that implants, supporting fixed prostheses for the rehabilitation of periodontally compromised dentitions, did not have larger amounts of bone loss, compared to healthy individuals. Although studies, investigating influence of prior periodontitis in development of peri-implantitis-related bone loss vary and very strict conclusions cannot be made, generally it is accepted that subjects with history of periodontitis are at greater risk for peri-implant disease.

Lindquist et al reported an association between poor oral hygiene and peri-implant bone loss at 10-year follow-up [139]. However, Apse et al. study reported no correlation between oral hygiene status and crestal bone loss around osseointegrated implants after

follow-up period of 9-years [140]. It must be reminded that usually peri-implant diseases may take years to develop, as in case of periodontitis and bone loss due to these causes is usually registered in later stage of implant loading. Thus, the relevance to early crestal bone loss of these two factors may be limited.

Tarnow et al raised the hypothesis that crestal bone stability may be dependant on inter-implant distance, if two fixtures are placed adjacent to each other [141]. Indeed, Scaranno et al as studied the correlation of inter-implant distance between implants placed 2, 3, 4 and 5 mm apart with intensity of crestal bone loss. It was reported, that vertical crestal bone loss decreased, as inter-implant distance was increasing. On the contrary, Novaes et al [142] and de Oliveira et al [143] have demonstrated, that crestal bone loss was not higher, if implants were located closer than 3 mm to each other.

Some systematic factors were shown to influence crestal bone loss also. Galindo-Moreno et al [144] investigated the influence of alcohol and tobacco habits on peri-implant marginal bone loss. One-hundred and eighty-five patients who received 514 implants were followed for 3 years. Multivariate analysis showed that peri-implant marginal bone loss was significantly related to a daily consumption more than 10 g of alcohol, tobacco use and increased plaque levels and mucosal inflammation. It was of note that alcohol use induced greater marginal bone loss compared with tobacco use.

Smoking, as another cause for crestal bone loss was considered by Fransson et al [145] Comprehensive systematic review was published by Strietzel et al [146] with a conclusion that there is strong correlation between crestal bone loss and daily smoking. However, it must be acknowledged that systematic factors seem more to be related to late crestal bone loss and may have no strong relationship with marginal bone loss during first year of function.

Additional factors which are related to crestal bone stability - tissue thickness with BW formation and platform switching modification will be discussed separately.

2.2. Mucosal tissue thickness and biologic width around implants

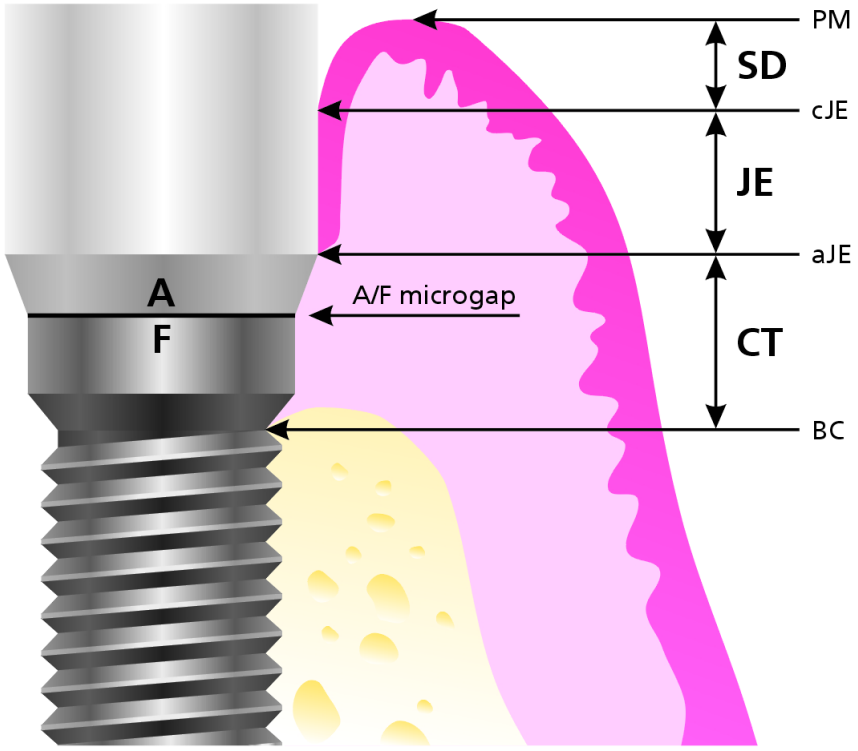
Dental implants residing in the bone have to penetrate oral mucosa and enter the oral cavity environment in order to function as anchorage for some sort of prosthesis. Thus, a

transmucosal connection between external surroundings and inner part of the human body is created. Bacterial invasion could threaten longevity of implants, therefore some sort of soft tissue barrier, protecting implant-bone interface is mandatory. This soft tissue seal is critical and contributes to generation of biologic width (BW), which prevents oral microorganism and their products form reaching the body. The glossary of oral and maxillofacial implants states that BW around implants can be described as a unity of junctional epithelium and connective tissue, facing the surface of implant and/or abutment. It is very similar to definition of BW around teeth, which states that it is composed of junctional epithelium and connective tissue parts, attaching to tooth surface. The biologic explanation for the development of BW is that when bone is exposed to oral environment, it covers itself with periosteum, connective tissue and epithelium. Listgarten and co-authors in a review article stated that BW around implants consists of three distinct zones: sulcural epithelium, junctional epithelium and connective tissue [147]. Berglundh et al investigated peri-implant tissue in a dog model and were the first to list the exact measurements of peri-implant tissues: epithelial attachment (peri-implant sulcus and junctional epithelium) - 2.14 mm and connective tissue – 1.66 mm, that makes BW to be 3.80 mm [148]. Components of the BW around implants can be discussed separately – (1) peri-implant sulcus epithelium, (2) junctional epithelium and (3) connective tissue zone. The schematic composition of BW around implants can be seen in Figure 2.

As in the natural dentition, the sulcular epithelium around implants resembles a non-keratinized extension of the oral epithelium. It extends from the crest of the marginal peri-implant mucosa to the most coronal level of the junctional epithelium [149;150]. Histologically, sulcus depth around implants is about 0.5 mm [151]. Clinical peri-implant sulcus depth is determined with a periodontal probe and is deeper, than histologically measured sulcus, because the probe often penetrates the delicate epithelial lining or even connective tissue [152]. On the average clinical peri-implant tissue probing depth is about 3 mm and is considered significantly deeper than same parameter around teeth [153]. It is thought that due to absence of fiber insertion into implant surface, the probe tends to penetrate deeper into tissues, even the probing force being the same, as around teeth. In comparison histological sulcus depth around teeth was reported by Gargulio et al [154]

to be 0.69 mm and 1.34 mm by Vacek and co-authors [155]. Pocket epithelium can be considered as the first barrier for bacteria invasion to deeper tissues.

Fig. 2. The composition of biological width around implants. Sulcus depth (SD) - distance from peri-implant mucosa margin (PM) to the most coronal point of junctional epithelium (cJE). Junctional epithelium (JE) – distance from cJE to most apical point of the junctional epithelium (aJE). Connective tissue zone (CT) – distance from aJE to the first bone to implant contact (BC).



The junctional epithelium is attached to the implant surface via hemidesmosome-like structures and begins at the base of peri-implant sulcus and ends with the first fibers of the connective tissue zone [156]. Junctional epithelium facing the implant or abutment surface is thin (mean width about 0.04 mm) and is composed of only few rows of cells (*stratum basale* and *stratum granulosum*) in its most apical portion [157]. Connective tissue immediate lateral to junctional epithelium has a number of vascular vessels, but in comparison with teeth, vessels are of smaller diameter and sparser [158]. This is the reason why disconnection of abutment, which occurs during prosthetic treatment, may disrupt junctional epithelium from immediate lateral connective tissue, denude it and

cause bleeding from connective tissue blood vessels. In contrast to periodontium, it was reported that connective tissue central part is poorly vascularized, some portions completely devoid of vascular structures. This partly explains more extensive progression of plaque associated infiammation that occurred in the peri-implant mucosa than in mucosal tissues, as collateral circulation in peri-implant tissues is absent.

The apical extension of junctional epithelium was reported to vary, but on the average is about 2 mm.[159]. In contrast the length of junctional epithelium around teeth was calculated to be about 1 mm. However it should be noted that around teeth significant variations of epithelial attachment extent were observed, ranging from 1.0 to 9.0 mm. The attachment of junctional epithelium to the implant/abutment surface appears to be a barrier for the internal peri-implant tissues against oral environment, protecting the underlying bone around osseointegrated implant [160;161].

Connective tissue zone is situated between apical termination of junctional epithelium and alveolar bone. Berglundh termed it “connective tissue integration” [162]. Peri-implant connective tissue is characterized by low density of cells and blood vessels, but rich with collagen fibers and abundant fibroblasts. Morphometric measurements have shown that this tissue is comprised of 80 % of collagen, 13% of fibroblasts, 3 % of blood vessels and 3 % of residual tissue. This composition makes it very similar to scar-like tissue [163].

The distribution of connective tissue components is not equal through out the peri-implant mucosa. Buser et al observed the direct connective tissue contact to implant surface was 50 to 100 μm wide and contained dense circular fibers without blood vessels. Lateral to this area there was a less dense connective tissue with horizontal and vertical collagen fibers and numerous blood vessels [164]. Moon et al. divided connective tissue, into 2 zones: the inner zone (0-40 μm), that has relatively more fibroblasts and no blood vessels and outer zone (40– 200μm), that was filled with collagen and substantial number of vascular structures [148]. These two researches show that there are no vascular units in connective tissue zone in contact with implant or abutment.

Schierano et al investigated the direction of collagen fibers and found that circular direction was dominant around the abutment and implant. Fibers commence from marginal bone crest, come close to implant surface and align themselves parallel with the

junctional epithelium [165]. The alignment of the collagen fibers suggests that the connective tissue may function as a support for junctional epithelium. Connective tissue does not attach to the implant, only contacts it, which is in contrast to connective tissue around teeth, where fibers (Sharpey fibers) invest at an oblique angle in cementum [166]. This may mean that connective tissue zone plays a smaller role in protection of bone around osseointegrated implant. As no cementum or fiber insertion is reported on the surface of titanium perimucosal abutments, an epithelial perimucosal seal could provide the only barrier against pathologic insults to deeper tissues.

The absence of direct insertion of connective tissue fibers into implant surface and their parallel orientation to the long axis of the implant may be the reason that there is less resistance to probing in comparison to teeth as probing depths are significantly deeper around implants [167].

The connective tissue contacts the titanium implant or abutment, but this interaction does not induce apical migration of the epithelium. Rompen et al assumed that this contact would be better described as adhesion [168;169]. It is suggested that the adhesion is sufficiently tight to preclude epithelial down-growth, which could induce bone resorption [170]. Another hypothesis explaining the limitation of apical epithelial migration can be found in periodontal wound healing studies. It has been shown that epithelial migration will continue along the root surface as long as there are no attached collagen fibers on the root surface. Apical migration of the epithelium ceases as soon as such fibers are encountered [112;171]. Similar mechanisms may be considered to be applied to peri-implant tissues.

The extension of connective tissue zone varies in different studies, but on average is about 1-1.5 mm in length [135], which seems to be constant value at healthy implant sites. The stability of this parameter is similar to teeth, where connective tissue attachment was found to be a fairly consistent measurement [148; 149].

In summary it can be said that in total BW around implants is about 4 mm wide and is longer when compared to BW around teeth. Gargulio et al found the dimension of BW around teeth to be 2.73 mm and Vacek et al - 3.25 mm respectively [148; 149]. Although there are morphometric differences between BW around teeth and implants, the constant

factors of connective tissue apical extension may be significant similarity in the maintenance of the integrity of the internal tissue structures.

Human histology studies are in agreement with the outcome of animal experiments, listing the same component parts of the biological dimension [83;172-174]. The results of dog studies indicate that the parameters of BW are very similar around one-piece and two-piece implants. Submerged and non-submerged implants, as studied by Weber et al [175], Ericsson et al [176;177], Abrahammson et al [178], had a very similar soft tissue length; therefore, it can be concluded that surgical techniques do not influence formation, composition or extension of BW. It seems that conventional or immediate loading of implants does not influence the parameters of peri-implant seal, as it was observed in comparative studies with unloaded implants [179]. Only the position of implant/abutment interface (microgap) to bone level proved to affect the vertical extension of BW – the deeper implant is placed, the longer biological dimension is formed [180]. It was shown that type implant-abutment connection can significantly influence the parameters of peri-implant tissue seal. Tenenbaum et al inspected histological structure of implants with platform switching and found longer extension of connective tissue zone (2.01 mm to 3.62 mm) and shorter length of junctional epithelium. It is suggested that limitation of epithelium downgrouth is associated with less bone loss [181].

In a human histological study the length of the peri-implant seal was found to be about 4-4.5 mm. In contrast, Liljenberg et al reported the same measurement to be 1.57 mm [182]. However, the authors of the latter experiment admitted that such results may have occurred due to improper biopsy harvesting. The mean extension of BW around implants in primate studies was recorded to be 3.84 mm. In histological dog studies this distance was calculated to be around 4 mm. As compared to BW around teeth, the same parameter around implants was longer nearly by the factor of 1.5 mm. It is evident that the peri-implant seal around implants tends to be longer, than around teeth. However, the clinical importance of this difference is unknown.

Clinical study by Kan et al [183] recorded most extension of BW around implants – 6.17 mm at mesial and 5.93 mm at distal sites of implants. These results were obtained by probing to bone level and may have been influenced by the emergence profile of the crowns on implants. Additionally, proximal sites frequently show deeper probing depths

due to position of the bone crest. However, the mid-facial measurement was recorded to be 3.63 mm, which is very close to the width observed in animal and human histology studies.

The function of peri-implant soft tissues as a unit is thought to be the protection of bone around the osseointegrated implant. The proceedings of the 3rd European Workshop on Periodontology and Implant Dentistry state that the function of the peri-implant seal is "to maintain homeostasis of the internal environment in response to challenges from external environment".

It was demonstrated in experiment with dogs that plaque formation resulted in reaction of peri-implant mucosa and establishment of infiltrate of inflammatory cells in connective tissue lateral to pocket and junctional epithelium [184]. Similar results were obtained in experiments, where peri-implant mucositis was caused in humans [185;186].

The area of infiltrate and also the apical extent seems to be dependent on the period of plaque accumulation. The vertical extension of infiltrate was reported to be longer after 5 months of undisturbed plaque accumulation in comparison to its size after 3 weeks or 3 months of plaque accumulation. The apical extension of this infiltrate was consistently within the dimension of the junctional epithelium [187-189].

The composition of infiltrate in comparison to healthy tissue shows significant decrease of collagen fibers and increase of vascular units, leukocytes and residual tissue. Morphometric measurements show, that in comparison to healthy condition, inflamed peri-implant sulcus epithelium exhibited areas of ulceration, had *rete peg* formations and contained numerous polymorphonuclear granulocytes, macrophages and leukocytes [190]. Animal and human histology studies show that there is an increase of inflammatory cell migration through junctional epithelium, in response to bacterial presence [191;192]. These findings support the idea that junctional epithelium of BW around implants serves as a protective mechanism against bacterial invasion.

Lindhe and co-workers, in an experiment with dogs, put silk ligatures submarginally around the implant to damage junctional epithelium attachment and to open deeper peri-implant tissues for plaque formation. Within 4 months, about 3 mm of bone height was lost [193]. Marinello et al [194] in a similar study with dogs reported the loss of 25% of the original bone height Other animal studies which experimentally induced peri-

implantitis may be another argument that junctional epithelium attachment protects bone. Mechanical damage of junctional epithelium by means of submucosal ligature placement resulted in the loss of protective abilities and constant bone loss around implants [195-203]. In contrast Berglundh et al enhanced plaque formation for 3 weeks without disruption of junctional epithelium and observed soft tissue inflammation, but no bone loss. A zone of normal connective tissue consistently separated the inflammatory lesion from the marginal bone [204]. Furthermore, Ericsson et al. inspected peri-implant tissues after uninterrupted plaque build-up for 3 months [205], Abrahamson et al. after 5 months [206] and Ericsson et al. after 9 months [207]. Interesting results aroused from Watzak et al experiment, as implants were subjected for 1.5 year continuous plaque accumulation without hygienic control. Histological analysis did not show an increased bone loss around plaque-contaminated implants [208]. The results of all four studies showed that plaque accumulation caused inflammation of peri-implant soft tissues, but no bone resorption was noted. Stable bone level around osseointegrated implant can be maintained even under the onset of plaque-induced inflammation if components of BW are not mechanically damaged.

Zitzmann and co-authors combined both research models mentioned above (disruption of the junctional epithelium with ligatures and assessment of the effects of plaque accumulation without junctional epithelium disruption) in one study. In the first part of an experiment plaque accumulation was enhanced by submarginal ligature placement. Mechanical separation of the attachment between the mucosa and the implant, and the build-up of plaque in this submarginal location initiated an inflammatory reaction that involved not only the mucosa but also the peri-implant bone. Thus, in the interval of 2 months about 2.5–3 mm of the marginal bone was lost. After the removal of the ligature and allowing a healing period of 3 months, most of the lesions caused by the ligature-induced inflammation were separated from the bone by a collagen-rich connective tissue and no further bone loss occurred. Only isolated osteoclasts could be found on the surface of the marginal bone [209] .

One of the functions of the connective tissue zone is to support epithelial tissues and limit its migration apically. The dominance of Type I collagen fibers (strong and inelastic) in connective tissues confirms their supportive role. However, it must be pointed out that in

Chavier and Coubles' study, biopsies were taken from keratinized mucosa and may differ from that of non-keratinized peri-implant mucosa [210].

Formation of soft tissue seal around implants was shown to be a complex process, which lasts about 6 weeks. It starts immediately after the placement of a non-submerged implant as mucosal tissues are sutured. If a two-stage procedure is applied, the structuring of BW begins with the connection of healing abutment during the second stage surgery. At that time, the implant becomes exposed to adverse oral environment; therefore, a particular protective mechanism has to be organized to avoid direct contact of the bone with other oral tissues. Epithelial proliferation with further attachment, followed by collagen fiber organization results in the establishment of stable dimension of about 4 mm in vertical extension, responsible for protection of alveolar bone around osseointegrated implants. Morphogenesis of peri-implant tissues was described in vast dimension animal study, which involved 160 implants and 20 Labrador dogs [211]. Implants were placed in non-submerged installation technique. The animals were sacrificed and biopsies obtained at various intervals to provide healing periods from 2 hours till 8 weeks. Such study design allowed to track whole process of peri-implant mucosa formation. Immediately after surgery a coagulum occupied the space between the mucosa and the implant. Within week of healing, the blood cloth was infiltrated by neutrophils and an initial mucosal seal was established by dense fibrin network. This provisional seal persisted at 1 week of healing. The tissue in the apical part of the mucosal interface at 1 week was dominated by collagen and fibroblasts. At 2 weeks after surgery, the peri-implant mucosa adhered to the implant surface by a connective tissue that was rich in cells and vascular structures. In the crestal portion of the tissue, proliferation of epithelium had occurred and the first signs of a barrier (junctional) epithelium were observed. Bone remodeling was intense at this phase of healing and the marginal level of bone to implant contact was located at a more apical position than at 1 week of healing. At 4 weeks of healing barrier epithelium had formed and occupied almost halft of the mucosal interface to titanium. The connective tissue was well organized and contained large portions of collagen and fibroblasts. Tissue maturation and collagen fiber organization was evident from 6 to 12 weeks of healing, and the formation of barrier epithelium was completed between 6 and 8 weeks. A dense layer of elongated fibroblasts formed the connective tissue interface to

titanium. In connective tissue compartments lateral to the implant interface, few vascular structures were found. Fibroblasts were interposed between thin collagen fibers, the direction of which was mainly parallel to the implant surface. It is very important to mention, that bone remodeling had resulted in a distinct crestal bone portion at a position of about 3.2 mm apical of the soft tissue margin.

Mucosal tissues take part in peri-implant seal formation; therefore the composition and features of mucosa must be important to study.

Historically, two types of mucosal phenotype are distinguished: thin, which is described as prone to recession with sharp papillae; and thick, generally stable with blunt interdental tissue. However, there is some controversy in literature about what kind of soft tissue thickness could be referred to as thin or thick. Muller at al reported that about 80% of all examined soft tissues are of mixed pattern, which cannot be strictly attributed to thin or thick biotype [212]. Differences in width and thickness of gingiva in particular and thickness of masticatory mucosa in general are largely genetically determined and appear to be strongly associated with periodontal characteristics. Subjects with a narrow band of thin gingiva, clearly more vulnerable to traumatic injury, tended to suffer from more mucosal recession than subjects with thicker keratinized tissue. Conceivably, a close mutual interrelationship exists between mucosal dimensions and thickness of the underlying alveolar bone. Thick masticatory mucosa in combination with thick alveolar bone may lead to a higher frequency of periodontal and, in particular, infrabony pockets, whereas a thin phenotype may lead to more mucosal recession.

However, it must be noticed that usually facial or palatial/lingual tissue set was investigated for the determination of periodontal biotype. Mucosal tissue at the top of the edentulous alveolar crest usually remained out of the scope of authors' interest.

Mucosal tissue covering edentulous alveolar ridge was shown to be composed of oral epithelium, connective tissue and periosteum. The oral epithelium is a keratinized, stratified and squamous epithelium, which can be divided into following cell layers: (1) basal layer; (2) prickle cell layer; (3) granular cell layer and (4) keratinized cell layer. The function of oral epithelium is the protection of inner layers of mucosa from contaminated oral environment. Predominant tissue component of the gingiva is the connective tissue (lamina propria). It consists of 2 layers: (1) papillary layer subjacent to the epithelium,

which consists of papillary projections between the epithelial rete pegs, and (2) a recticular layer contiguous with the periosteum of the alveolar bone. Connective tissue in composed of collagen fibers, fibroblasts, vessels and nerves [213]. This part of oral tissues is known to be transformed to peri-implant tissues after placement of dental implants. Consequently, its feature, like thickness is shown to be very important in this process. Animal experiment by Berglundh et al has proved that bone loss could be induced by inadequate soft tissue thickness [214]. However, it would be very important to find similar relationship in clinical reality, as animal studies do not completely reflect processes proceeding in humans. Equally, more precise study protocol would be required to test the influence of mucosal tissue on crestal bone stability, as tissues were surgically thinned in previuos experiment. Additionally, there is lack of information what kind of mucosal tissue at the edentulous ridges can be classified as thin, medium or thick.

2.3. Platform switching

Platform switching concept is no novelty, as it is usually presented. Already in 1980's some large diameter implants, like Ankylos (Friadent, Densply, Germany) were restored with narrower prosthetic abutments, thus unintentionally creating mismatch at implant-abutment interface and establish benefits of platform switching (Fig. 3).

Fig. 3. Implant with platform switching modification. Note that abutment is narrower that implant platform.

Platform switching is based on assumption that moving implant-abutment connection away from bone crest by connecting prosthetic abutment of narrower diameter will reduce crestal bone loss. The explanation for such hopes lies in study by Ericsson et al [215], which detected inflammatory cell infiltrate in connective tissue zone, contacting implant-abutment interface. Authors suggested that formation of infiltrate is a defensive action of the host from microgap, contaminated with oral bacteria. Microorganisms attract neutrophils, which, in turn are responsible for osteoclasts presence, thus explaining crestal bone loss. As in implants with platform switching microgap is shifted away from bone, inflammatory cell infiltrate forms not in close proximity to bone, therefore, crestal bone loss is reduced. This hypothesis was described by Lazzarra et al [216] in article based on the summary of radiographic observations of implants with platform switching from 5 to 13 years. Authors have suggested that platform switching repositions inflammatory infiltrate within approximate 90 degree-confined area of exposure, instead of 180 degree surface of regular connection implants, thus infiltrate is smaller around platform switched implants.

Additionally, it was proposed that first component placed on implant (healing or prosthetic abutment) should be smaller in diameter for the horizontal establishment of biological width around implants. However, it must be noted that this article in nature and be described as hypothetical review, therefore should not be considered as strong evidence for efficiency of platform switching in bone loss preservation.

The proofs for platform switching rationale are presented on various levels of evidence. Maeda et al in three-dimensional finite element analysis tested, if there was a biomechanical basis for applying platform switching in implant dentistry [217]. Study included comparison of 4 mm diameter external hex implant with 4 mm healing abutment and 3.25 mm diameter abutments on top. Results have showed that the stress levels in cervical bone area at the implant was greatly reduced when the narrow diameter abutment was connected compared with regular-size one. Therefore authors concluded that platform switching modifications has inherited biomechanical advantage of shifting the stress concentrations away from cervical area of the implant.

Baggi et al conducted a similar finite element analysis experiment to define stress distribution and magnitude in the crestal area around 3 commercially available implants –

ITI Straumann, Nobel Biocare and Ankylos. Numerical models of maxillary and mandibular molar bone segments were generated from computed tomography images, and local stress measures were introduced to allow for the assessment of bone overload risk. Different crestal bone geometries were also modeled. Type II bone quality was approximated, and complete osseous integration was assumed. It was concluded that Ankylos implant based on the platform switching concept and subcrestal positioning demonstrated better stress-based performance and lower risk of bone overload than the other implant systems evaluated [218]. Additional verification of platform switching benefits for reduction of stress concentration in the implant neck region were presented in another computer-generated study by Schrotenboer et al [219], which compared the influence of reduced abutment diameter on amount of stress transmission to bone. Results showed that reduced abutment diameter (i.e., platform switching) resulted in less stress translated to the crestal bone in the micro-threaded and smooth-neck groups.

Histological animal studies provide contrary evidence. Becker et al [220] conducted experiment, when two-piece implants were placed in submerged approach in 9 dogs. At the time of second stage surgery, half of the implants were fitted with horizontally matching healing abutments and the other half – with smaller in diameter healing abutments, thus imitating platform switching modification. Histological specimens for analysis were taken 7, 14 and 28 days after uncovering of implants. Results have shown that implants with platform switching had increased length of junctional epithelium, compared to implants with standard abutments. However, no difference in bone crestal bone loss between control and test groups was noticed. Authors concluded that within limitations of their study, platform switching modification failed to preserve more bone at the crest.

Jung et al [221] in an animal experiment compared implants with platform switching, placed in 3 different positions to the bone level. Implants were restored, followed for 6 months and underwent radiographic. In general, it was concluded that position of the implant (supracrestal, crestal or subcrestal) did not statistically significantly influence amounts of bone loss. Additionally authors suggested that implants with non-matching implant-abutment interfaces revealed small amounts of bone loss relative to the top of the implant compared to implant-abutment interfaces when the implant and the abutment

diameter do not differ. However, it must be mentioned that this experiment did not poses a control group, comprised of regular connection implants, therefore conclusion should be evaluated carefully.

Material from human histology studies can provide valuable information about performance of platform switched implants. Recent study by Luongo et al [222] evaluated 1 implant (Prevail, 3iBiomet, USA) with fully integrated peri-implant tissues, retrieved from the mouth due to very unfavorable position for prosthetic rehabilitation. It was observed that in connective tissues, facing implant-abutment connection, inflammatory cell infiltrate was located, extending vertically for about 0.35 mm, while horizontal extension did not exceed the extension of implant platform. No inflammatory infiltrate was observed below implant platform.

Degidi and colleagues [223] in similar case report inspected single Ankylos (Densply-Friadent, Manheim, Germany) implant with platform switching and Morse cone connection. This implant was immediately loaded with plastic provisional prosthesis after placement about 2 mm below level of the bone, however was retrieved from the patient after 1 month due to psychological reasons. Histological evaluation revealed no microgap-related inflammatory cell infiltrate, no osteoclasts and no bone loss was present, in spite of the fact that implant-abutment connection was positioned approximately 2 mm below crest. Authors concluded that platform switching, together with stable implant-abutment connection are preferable implant design features, needed to reduce or eliminate early crestal bone loss.

Obviously, clinical studies provide the highest rank evidence, thus must be discussed properly. Until now there are three controlled clinical trials, investigating the benefits of platform switching of implants for crestal bone preservation. Vela-Nebot et al studied crestal bone stability around 30 implants with platform modification and 30 implants with regular connection. After 1-year follow up radiographic examination of bone loss revealed that mesial measurement for the control group was 2.53 mm, whereas for patients in test group, it was 0.76 mm. The mean value of bone resorption observed in the distal measurement for patients in the control group was 2.56 mm, while for implants in study group, it was 0.77 mm. It was concluded that implants with platform switching

modification had significant reduction of bone loss in comparison to the control group [224].

Hurzeler et al carried out an experiment to test if crestal bone height around dental implants could be influenced using a platform switch protocol and that the bone level would remain stable within 1 year after final prosthetic reconstruction. Fifteen patients were treated with fixed implant retained prosthesis; 14 wide-diameter implants were supplied with platform-switched abutments and served as the test group. Eight implants with regular diameter were reconstructed with traditional abutments and served as the control group. One year after final restoration, the mean value of crestal bone height was about -0.22 mm for the test group and approximately -2.02 mm for the control group. The concept of platform switching appears to limit crestal resorption and seems to preserve peri-implant bone levels. A certain amount of bone remodeling 1 year after final reconstruction occurs, but significant differences concerning the peri-implant bone height compared with the non-platform-switched abutments are still evident 1 year after final restoration. The reduction of the abutment of 0.45 mm on each side (5 mm implant/4.1 mm abutment) seems sufficient to avoid peri-implant bone loss.[225]

There are results form larger sample sizes. Cappiello et al [226] published outcome of controlled clinical trial, where one hundred thirty-one implants were consecutively placed in 45 patients following a non-submerged surgical protocol. On 75 implants, a healing abutment 1 mm narrower than the implant platform was placed at the time of surgery. On the remaining implants, a healing abutment of the same diameter as the implant was inserted. All implants were positioned at the crestal level. The data collected showed that vertical bone loss for the test cases varied between 0.6 mm and 1.2 mm (mean: 0.95 +/- 0.32 mm), while for the control cases, bone loss was between 1.3 mm and 2.1 mm (mean: 1.67 +/- 0.37 mm). These data confirm the important role of the microgap between the implant and abutment in the remodeling of the peri-implant crestal bone. Platform switching seems to reduce peri-implant crestal bone resorption and increase the long-term predictability of implant therapy. Canullo and Rasperini in case series analyzed 10 platform switching implants placed immediately into fresh extraction pockets with prosthetic loading in 9 patients and followed-up for 22 months on average. Analysis of radiographic films showed a bone resorption of 0.78 mm, whereas clinical examination

showed that there was a mean gain in the buccal margin of 0.2 mm and a mean gain in papilla height of 0.25 mm. Outcome of the study led to the conclusion that immediate loading with platform switching can provide peri-implant hard tissue stability with soft tissue and papilla preservation. Similar conclusion was made by Calvo-Guilardo et al in an uncontrolled clinical trial with 10 platform switched implants placed into fresh extraction pockets in 10 individuals. Only very minimal amounts of crestal bone loss (0.06 mm) could be recorded after 6 months of loading [227].

Relatively bigger amount of bone resorption around Certain Prevail implants (3i, Biomet, USA) was recorded in another study, as crestal bone resorption was 0.6 mm after 16 months of loading [228]. Two retrospective studies by Norton reported minimal amounts of bone loss around implants with horizontally non-matching connection [229-231]. In the first trial 0.60 mm mesially and 0.62 mm distally of bone loss was registered after 4 years of loading. Second study with a follow-up of 7.5 years reported these measurements to be 0.56 and 0.70 mm, respectively. Chou et al reported bone loss around implants with platform switching to be only 0.2 mm within 3 years of loading, although bone resorption between implant placement and uncovering was from 0.5 to 2 mm on average [232].

Thus it can be concluded that current evidence from laboratory, animal or human histological and clinical studies suggest that platform switching modification can reduce crestal bone around implants. However, there is no information in the literature about the effect of thin mucosal tissues on crestal bone levels around implants with platform switching.

3. MATERIALS AND METHODS

3.1. The influence of mucosal tissue thickness on crestal bone changes around implants with regular horizontally matching implant-abutment interface.

Patients

Subjects were randomly selected among partially edentulous patients, who attended Vilnius Implantology Center Clinic (Vilnius, Lithuania) for implant treatment.

Inclusion criteria were as follows:

1. No less than 18 years of age;
2. Bone sites at least 6 months after tooth extraction;
3. No bone augmentation procedures before and during implant placement;
4. Edentulous gap for at least 2 implants in any region of the mouth with minimum 3 mm distance in-between and minimum 1 mm range from adjacent tooth/teeth;
5. No medical contraindication for implant surgery;
6. Signed informed consent form for participation and permission to use obtained data for research purposes;
7. Sufficient bone vertical dimension to 9 mm implant in length could be placed.

Patients were excluded, if they did not meet requirements listed above and additionally had:

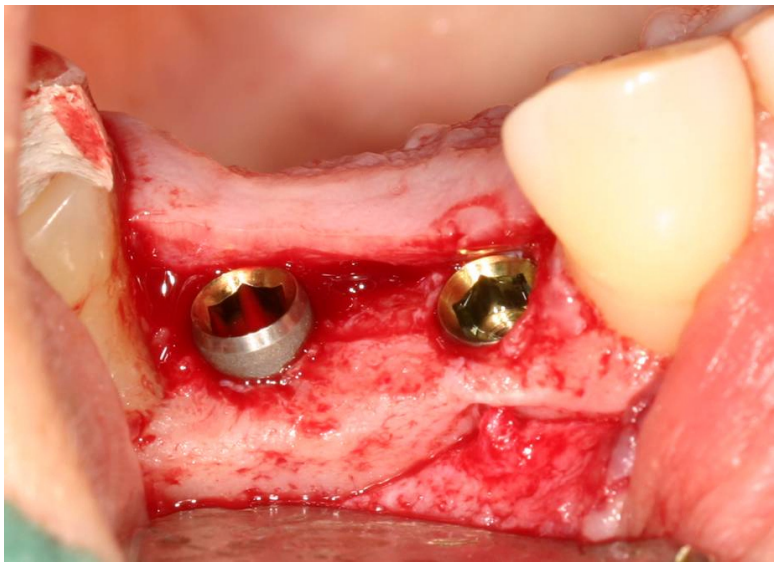
1. Poor oral hygiene;
2. Symptoms or history of periodontitis or peri-implantitis treatment;
3. Poor co-operation, required for the study;
4. Smoking;
5. Alcoholism;
6. Diabetes;
7. Alveolar ridges with bone defects at implantation sites.
8. Poor primary stability, precluding healing abutment connection at a time of surgery;
9. Absence of attached gingiva or presence less than 1 mm.

Initially, 34 patients agreed to participate in the study. A group of 5 patients was excluded from the study on the basis of refusal to attend follow-up checkups. Additionally, 3 subjects were excluded from the study, because radiographic images of implants they received were not sufficiently parallel to correctly calculate crest bone changes. The final sample included 26 patients consisting of 14 males and 12 females. Subjects' average age was 45.6 y., ranging from 23 to 71 years at the beginning of the experiment.

Study design

A prospective controlled randomized clinical trial was initiated. Two implants 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, according to standard insertion protocol (Fig. 4).

Fig. 4. Position of test (left) and control (right) implants



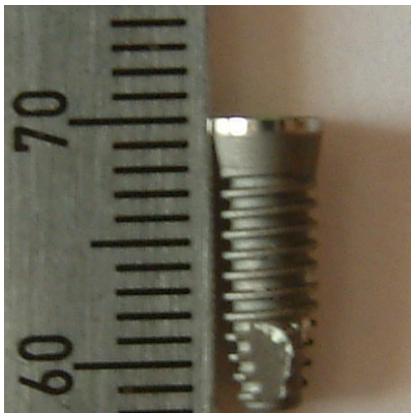
Supracrestal location of the test implant aimed to reduce the impact of other factors, responsible for crestal bone loss of the particular implant. Control implants were inserted equally with crest, as placement of implants at the bone level is used as a common practice standard, recommended by majority of manufacturers and studies. The reason for such particular study design will be more broadly disputed in "Discussion" part.
Cases for the study were randomly selected among partially edentulous patients, who attended clinic for treatment. Therefore, primary patient sample was collected incidentally. Secondly, patient birth date was used to randomize which implant will be allocated as test implant and positioned supracrestally. If a patient's birth year ended with an even number (e.g., 1970), the first implant was considered to be test one and positioned 2 mm above the bone crest. If the number was odd (e.g., 1971), the first

implant was placed equally with crest and served as a control. In both cases second implant was inserted conversely.
As it was prospective clinical trial, special data sheet was developed for data gathering, recording and analysis.

Implant placement

Placement of implants was planned after clinical and radiographic examination. Implants with internal hex (Prodigy; BioHorizons, Alabama, USA) were placed in a single stage (non-submerged) technique by an experienced surgeon. Operating person was not informed about purpose and possible outcome of the study; therefore he could not intentionally influence the results. Implants used in the study were made from Ti-6Al-Nb alloy; implant surface was roughened with resolving blasting media (RBM). The top of implant neck had 0.5 mm polished part for connection with abutment. Before implant placement a trial implant was inspected to measure visually the extent of implant to be left supracrestally, as study design indicated (Fig. 5).

Fig. 5. Evaluation of the training implant. Note 0.5 mm polished part at the top of the implant

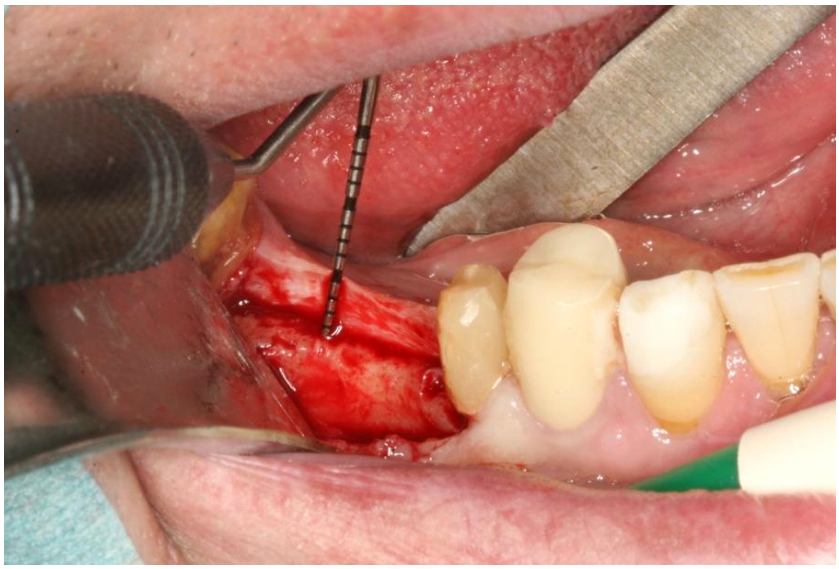


This assisted surgeon to position implants about 2 mm above the bone level.
All patients received a prophylactic dose of antibiotics of 2 g amoxicillin (Ospamox; Biochemie, Austria) 1 hour prior to the surgery. After the administration of 4% articaine

solution (Ubistesin; 3M ESPE, Germany) for local anesthesia, a mid-crestal incision on the center of edentulous ridge was performed. The flap was raised in two stages:

1. Buccal flap was raised and mucosal thickness of unseparated palatal-lingual flap was measured with 1.0 mm marked periodontal probe (Hu-Friedy, Chicago, IL, USA) at the bone crest in the place in the center of future implant placement (Fig. 6). This ensured direct visibility of mucosal thickness measurement.
2. Palatal/lingual flap was raised to expose implant site.

Fig. 6. Measurement of tissue thickness after buccal flap elevation. Note the unseparated lingual flap.



The osteotomy site was measured to allow a minimum 3 mm distance between the two implants, 1 mm range from adjacent tooth/teeth and 1 mm space between buccal and lingual/palatal crest of the alveolar ridge and implant. Test and control implant sites were allocated following to the afore-described randomization order. The implants were placed at crestal level (control implant) and 2 mm above the bone level (test implant). The verification of the position of the implant was performed with probe. Implants of different diameter (3.5 and 4.0) were placed, according to the clinical situation. After implant placement, healing abutments were connected and 5/0 interrupted sutures (Polysorb; USS-DG, Norwalk, CT) were placed. Flaps were approximated without tension and sutured without leaving gaps. Immediately after suturing, radiographs were

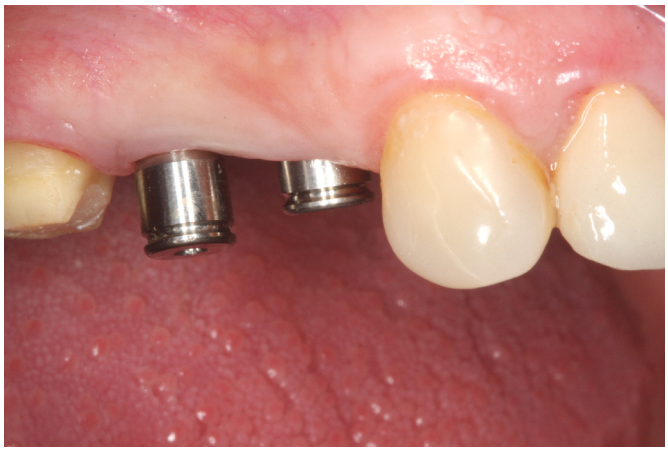
taken using RVG Windows Trophy 5.0 (Trophy Radiologie Inc., Paris, France) periapical films in high-resolution mode. Patients were instructed to rinse the operated site with 0.12% chlorhexidine-digluconate (Fresenius Kabi Norge; AS, Norway) solution twice a day for a week. For pain control, patients were prescribed 400 mg of ibuprofen (Ibumax; Vitabalans Oy, Finland) to be taken as needed. Patients were advised to minimize trauma to the site without special diet introduced. The sutures were removed 7-10 days following the surgery. Patients were advised to clean healing abutments with very soft tooth brush.

Restorative procedures

Prosthetic procedures were initiated following 2 months of healing in the lower jaw and 4 months in the upper jaw (Fig. 7). Before starting prosthetic treatment, implant success criteria were applied. The implants were considered successful and suitable for restoration, if they had:

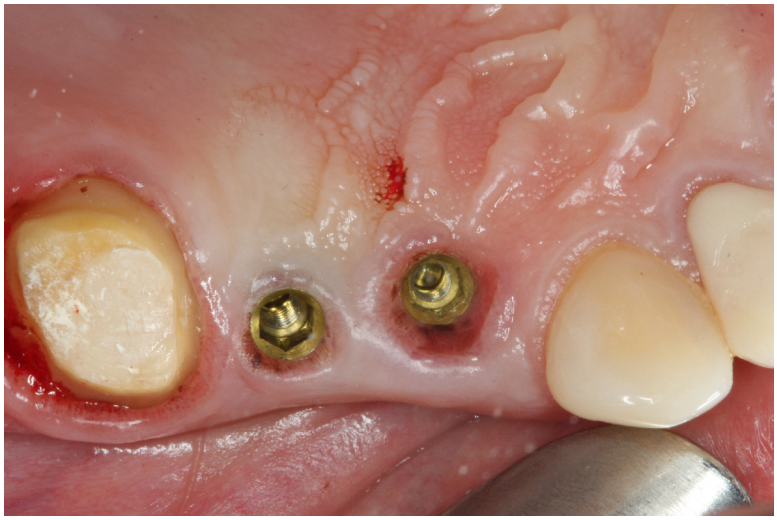
1. absence of radiolucency around the implant,
2. no clinically detectable mobility and
3. no suppuration, pain, or ongoing pathologic processes [233].

Fig. 7. Test implant (left) and control implant (right) with healing abutments



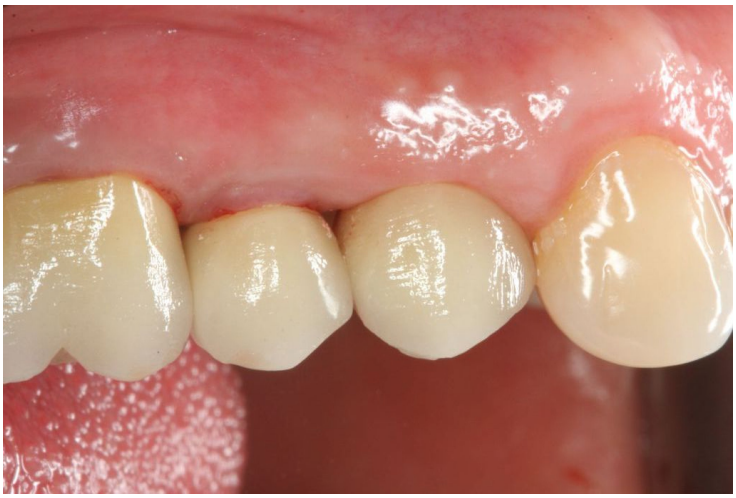
After first disconnection of healing abutments soft peri-implant tissues were visually inspected for good healing and depth of implant platform (Fig. 8). Impressions were taken using an open-tray technique. If a fixed partial denture was constructed impression transfers were splinted together with cold-cured resin (Pattern resin; GC, Japan). A-polyvinylsiloxane (Flexitime; Heraeus Kulzer, USA) putty and correction material was used for a one-step impression with the individual tray covered with adhesive.

Fig. 8. Soft tissues after disconnection of healing abutments – control implant (right) and test implant (left).



Porcelain-fused-to-metal fixed restorations were constructed and cemented with resin modified glass-ionomer cement (Fuji Plus; GC, Tokyo, Japan) on roughened surface modified standard abutments. Prosthetic abutments were fabricated from titanium alloy, no castable abutments were used. Preparation line on abutments was located not deeper than 0.5 mm below the mucosal margin. Prior to prostheses cementation abutments were tightened to the implants, using a torque wrench set to 30N/cm^2. Soft tissue probing was not performed to avoid disruption of soft tissues. Prosthetic treatment was performed by the same prosthodontist. It took about 1 month of treatment to finish one case.

Fig. 9. Single metal-ceramic implant-supported crowns on 14 and 15 implants.



After cementation radiographic images were taken to ensure abutment seating and check for residual cement. After prosthetic treatment patients were instructed on cleaning implant-supported restorations (Fig. 9).

Follow-up examinations and maintenance schedule

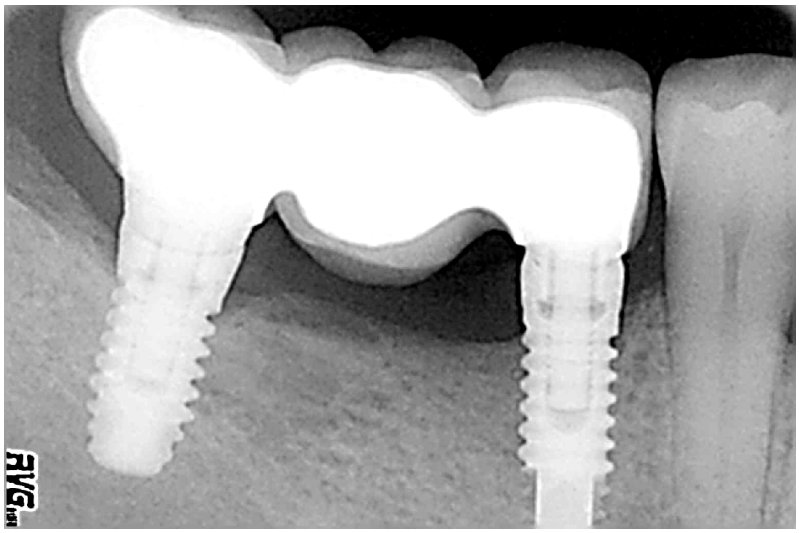
Patients were recalled 6 and 12 months after prosthetic treatment for oral hygiene and evaluation. At each visit the restorations were evaluated for mobility, peri-implant soft tissue condition and patient satisfaction. Intra-oral radiographs were taken to evaluate bone changes.

Radiographic assessment and measurements

Intra-oral radiographs were taken using a paralleling technique with Rinn-like film holder in high-resolution mode. The x-ray machine standard set-up was as follows: voltage - 70 kV, intensity of power - 4mA and exposure time was set to usual program 7. Standard set-up was used for all radiographs and exposure time was specified manually depending on implant location, ranging from 0.110 – 0.189 s. The images were obtained to make sure implant/abutment interface and the threads were clearly visible. Before measurement the parallelism of all intra-oral radiographs was evaluated. Therefore, radiographic

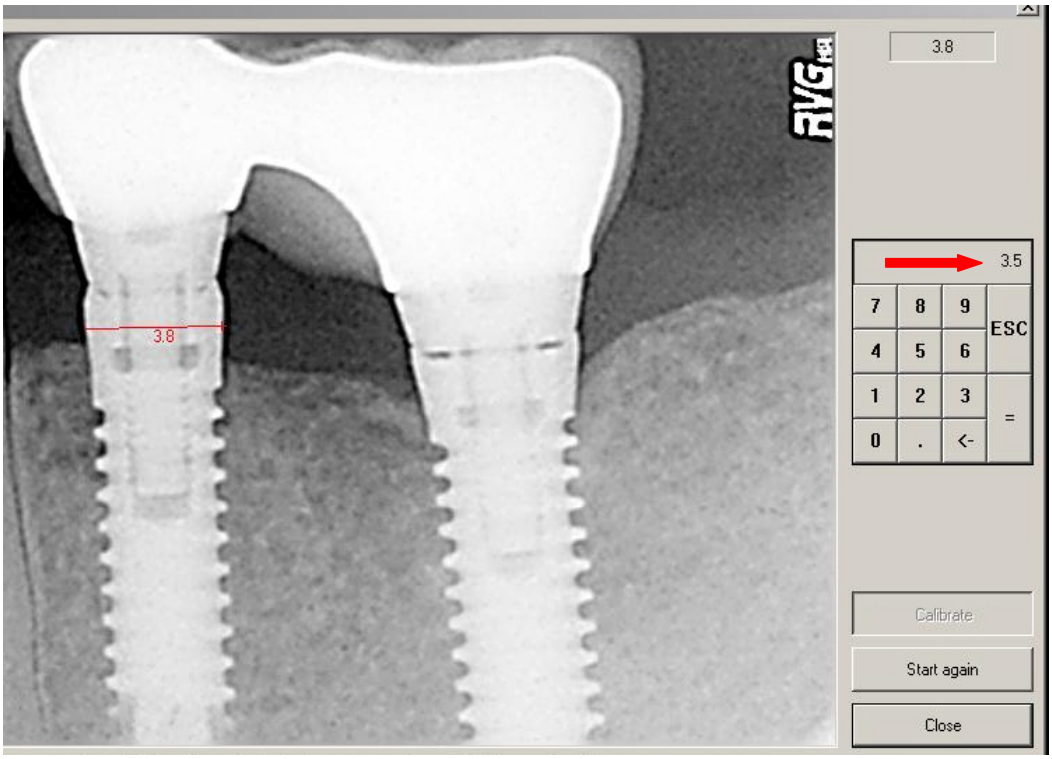
images of 3 cases were excluded as they were not considered sufficiently parallel for accurate calculation of bone changes (Fig. 10).

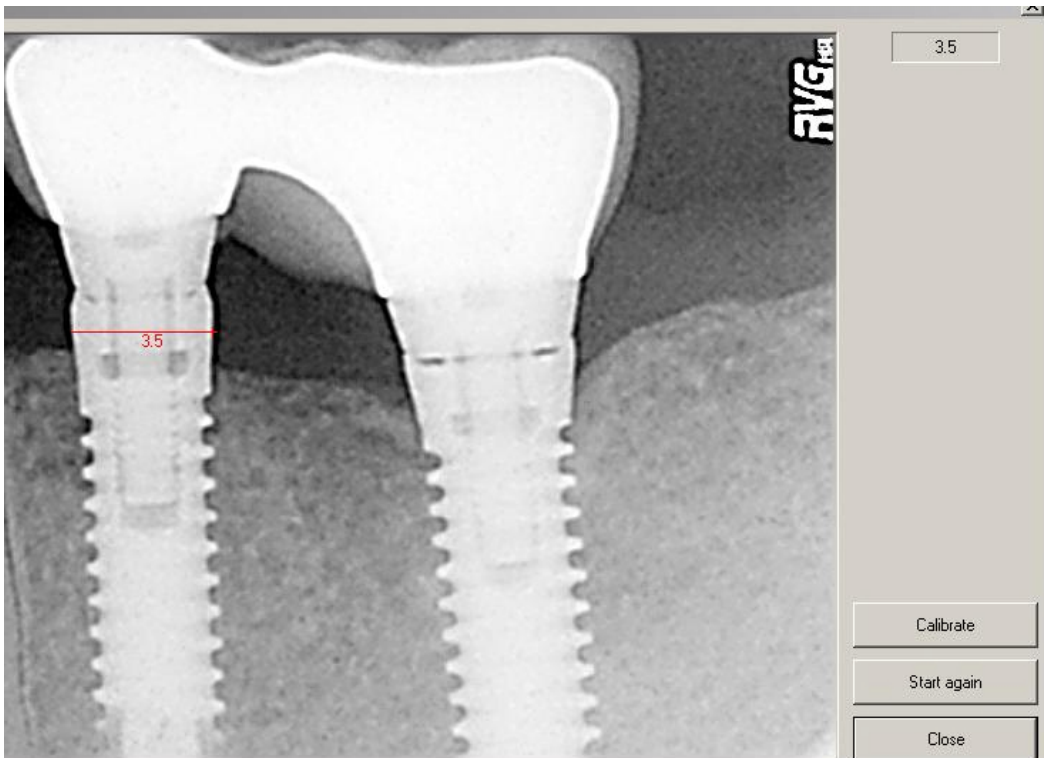
Fig. 10. Excluded radiographic image. Note not parallel visibility of implant threads.



All test implants (placed 2 mm supracrestally) were divided into 2 groups according to the thickness of mucosa at the time of their placement. Patients with 2 mm or less mucosal thickness were assigned to group A with thin mucosa (12 cases), and patients whose mucosal thickness was more than 2 mm were assigned to group B that represented a thick mucosa set (20 cases). The assignment to two groups was performed following the methodology of animal experiment. Radiological evaluation and measurements were performed by one of the examiners using radiovisiography (RVG) Windows Trophy 5.0 software measurement program with a magnification (x 6). Two images were selected for calculation of crestal bone changes, such as *(1)* after implant placement, and *(2)* after 1 year post reconstruction. Before calculation of the crestal bone changes the calibration of RVG images was performed, using calibration program in the Trophy RVG software (Fig. 11). The diameter of implants was used for calibration as a reference point.

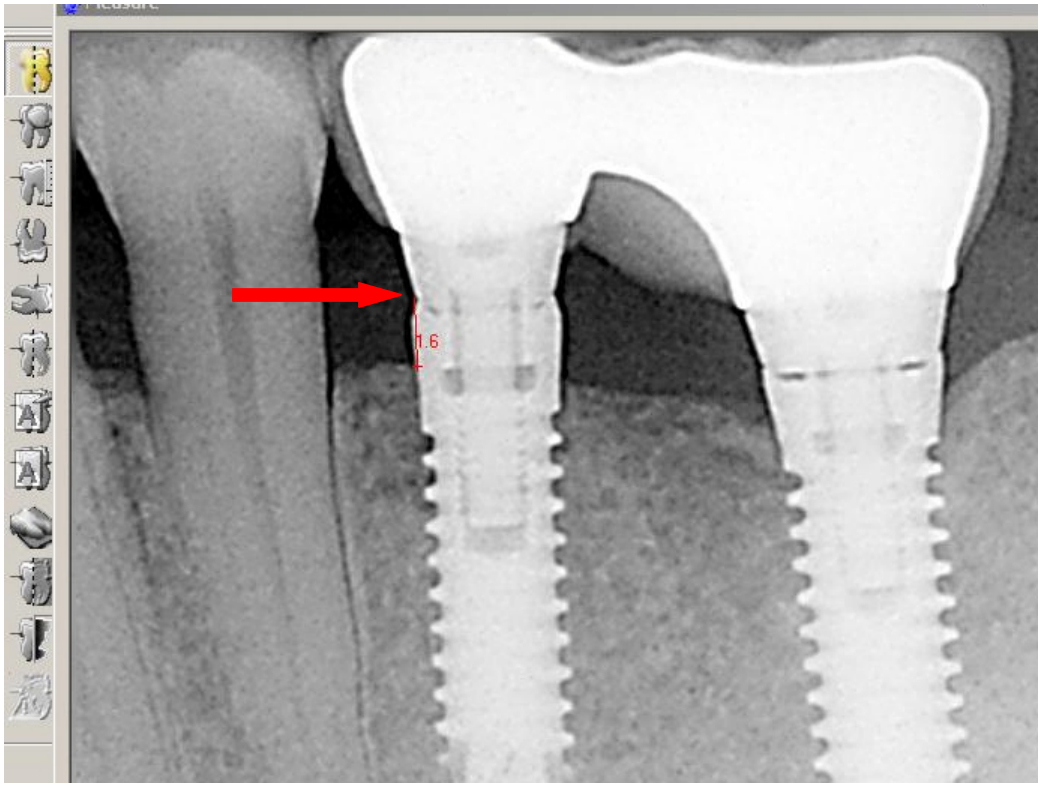
Fig. 11. Calibration device in measuring program Trophy RVG software. Note 3.8 measurements on 3.5 diameter implant and 3.5 measurements after calibration.





Implant/abutment interface was chosen as a starting point for a calculation, as it was easily identified in parallel RVG image (Fig. 12). The first measurement demonstrated the distance between implant/abutment junction and crestal bone after implant placement in distal and mesial aspects. The second measurement evaluated the same distance after 12 months of follow-up. The difference between these values showed the amount of proximal actual amount bone loss. The measurements were repeated after 1 month.

Fig. 12. Implant-abutment interface (red arrow) and mesial measurement



Statistical analysis

Data were analyzed using SPSS 15.0 Windows (SPSS; Chicago, IL, USA) statistical software. The single implant was treated as a statistical unit. Initially, each variable was assessed using parametrical methods. As variables appeared to be normally distributed frequencies were calculated. In this case, Pearson's correlation coefficient was calculated to explore the direction and strength of the relationship between mesial and distal sites of the same implant. In case if one parameter is continuous and normally distributed, and the

second parameter is discrete nominal, analysis of variance was applied. Next, a two-way analysis of variance (ANOVA) was conducted to assess mean differences within the groups. The statistical significance between groups was assessed using F test.
For comparison of continuous variables means and standard deviation were calculated. Then, paired t-test analysis was conducted to assess mean differences between test and control groups. The mean differences were considered statistically significant at $P \leq 0.05$ with a confidence interval of 95%. To visualize the differences 95% confidence intervals were plotted. The intra-examiner agreement was determined by second measurement, which was performed after a month interval. The mean difference between measurements was 0.1 mm ± 0.16. All measurements were reproduced with within difference of ± 0.5 mm. Later, continuous variable were converted in two discreet ordinal values, using rules of distribution analysis. At first stage minimum and maximum was found, after those, median and lower and upper quartiles were calculated. This allowed distributing all mucosal thickness measurements into 3 distinct groups – thin, medium and thick.
Bone loss and comparison between groups and within groups was reported in two ways: separately, on distal and mesial sites and combined value per implant, which was obtained by merging both distal and mesial values.
Statistical data evaluation was performed in following stages:

1. Descriptive data analysis;
2. Bone loss calculation around test and control implants;
3. Comparison between test and control groups;
4. Comparison within groups, considering two thickness groups (thin and thick);
5. Comparison within groups, considering three thickness groups (thin, medium and thick);
6. Influence of prosthetic configuration, gender and jaw on crestal bone changes.

3.2. The influence of thin mucosal tissues on crestal bone changes around implants with platform switching.

Patients

Subjects were randomly selected among partially edentulous patients, who attended Vilnius Implantology Center Clinic (Vilnius, Lithuania) for implant treatment.
A major inclusion criterion was the presence of thin mucosal tissues 2 mm or less, covering edentulous alveolar ridge. Other inclusion and exclusion criteria were the same as in previous clinical study.

Study design

A pilot controlled prospective clinical trial was initiated. Implants with platform switching modification (Prevail, 3iBiomet, USA) were assigned as a test group and implants with horizontally matching implant-abutment connection (Prodigy, BioHorizons, Alabama, USA) formed a control group. The reason for starting pilot investigation was intention to find out possible results, before initiating large, expensive investigation. Pilot studies provide an opportunity to make adjustments and revisions before investing in, and incurring, the heavy costs associated with a large study. Both types of implants were positioned equally with bone level according to standard implant placement recommendations. Implants with traditional horizontally matching implant-abutment interface was selected as a control group, because platform switching concept, compared to traditional two-piece implant connection can be considered novel and needs to be researched more intensively.

Implant placement

Control implants with internal hex (Prodigy; BioHorizons, Alabama, USA) were placed in a single stage method. Control implants used in the study were made from Ti-6Al-Nb

alloy; implant surface was roughened with RBM. The top of implant neck had 0.5 mm polished part for connection with abutment. Test implants (Prevail, 3iBiomet, USA) with platform switching were made of titanium alloy; surface was acid-etched and blasted. Implant had no polished part ay the top. Test and control implants were positioned equally with crest.

Preparation for the surgery, the raising of the mucoperiosteal flaps, measurements, implant placement methodology, postoperative care were the same as in previously described study. The sequence of the intervention can be seen in figures 13-15.

Fig. 13. Thin tissue biotype before implant placement.

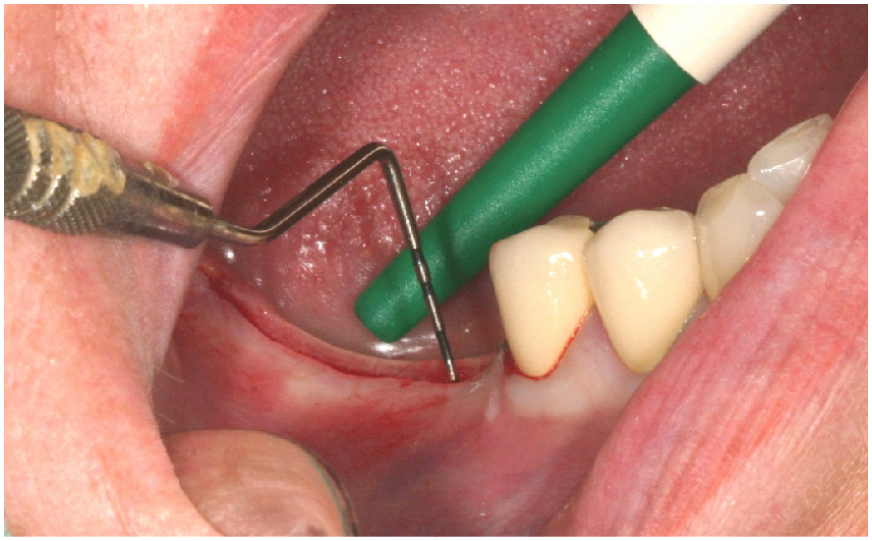


Fig. 14. Crestal position of test implant (left) and control implant (right)

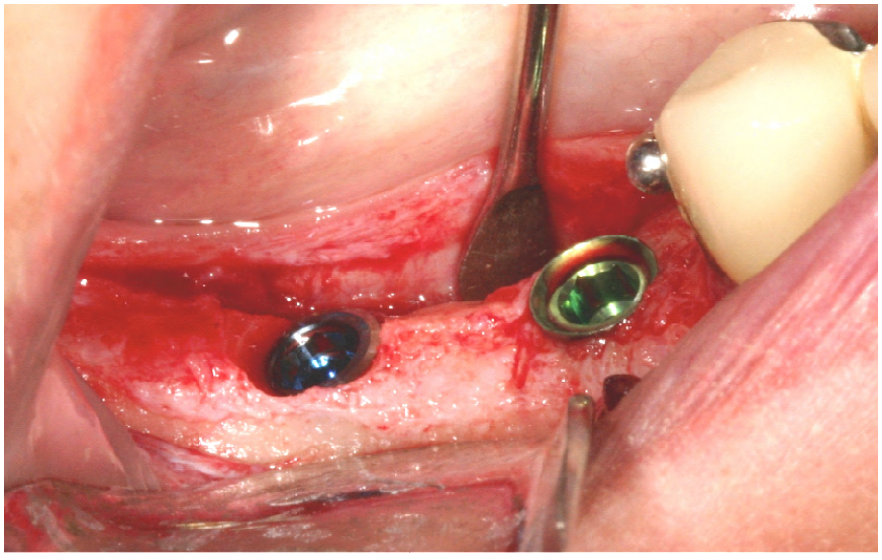
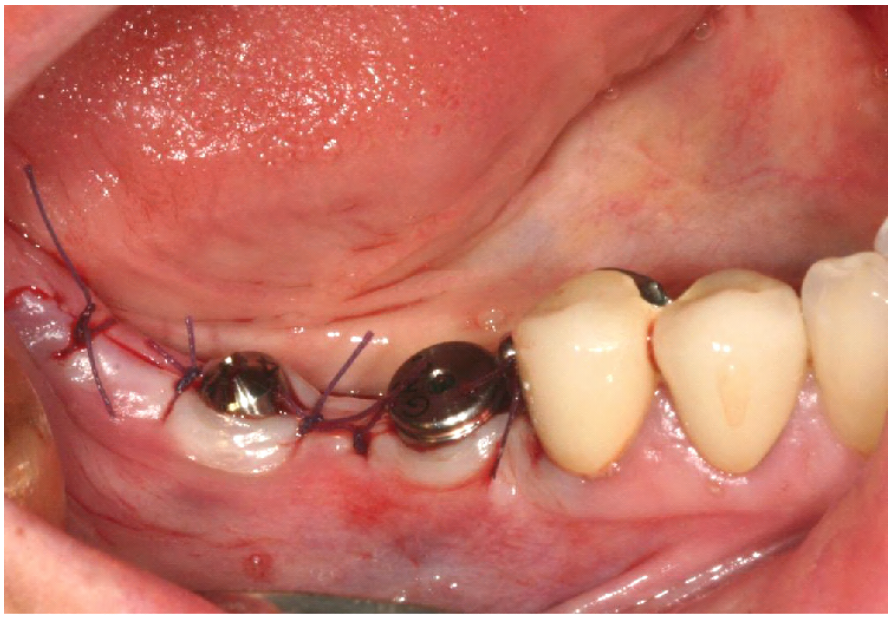


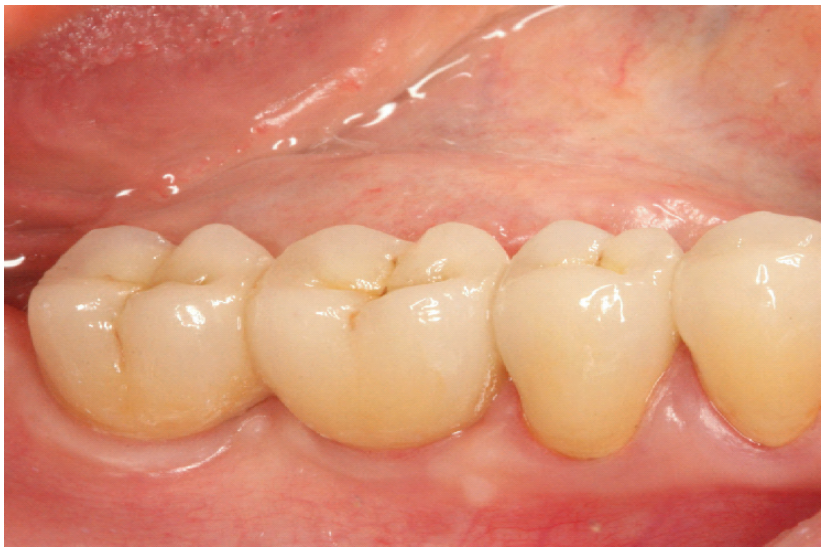
Fig. 15. One-stage surgery, as healing abutments connected



Restorative procedures

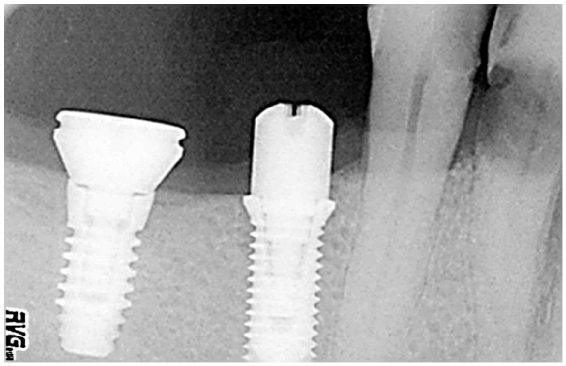
Implants were restored with metal-ceramic prostheses (Fig. 16). Restorative procedures were identical to previous study, except that test implant abutments were secured with gold abutment screw with the help of 3i torque-wrench, set to 35N/cm^2.

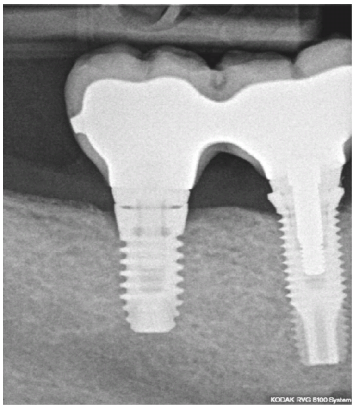
Fig. 16. Splinted metal-ceramic 46-47 crowns



Follow-up examinations, maintenance schedule and radiographic assessment (Fig. 17) and measurements were performed the same, as in previous study.

Fig. 17. Crestal bone after implant placement (left) and after 1-year follow-up (right)





Statistical analysis

Data were analyzed using SPSS 15.0 Windows (SPSS; Chicago, IL, USA) statistical software. The single implant was treated as a statistical unit. Initially, each variable was assessed using parametrical methods. As variables appeared to be normally distributed frequencies were calculated. In this case, Pearson's correlation coefficient was calculated to explore the direction and strength of the relationship between mesial and distal sites of the same implant. In case if one parameter is continuous and normally distributed, and the second parameter is discrete nominal, analysis of variance was applied. Next, a two-way analysis of variance (ANOVA) was conducted to assess mean differences within the groups. The statistical significance between groups was assessed using F test.

For comparison of continuous variables means and standard deviation were calculated. . The mean differences were considered statistically significant at $P \leq 0.05$ with a confidence interval of 95%. To visualize the differences 95% confidence intervals were plotted.

4. RESULTS

4.1 The influence of mucosal tissue thickness on crestal bone changes around implants with regular horizontally matching implant-abutment interface.

4.1.1. Descriptive analysis

Initially, 34 patients agreed to participate in the study and received 78 implants - equal number of tests and controls. A group of 3 patients with 6 implants placed was excluded from the study on the basis of refusal to attend follow-up checkups and change of living place. Additionally, 3 cases, complied of 6 implants were removed from the study, because radiographic images of implants they received were not sufficiently parallel to correctly calculate crest bone changes. One case (2 implants) was excluded after statistical analysis, as bone loss around control implant was abnormal, compared to mean distribution. This was done, because if sample size is not very high, values with very high deviation can influence means, thus making results of the study less reliable.
Therefore, the final sample included 26 patients consisting of 14 males and 12 females. Subjects' average age was 45.6 y., ranging from 23 to 71 years at the beginning of the experiment.
In total 64 implants (32 test and 32 control) were evaluated. A pair of implants (test and control) was treated as a single case. Mandible group consisted of 27 cases (54 implants in total; 84%) with 5 cases assigned to maxilla group (10 implants; 16%).
Depending on the quadrant of the jaws, the implants were distributed in the following way: I quad. – 2 cases (4.3%), II – 3 cases (9.4%), III – 15 (46.9%) cases, and IV – 12 cases (37.5%).
All 64 implants integrated successfully, as evaluation under implant success criteria was applied. Six single crowns (18.8%), eighteen 2-unit splinted crowns (56.3%) and eight 3-unit (25%) fixed partial dentures were constructed afterwards. Overall, the implant survival rate after 1 year of function in test and control groups was 100%. Survival was defined stable functioning implant in the mouth at a time of evaluation. No prosthetic complications were recorded at follow-up visits.

4.1.2. Bone loss calculation around test and control implants

Crestal bone loss was calculated around mesial and distal sites of implants in test and control groups. Measurements and cases are depictured in the Table 1.

Table 1. Bone loss around test and control implants on mesial and distal sites.

Cases	Bone loss TIM	Bone loss TID	Bone loss CIM	Bone loss CID
1	-1,900	-1,000	-2,600	-2,500
2	-1,500	-1,900	-2,600	-2,800
3	-1,500	-1,000	-2,200	-1,600
4	-1,000	-1,000	-1,400	-2,600
5	-,900	-,800	-2,100	-1,500
6	-1,300	-1,800	-1,500	-2,100
7	-1,900	-2,100	-,600	-1,300
8	-1,900	-1,200	-,800	-2,100
9	-1,200	-,800	-1,500	-2,000
10	-,300	-,200	-1,500	-1,900
11	-,100	-,300	-2,500	-1,900
12	,000	,000	-,600	-1,400
13	-,300	-,600	-2,200	-,300
14	-,300	-,300	-,800	,000
15	-,200	,100	-1,400	-1,600
16	-,100	,200	-2,300	-1,800
17	-,200	,000	-1,900	-1,800
18	,200	,000	-1,200	-1,800
19	-,100	,000	-1,800	-1,700
20	-,300	,000	-1,500	-1,800
21	-,900	-,200	-2,300	-2,000
22	-,200	,000	-2,300	-2,400
23	-,200	,000	-1,700	-1,600
24	,000	-,300	-,900	-,900
25	,000	,000	-1,300	-1,200
26	-1,400	-1,500	-2,500	-2,800
27	-,900	-,900	-1,100	-1,300
28	,000	,000	-2,400	-2,000
29	,000	,000	-,900	-,900
30	-1,100	-1,400	-1,300	-1,500
31	1,000	-1,200	-2,300	-2,200
32	-1,500	-1,600	-1,300	-1,400
Total	-,625	-,619	-1,666	-1,709

Crestal bone loss on distal site of test implants was 0.61 mm ± 0.72 SD (range, 1.9 – 1.0mm), around mesial site – 0.62 mm ± 0.68 SD (range, 2.1 – 0.2 mm). Control implants overcame bone loss around mesial aspect 1.66 ± 0.62 SD (range, 2.6 – 0.6 mm) and 1.70 mm ± 0.63 SD around distal site (range, 2.8 – 0.0 mm).

Next, Pearson's correlation was calculated to bind distal and mesial measurements and calculate crestal bone loss per single implant. Pearson's correlation showed significant positive relationship in the amount of bone loss between mesial and distal sites of implants in the control ($r = 0.734$) ($P = .002$) and in the test group ($r = 0.529$) ($P = .000$) Thus, the mean bone loss per implant in all groups could be calculated and compared (Table 2).

Table 2. Correlation between mesial and distal measurements of test and control implants.

		Bone loss TIM	Bone loss TID
Bone loss TIM	Pearson Correlation	1	,734(**)
	Sig. (2-tailed)		,000
	N	32	32
Bone loss TID	Pearson Correlation	,734(**)	1
	Sig. (2-tailed)	,000	
	N	32	32

		Bone loss CIM	Bone loss CID
Bone loss CIM	Pearson Correlation	1	,529(**)
	Sig. (2-tailed)		,002
	N	32	32
Bone loss CID	Pearson Correlation	,529(**)	1
	Sig. (2-tailed)	,002	
	N	32	32

** Correlation is significant at the 0.01 level (2-tailed).

As correlation between mesial and distal measurements of implants in test and control groups was statistically significant, mean bone loss around test and control implants was calculated. Therefore, on average crestal bone loss around test implants was 0.66 mm ± 0.64 SD (range, 2.00 – 0.10 mm) and 1.68 mm ± 0.55 SD (range, 2.70 – 0.40).

4.1.3. Comparison of control and test groups

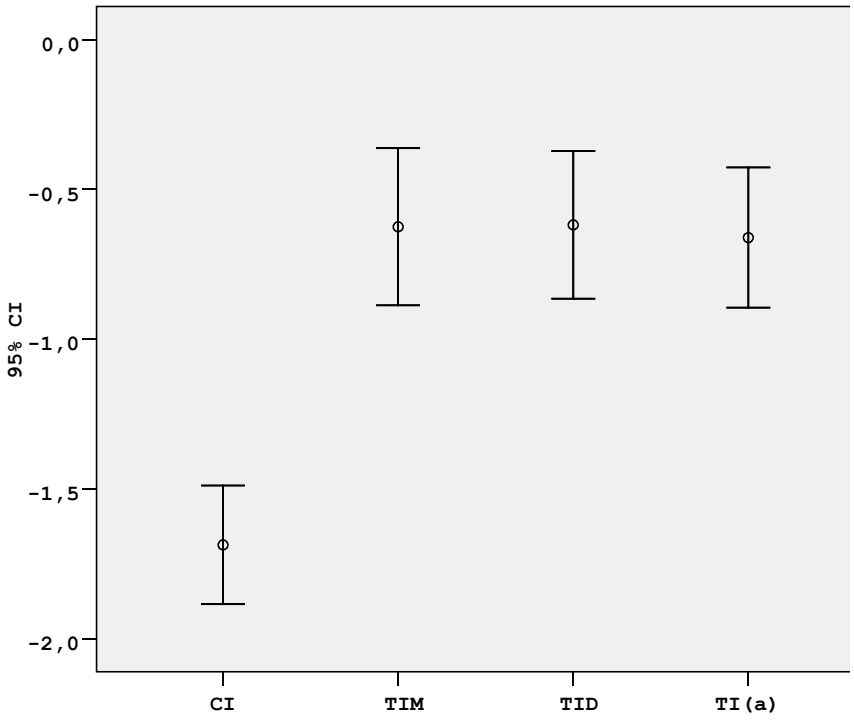
First control implants were compared to test implants without taking into account mucosal tissue thickness. Paired sample t-test showed significant differences between control implants and bone loss on mesial and distal sites, as well, as combined measurement (Table 3, Fig. 18).

Table 3. Differences between control and test implants.

		Paired Differences				
		Mean	Std. D	t	df	Sig(2-tailed)
Pair 1	TIM - CI	1,06250	,84118	7,145	31	,000*
Pair 2	TID - CI	1,06875	,80640	7,497	31	,000*
Pair 3	TI (a) - CI	1,02656	,75754	7,666	31	,000*

* Statistical significance at 0.05 level.

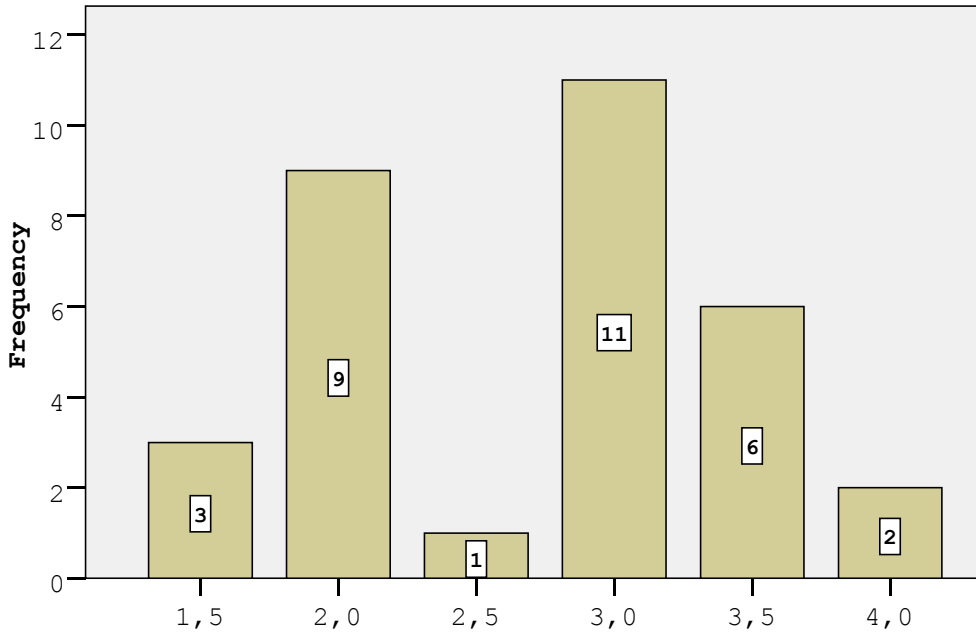
Fig. 18 Differences between groups. TIM – bone loss around mesial site of test implants; TID – distal measuremnt; TI(a) – averidge mmeasurement; CI – control implants.



4.1.4. Comparison of crestal bone loss within and between two groups of mucosal tissue thickness

Mucosal tissue thickness appeared to vary from 1.5 – 4.0 mm, mean 2.71 ± 74 SD. Distribution of measurements can be seen in Figure 19.

Fig. 19. Distribution of mucosal thickness measurements



As indicated earlier, all mucosal tissues were divided into 2 groups: thin (A) and thick (B) by the value of 2 mm. Mean measurements and distribution of cases between thick and thin mucosal tissues are presented in the Table 3.

Table 3. Distribution of mucosal thickness between groups

Group	Mean	N	SD
Thick (B)	3,225	20	,3796
Thin (A)	1,875	12	,2261
Total	2,719	32	,7399

After measuring of radiographs, bone loss around test implants in group A (thin tissues) was 1.18 mm ± 0.75 SD on mesial site of implant and 1.35 ± 0.43 SD on distal site. Bone loss in group B with thick tissue pattern was reported to be 0.29 mm ± 0.46 SD on mesial and 0.17 ± 0.32 SD on distal site of implants.

Loss of bone around control implants was recorded as follows: 1.66 mm ± 0.62 SD on mesial site and 1.70 mm ± 0.63 SD on distal aspect of implants.

Overall bone loss around test implants was 0.25 mm ± 0.37 SD in thick tissues (group B) and 1.35 mm ± 0.33 SD in thin tissues (group A) is reported in Table 4.

Table 4. Bone loss around implants in test and control group, according to tissue thickness

Thick or thin		Bone loss TI	Bone loss CI
Thick (B)	Mean	-,2450	-1,6000
	N	20	20
	SD	,36989	,56172
Thin (A)	Mean	-1,3542	-1,8333
	N	12	12
	SD	,33741	,52063
Total	Mean	-,6609	-1,6875
	N	32	32
	SD	,64953	,55022

Two-way ANOVA test revealed a significant mean difference in terms of bone loss within the test A (thin) and B (thick) groups, where implants were positioned about 2 mm above bone level on mesial aspect ($F_{[1,30]} = 17.2$; $P = .000$), distal ($F_{[1,30]} = 78.6$; $P = .000$) and combined measurements ($F_{[1,30]} = 71.8$; $P = .000$). There was no statistical difference found within control implants group in thin or thick tissue ($F_{[1,30]} = 3.1$; $P = .252$).

As ANOVA analysis showed statistically significant differences, Error bar method was chosen to visualize differences between test and control implants. Separate depicturing of mesial, distal and combined measurements of each group was chosen (Fig. 20-23).

Fig. 20 Differences between control implants in thin or thick mucosal tissues (CIM – mesial measurement, CID – distal measurement).

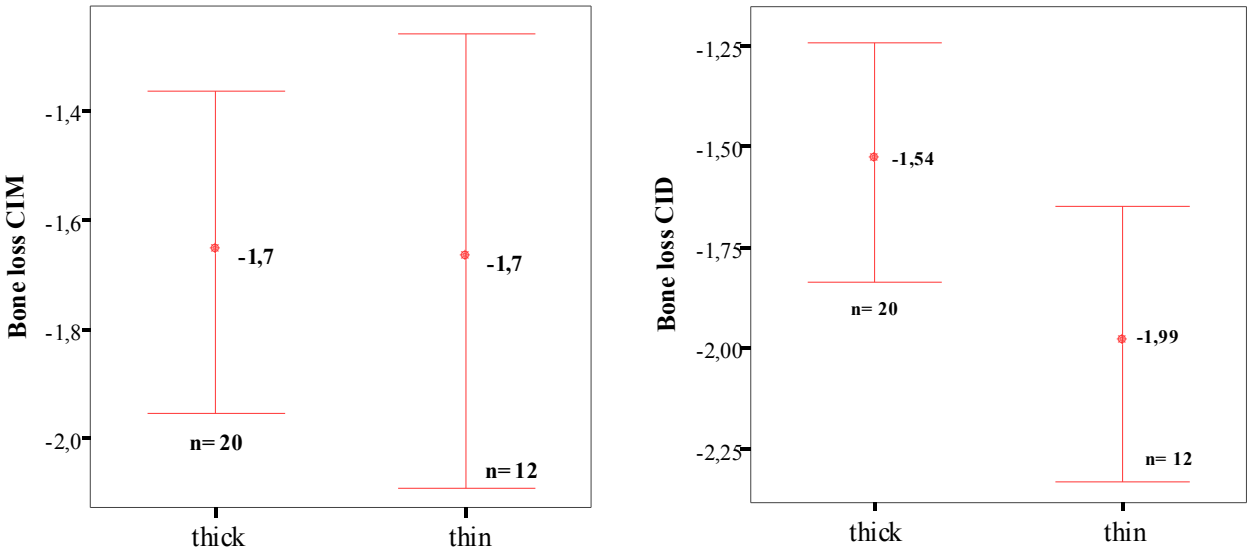


Fig. 21 Differences between test implants in thin or thick mucosal tissues (TIM – mesial measurement, TID – distal measurement).

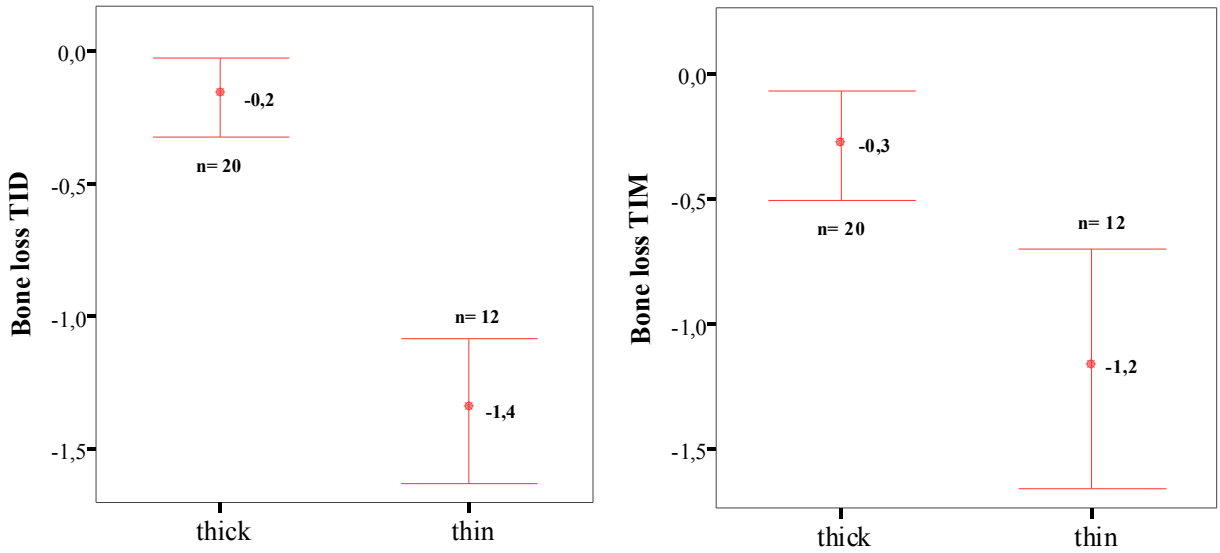


Fig. 22 Differences between test implants in thin or thick mucosal tissues.

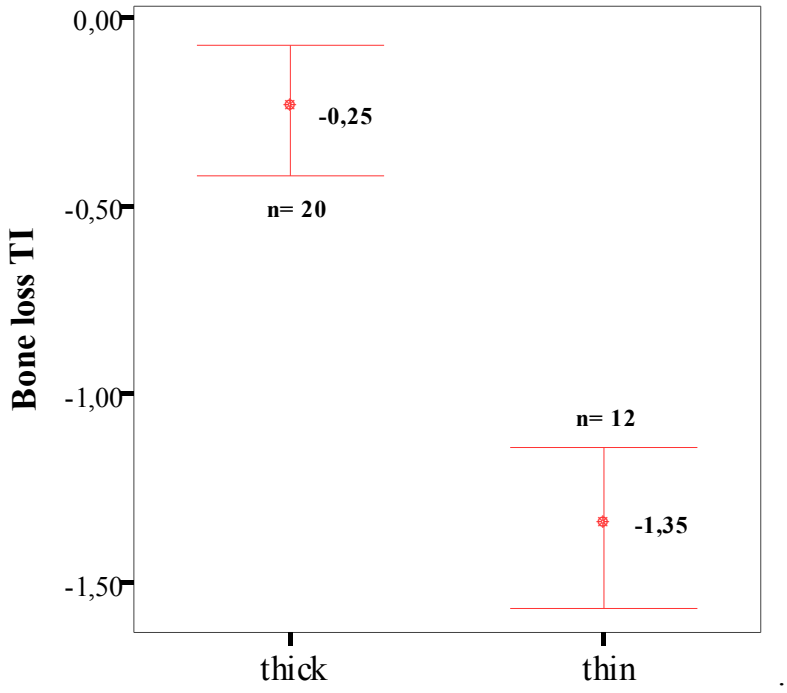
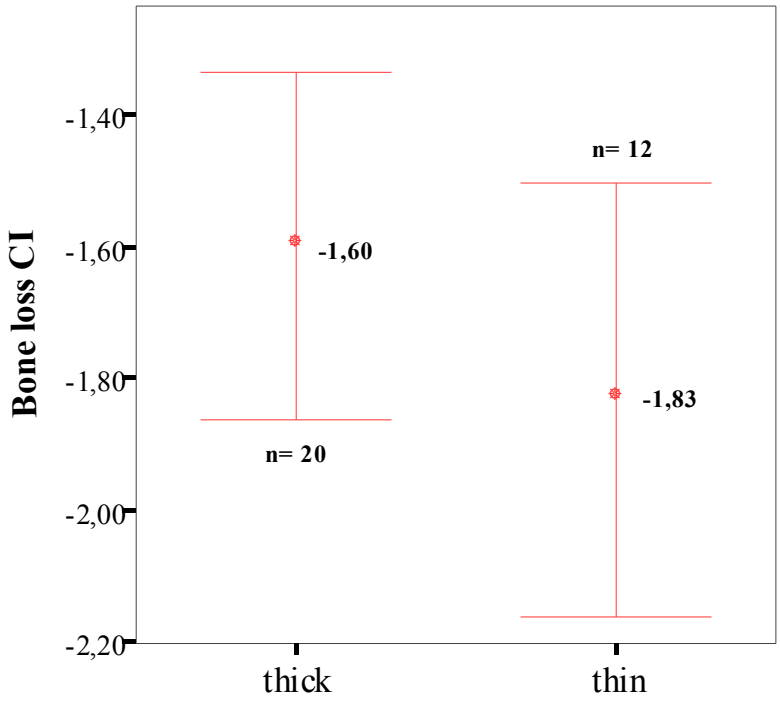
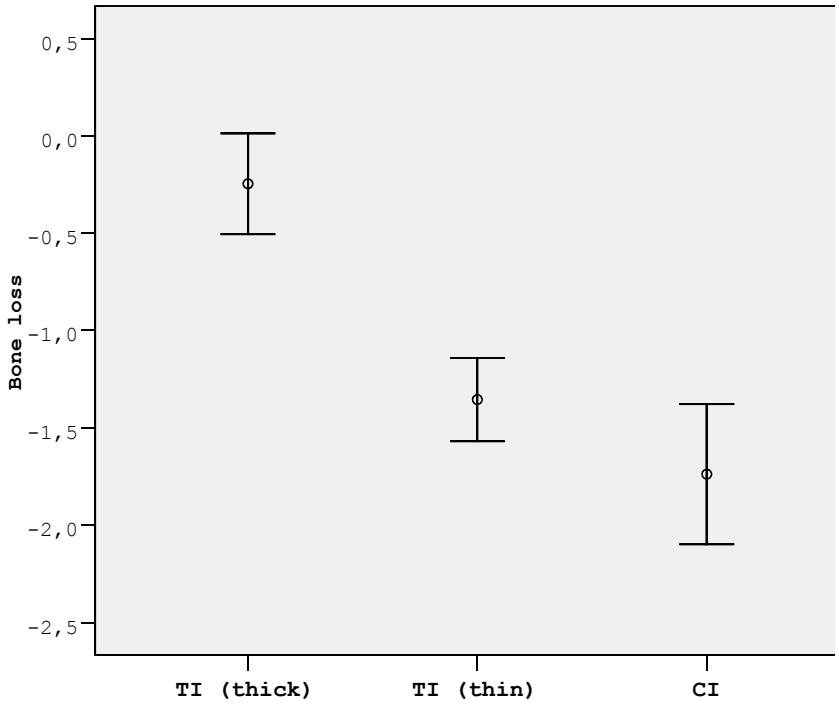


Fig. 23 Differences between control implants in thin or thick mucosal tissues.



In addition, t-test showed that there was no statistical difference between control implants and test implants in thin mucosal tissue group and statistical difference between control implants and test implants in thick group (Figure 24).

Fig. 24 Differences between test and control groups. CI – control implants; TI – test implants.



4.1.5. Definition of 3 groups of mucosal tissue thickness and influence on bone loss.

Continuous variable were converted in two discreet ordinal values, using rules of distribution analysis. At first stage minimum and maximum was found, after those, median and lower and upper quartiles were calculated. This allowed distributing all mucosal thickness measurements into 3 distinct groups – thin group with tissues up to 2 mm; medium thickness from 2.1 – 3.0; and thick group with tissue 3.1 mm and more. Distribution and frequencies of values are presented in the Table 6.

Table 6. Distribution of measurements in 3 thickness groups

Groups	Mean	N	SD
up 2	1,875	12	,2261
2.1-3.0	2,958	12	,1443
Over 3.1	3,625	8	,2315
Total	2,719	32	,7399

Mean crestal bone loss around test and control implants was calculated, if mucosa is divided into 3 groups of thickness – thin, medium and thick.

Crestal bone loss around mesial site of test implants in the group up to 2 mm was 1.18 mm ± 0.75 SD and 1.38 mm ± 0.43 SD on distal site. In the medium thickness group bone loss around mesial site was 0.39 mm ± 0.58 SD and 0.23 ± 0.36 mm on distal site. In thick tissue group, which consisted of mucosal tissue with thickness more than 3.0 mm bone loss mesially was 0.13 mm ± 0.11 SD and 0.09 mm ± 0.24 SD distally. Bone loss around control implants. Control group distal and mesial measurements are reported in Table 7. Overall bone loss around test and control implants is reported in Table 8.

Table 7. Bone loss around distal and mesial aspects of control implants in 3 mucosal thickness groups

3 groups		Bone loss CIM	Bone loss CID
up to 2	Mean	-1,675	-1,992
	N	12	12
	SD	,6552	,5401
2,1-3,0	Mean	-1,642	-1,617
	N	12	12
	SD	,6302	,6900
3,1 and more	Mean	-1,688	-1,425
	N	8	8
	SD	,6707	,5548
Total	Mean	-1,666	-1,709
	N	32	32
	SD	,6287	,6301

Table 8. Bone loss around test and control implants in 3 mucosal thickness groups

3 Groups		Bone loss TI	Bone loss CI
up to 2	Mean	-1,3542	-1,8333
	N	12	12
	Std. Deviation	,33741	,52063
2,1-3,0	Mean	-,3250	-1,6292
	N	12	12
	SD	,44949	,63406
over 3,1	Mean	-,1250	-1,5563
	N	8	8
	SD	,16257	,47013
Total	Mean	-,6609	-1,6875
	N	32	32
	SD	,64953	,55022

Table 9. Results of ANOVA tests of test and control implants in 3 mucosal tissue thickness groups.

		df	F	Sig.
Bone loss TIM	Between Groups	2	9,034	,001*
	Within Groups	29		
	Total	31		
Bone loss TID	Between Groups	2	39,379	,000*
	Within Groups	29		
	Total	31		
Bone loss TI	Between Groups	2	37,317	,000*
	Within Groups	29		
	Total	31		
Bone loss CIM	Between Groups	2	,014	,986
	Within Groups	29		
	Total	31		
Bone loss CID	Between Groups	2	2,334	,115
	Within Groups	29		
	Total	31		
Bone loss CI	Between Groups	2	,703	,503
	Within Groups	29		
	Total	31		

* Statistically significant difference at 0.05 level.

ANOVA analysis showed statistically significant differences between 3 groups of thickness, as crestal bone loss around test implants is concerned. ($F_{[2,29]}$ = 37.3; P = .000). In control implants bone loss did not vary between 3 groups of tissue thickness ($F_{[2,29]}$ = 0.73; P = .503) (Table 9).

As ANOVA analysis showed differences within and between groups, error bar interactive graphics were employed to define more clear disparities.

It was determined that there were statistically significant differences of bone loss between thin and medium or thin and thick groups and there was no reliable distinction between medium and thick tissue in distal sites of test implants (Fig. 25, right). However, bone loss around mesial site of test implants showed no statistically significant difference between thin and medium tissues or medium and thick tissues. There was difference between thin and thick tissues (Fig. 25, left). Control implants error bar analysis showed no differences between 3 groups (Fig. 26). Analysis of merged distal and mesial measurements showed statistical difference between thin and medium and thick tissues and no difference between medium and thick tissues (Fig. 27). Control implants error bar analysis showed no differences between 3 groups (Fig. 28).

Fig. 25 Differences in test implant group. TIM – mesial measurement, TID – distal measurement; 1,0 – thin; 2,0 – medium; 3,0 – thick.

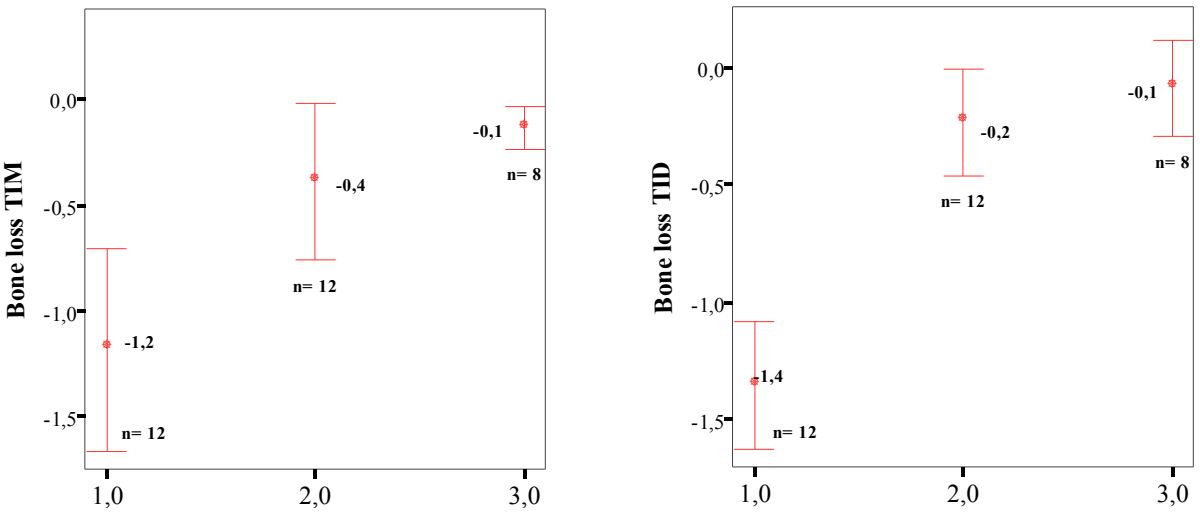


Fig. 26 Differences in control implant group. CIM – mesial measurement, CID – distal measurement; 1,0 – thin; 2,0 – medium; 3,0 – thick.

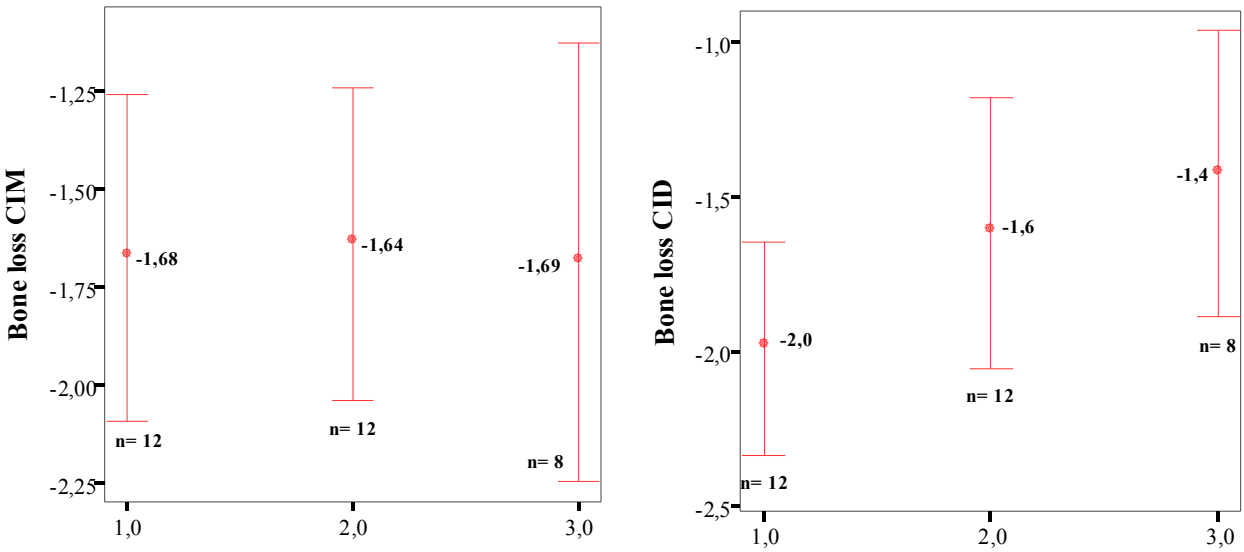


Fig. 27 Differences in test implants group. (1,0 – thin; 2,0 – medium; 3,0 – thick)

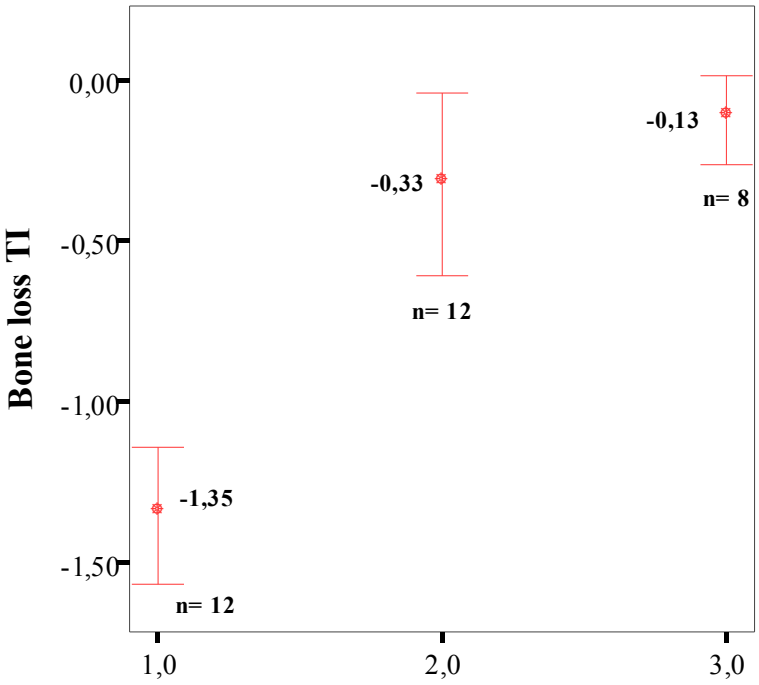
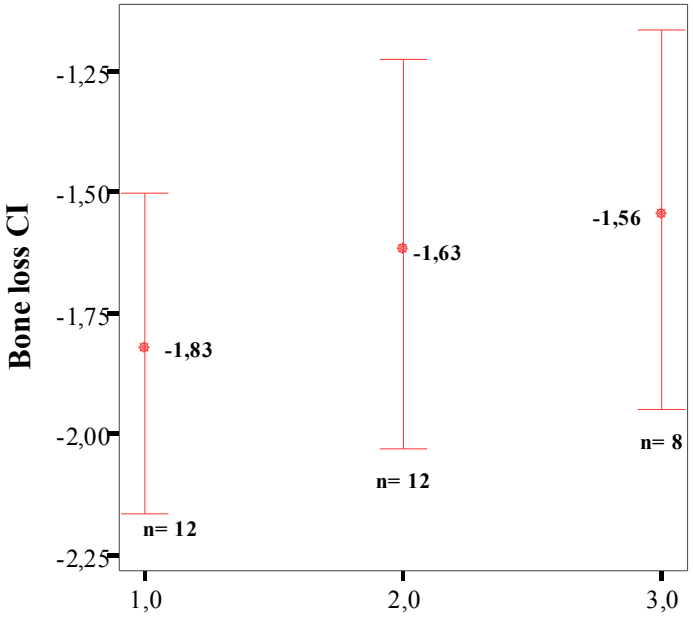
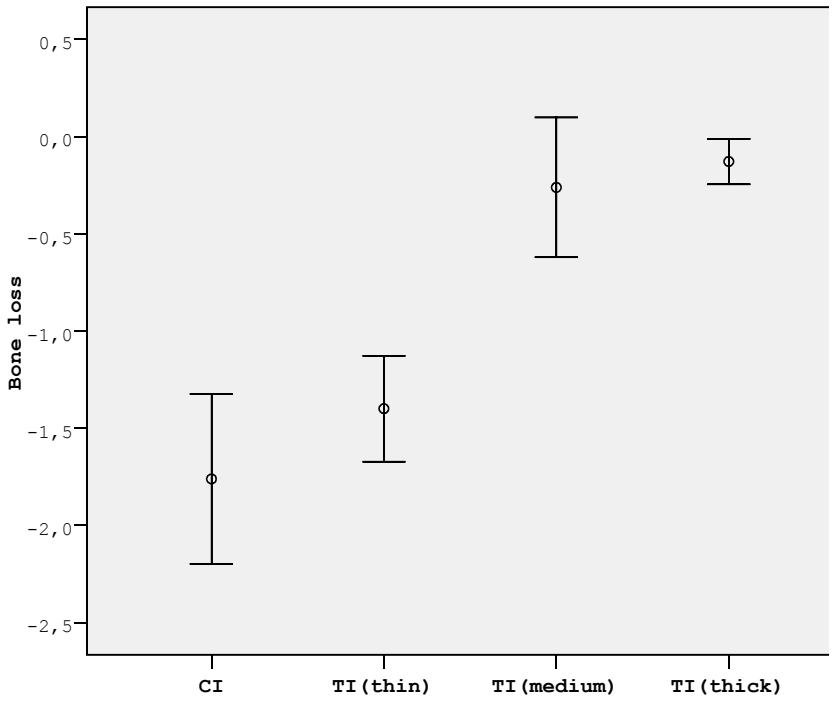


Fig 28. Differences in control implants group. (1,0 – thin; 2,0 – medium; 3,0 – thick)



In addition, t-test showed that there was no statistical difference between control implants and test implants in thin mucosal tissue group and statistical difference between control implants and test implants in medium and thick group (Fig. 29)

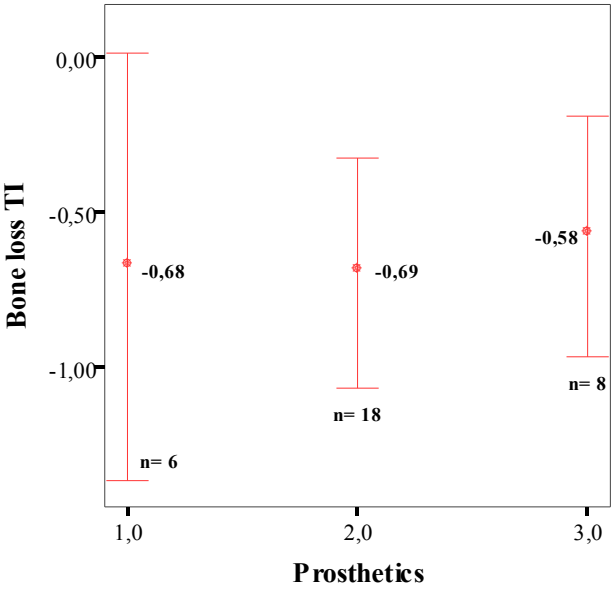
Fig. 29 Differences between test and control groups. CI – control implants; TI – test implants.

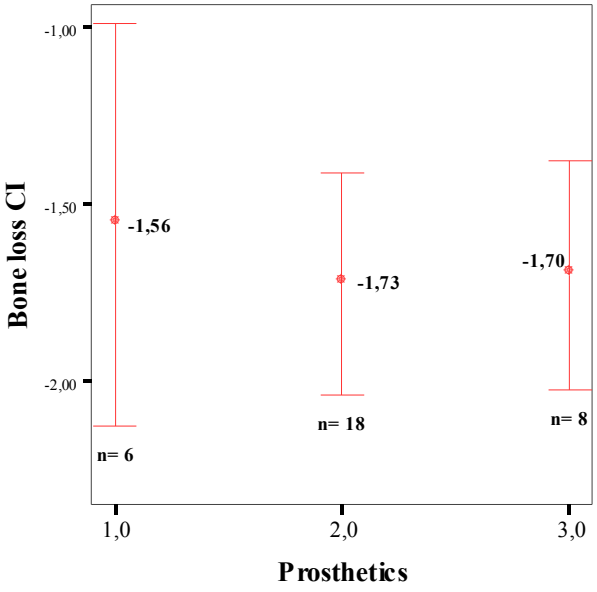


4.1.6. Influence of prosthetic configuration, jaw, gender on crestal bone changes around implants.

Evaluation of prosthesis impact on bone loss was additional objective of this clinical investigation. ANOVA analysis revealed that prosthetic configuration had no influence on crestal bone loss within test ($F_{[2,29]}$ = 0.90; P = .914) and control ($F_{[2,29]}$ = 0.19; P = .821) implants (Fig 30 and 31). Single crowns underwent 0.67 mm ± 0.65 SD, splinted crowns – 0.69 mm ±0.74 SD, while 3-unit FPD's supported by 2 implants had 0.57±0.46 mm SD. In control group bone loss was as follows: single crowns – 1.55 mm ± 0.54 SD; splinted crowns – 1.72 mm ±0.62 SD; fixed partial dentures – 1.68 mm ±0.55 SD (Fig. 30).

Fig. 30 Differences in test (left) and control (right) implant group (1 0 – single crowns; 2,0 – splinted crowns; 3,0 – 3unit fixed partial dentures).



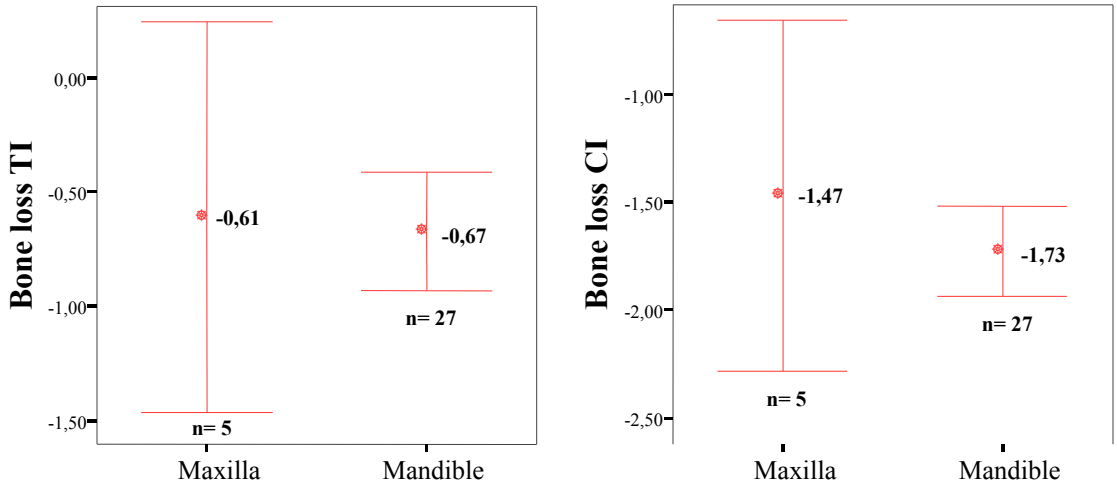


Analysis revealed that jaw had no influence of crestal bone loss within test ($F_{[1,30]} = 0.35$; $P = .825$) and control ($F_{[1,30]} = 0.92$; $P = .344$) implants. Test implants in maxilla overcame 0.61 mm ± 0.68 SD of bone loss and 0.67 mm ± 0.65 SD in mandible, while control implants underwent 1.47 mm ± 0.65 SD in maxilla and 1.72 mm ± 0.53 SD in the lower jaw (Fig. 31).

ANOVA analysis revealed that gender had no influence of crestal bone loss within test ($F_{[3,28]} = 0.13$; $P = .822$) and control ($F_{[3,28]} = 0.19$; $P = .613$) implants.

Test implants in men experienced 0.72 mm ± 0.73 SD of bone loss and 0.59 mm ± 0.56 SD in female, while control implants underwent 1.62 mm ± 0.37 SD in female and 1.74 mm ± 0.69 SD in male.

Fig. 31 Differences in test (left) and control (right) implant group.



4. 2 Influence of thin mucosal tissues on crestal bone changes around implants with platform switching.

Four patients (3 females and 1 male) received in total 12 two-piece implants, 6 implants with horizontally matching implant-abutment connection (Prodigy, BioHorizons, USA) and 6 implants with platform switching (Prevail, 3iBiomet, USA). Mean age of the patients was 43 years (range, 37-56 y).

Implants were restored with 5 splinted crowns and 1 FPD of 3-units, using metal-ceramic prostheses. Mean mucosal tissue thickness was 1.79 mm ± 0.25 SD (range, 1.5 to 2.0).

First, bone loss around implants on mesial and distal sites in both groups was calculated (Table10).

Table 10. Bone loss around mesial and distal sites of control and test implants.

Group		Bone resorbtion mesially	Bone resorbtion distally
Test 3i	Mean	1,8167	1,7000
	N	6	6
	Std. Deviation	,39707	,35214
Control BH	Mean	1,6000	1,7667
	N	6	6
	Std. Deviation	,46904	,45898
Total	Mean	1,7083	1,7333
	N	12	12
	Std. Deviation	,42950	,39158

Pearson's correlation analysis showed significant relationship between mesial and distal sites (Table 11).

Table 11. The extent of corretalion betweem mesial and distal measurements

		BRM	BRD
Bone resorbtion mesially	Pearson cor	1	,717(**)
	Sig. (2-tailed)		,009
	N	12	12
Bone resorbtion distally	Pearson cor.	,717(**)	1
	Sig. (2-tailed)	,009	
	N	12	12

** Correlation is significant at the 0.01 level (2-tailed).

ANOVA test revealed no significant (P<.05) difference between amounts of bone loss around test and control implants ($F_{[1,11]} = 0.29$; $P = .602$) (Table 12, Fig 32).

Table 12. ANOVA results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,047	1	,047	,290	,602
Within Groups	1,615	10	,162		
Total	1,662	11			

Fig. 32 Differences between test (3i) and control (BioHorizons) implants group.

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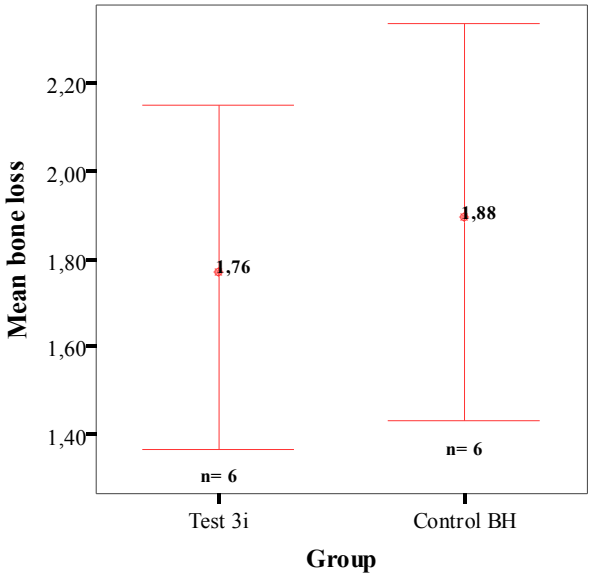

5. DISCUSSION

5.1. The influence of mucosal tissue thickness on crestal bone changes around implants with regular horizontally matching implant-abutment interface.

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The results of this study showed that mucosal tissue thickness may have an impact on crestal bone stability around implants. The present study focused on the influence of mucosal thickness at the time of surgery on crestal bone changes around non-submerged implants after a 1 year follow-up. The major finding showed that if thin mucosal tissues were present at a time of implant placement, the positioning of an implant 2 mm supracrestally did not prevent crestal bone loss. All implants in test group with initially thin tissues overcame additional bone loss on mesial and distal sites. In contrast, implants in the test group with thick tissue pattern had significantly less bone loss, compared to thin tissue test group or control implants group. In addition, there was no statistically significant difference between test implants in thin tissues and control implants. In other words, vertical distancing of microgap away from the bone crest can reduce marginal bone loss only if thick mucosal tissues are present at a time of implant placement. If mucosal thickness is 2 mm or less, supracrestal implantation cannot be recommended. Bone loss around control implants was expected, as the placement of microgap and polished implant collar at crestal level can cause marginal bone loss. This is the reason for considering bone loss around control implants was considered irrelevant to tissue thickness.

It is interesting to notice that t-test revealed significantly less bone loss around test implants in comparison to control group, if tissue thickness was not taken into consideration. This is agreement with studies showing that implant placement above the bone level can reduce bone resorption [234;235]. But when test implants were subjected to mucosal tissue thickness influence, results have showed that implants in thin mucosal tissues have developed crestal bone loss, similar to control implants. Test implants positioned in thick mucosal tissues had only 0.25 mm of bone loss on average and can be compared to results from clinical studies of implants with platform switching, which

show minimal amounts of bone [236-240]. On the other hand, it is consistent, as in both studies infected implant-abutment interface was distanced from peri-implant bone – in implants with platform switching microgap was moved horizontally and in the current study – vertically.

Bone loss around implants placed in thin mucosal tissues consisted of 1.35 mm on average and was very similar to reports from many studies, investigating marginal bone resorption after 1-year of loading. Thus it can be concluded that positioning implants above the level of bone is not recommended, if mucosal tissues at the bone crest are 2 mm or less at a time of implant placement. This is of particular importance in regions, where only short implants can be placed due to very limited bone height or close proximity of anatomical formations, such as mandible canal and maxillary sinus. It was suggested to employ supracrestal placement of longer implants in those areas to receive better implant-crown ratio and less bone loss. However, in the light of the current study results it should be noted that supracrestal implant placement in thin tissues does not limit bone loss, but even increase resorption, resulting in poor implant-crown ratio, which could be dramatic for shot implants. Conversely, if initial mucosal tissues are 3 mm or more, supracrestal implant placement could reduce bone loss and allow longer implant usage in areas with limited bone height. Some studies have suggested to position microgap above bone level in anterior implants or use scalloped implants to limit marginal resorption [241]. It is likely that one concern remains – in the presence of thin mucosal biotype tissue recession and esthetic failure is granted, as metal implant parts become exposed or shine through thin peri-implant mucosa. Finally, it is important to consider the thickening of thin mucosa before implant placement, as the transition of mucosa from thin to thick biotype would likely allow avoiding mentioned problems, associated with thin tissues. Bone loss around implants was constant and is similar to reported measurements of 2-piece implants with regular connection placed equally with crest after 1-year follow-up [242;243].

The outcome of this trial may play a significant role in further research on crestal bone stability. Animal and clinical studies, which explored microgap, loading, abutment manipulation, polished neck and other causes as potential sources for bone resorption, did not evaluate anatomical mucosal thickness, which, within the limitations of discussed

studies, may be standing out as additional factor to consider. Therefore, it could be recommended that measurement of initial mucosal tissue thickness would be mandatory in studies, exploring factors for crestal bone stability.

The decision to divide the test implants into two groups by the measurement of 2.0 mm was based on the results obtained in the animal study, which was the first attempt to analyze the influence of mucosal thickness on stability of bone [244]. In that experiment mucosa thickness in test implants group was about 2.0 mm on average, therefore this measurement was considered as a distinction point between thin and thick mucosa. During the second stage surgery in test implants peri-implant mucosa was thinned to approximately 2 mm, while control implants had the healing abutments connected without tissue thickness alteration. The histology showed that in test implants consistent bone resorption occurred after soft tissue healing, while total extension of BW was not statistically different between test and control implants. This finding was explained, based on the assumption that the minimum dimension of BW was not satisfied and bone resorption took place to allow a sufficient soft tissue attachment to form. However, exact bone loss was not recorded in this animal experiment, making it difficult to make clear-cut comparisons to outcome of this study. It should be noted that after healing, the mean tissue thickness around test implants was about 2.4 mm, while in control group – 3.65 mm.

The results of this animal experiment are consistent with outcome of this study, as implants, placed in thin tissues overcome significant bone loss, compared to implants with thick tissues. The pathogenesis of bone loss around test implants should be very similar or identical to one, described in Berglundh and Lindhe study [245]. Supracrestal implants with mucosal tissues of 2 mm developed vertical bone loss, as a consequence of peri-implant mucosa morphogenesis. As it was shown, peri-implant seal around implants in humans is about 4 mm [83;246] , therefore initial mucosal thickness of 2 mm is far not enough to establish BW around implants without bone loss. In test implants with thick mucosa at a time of implantation, ranging up to 4 mm, bone loss was significantly smaller. Apparently, the width of thick mucosal tissues is sufficient for formation of peri-implant tissues without or minimal bone resorption. However, it should be noted that soft tissues in Berglundh and Lindhe study were surgically trimmed, thus difficult to control

exact thickness. No report of exact measurements of trimmed mucoperiosteal flaps was provided in materials and methods of the latter study. Further, authors manipulated with peri-implant tissues, during second stage surgery, what can be considered as additional drawback.

First mentioning of tissue thickness-dependant crestal bone loss can be found in Abrahammson et al animal study [31]. Authors have observed that implant sites with thin tissues were prone to form angular defects around fixtures after healing, while thick mucosal tissues did not cause any visible change. The definition of the reasons for bone resorption was not the purpose of the study, which aimed to determine peri-implant tissue composition and extension around 3 different implant systems; however, it was proposed that formation of biological width around implants can be responsible for angular pattern of bone defects. Further indirect evidence for tissue thickness involvement in crestal bone loss genesis is presented in another Berglundh et al study, researching structuring of peri-implant mucosa [247]. Histological animal studies poses evidence that thin mucosal tissues can cause early crestal bone loss. The process of BW formation around implants was described by Berglundh et al in a dog study [248]. Additionally, authors observed that the morphogenesis of peri-implant mucosa involved loss of marginal bone level. Two piece implants (ITI Dental Implant System, Straumann AG, Basel, Switzerland) with 2.8 mm polished neck were placed using a non-submerged technique, leaving polished implant part and prosthetic abutment platform above the bone crest. Dogs, which were used in the experiment, may have a thin mucosa type, as it was recorded in a number of prior studies [249;250]. In the light of this study it can be speculated that reduction of marginal bone level occurred due to thin mucosa biotype. The further support for this argument can be found in another study, involving nonhuman primates. Oakley and co-authors observed the formation of the BW around teeth after clinical crown lengthening procedure, during which the connective tissue around the tooth was removed. The results showed that after osteoectomy, junction epithelium migrated to the bone level and connective tissue re-established within a 6 months period due to bone resorption and thus reforming the BW [251]. The excision of connective tissue of peri-implant mucosa in earlier quoted Berglundh and Lindhe study with implants could be compared with the removal of the mucosal connective tissue during clinical crown

lengthening procedure in Oakley et al [252] study. It is possible, that the removal of connective tissue around implants caused the bone resorption to create the room for the establishment of the new connective tissue zone, as around teeth.

Results of the study contradict the assumptions that positioning of an implant/abutment junction above the bone level can prevent apical migration of bone. The current study findings show that stable crestal bone was maintained only in the thick tissue pattern. The contradictory findings might have been obtained due to the lack of registration of initial mucosal thickness at a time of implant placement in microgap studies. Consequently, the interpretation of these studies may be different if mucosal factor would have been considered.

There have been few similar clinical studies. Kan et al [253] evaluated the difference between thick and thin biotype of peri-implant mucosa by probing around restored implants in anterior region. Results have showed that in all evaluated sites, peri-implant tissue dimensions were greater in presence of thick peri-implant biotype, as compared to thin biotype. However, the primary width of the mucosa before implant placement was not registered. Neither, the bone loss or position of the implant/abutment interface in relation to bone crest was reported. In fact, this clinical study aimed to determine postoperative soft tissue characteristics with no evaluation of mucosal conditions before implant placement. Cardaropoli et al [254] estimated mucosal thickness before implantation and calculated bone loss after 1-year follow-up. Mean mucosal thickness at the alveolar crest before implant placement was registered to be 2.2 mm that can be considered as thin tissue. During the second phase of the present study, i.e. from abutment connection to 1 year of follow-up, the radiographic assessments of bone-to-implant level at proximal sites revealed a significant loss of, on average, 1.6 mm. The greater part of this loss occurred during the time interval between abutment connection and crown placement, thus during formation of BW. However, the study design did not include elimination of microgap influence, as all implants were placed equally with the bone, therefore results can not be compared to the findings of current experiment. Additional distinction was that the study did not correlate bone loss after 1-year follow up with tissue thickness.

Literature analysis revealed that there no studies, which try to divide the thickness of mucosal tissues at the crest, according to magnitude of bone loss. Thus, statistical analysis was performed, when all tissues were assigned to 3 groups: thin group with tissues up to 2 mm; medium thickness from 2.1 – 3.0; and thick group with tissue 3.1 mm or more.

The division into 3 types of tissue thickness was partly based on the outcome of Berglundh et al [255] study, which defined thin tissue as that of 2 mm thick, and that of 3.5 mm in thickness as thick tissue. It is obvious that tissue width can vary within the interval from 2 to 3.5 mm; therefore, the division into 3 groups seems reasonable. From statistical point view, allotment to 3 groups also can be maintained justifiable. Medium thickness group forms a center or middle value, therefore is easy to understand and read. Four groups would lack the middle value and division into 5 groups would be too detailed for such sample size, as in this study. Additionally, the frequency of each group within all samples was very similar. The thin and medium groups consisted of 12 samples each and the thick group had 8 cases. This can be viewed as correct distribution and forms a basis for possible classification of soft tissue thickness measured at the crest. Similar division of mucosal tissue thickness into 3 groups or clusters was proposed by Muller and Eger, who measured facial mucosa thickness around teeth in young male individuals [256].

Thus mucosal tissues were divided and investigated the influence of thin, medium and thick mucosal tissues on crestal bone loss around implants. It was observed that crestal bone response around test implants varied in all the three groups – from 1.35 mm loss in the first group down to 0.32 mm in the second, and 0.12 mm in the third group. It is quite obvious that results showed increasing marginal bone loss around test implants positioned about 2 mm above the bone level, as the thickness of musoca before implant placement was decreasing. If an implant was placed in the site with mucosal tissue thickness of 2 mm or less, statistically significant increase of crestal bone loss was recorded, compared to the medium and thick tissue groups or control implants. This is in agreement with Berglundh et al animal study, which, despite methodological disparities with the current experiment (second stage surgery, peri-implant tissue trimming), showed the potential of 2 mm or less thickness soft tissue to cause crestal bone loss in the process

of BW formation. Until now, this animal experiment was the only evidence to illustrate the mucosal factor in marginal bone loss.

In contrast, the medium tissue thickness group, consisting of gingiva from 2.1 – 3.0 mm, had no statistically different outcome, compared to thick tissue group, although mathematical decrease of bone loss with the amplification of tissue thickness was recorded. The implants in the thick tissue group (3 mm ≤) had the least bone loss on average and in some cases even bone gain was recorded. The study revealed similar reaction of hard peri-implant tissues to medium and thick gingiva and completely diverse behaviour of crestal bone around implants with thin biotype.

A number of studies which evaluated the thickness of gingival tissues can be found in the literature. Eger et al measured the facial thickness of mucosa around teeth and found great inter- and intra-variations [257]. Masticatory mucosa thickness was the object of interest in several studies by Muller et al, who tested the influence of gender, age, and dental arch location of parameters of mucosal tissue width [258;259]. The major part of these studies tested facial or palatinal areas, leaving mucosal tissue thickness at the alveolar crest out of the scope of their interest. Thus, the results of these studies cannot be applied to the current experiment. It is interesting to mention, that the term “periodontal biotype” or “mucosal phenotype” is referred to thickness of facial tissue, which was measured in another clinical study [260] and has no direct connection with the thickness of mucosa covering edentulous regions of dental arches. Thus it is difficult to state that individuals with thin periodontal biotype, which is considered prone to recession, would also have thin mucosal tissues in the edentulous region of the mouth. In other words, thin mucosa at the buccal aspect of does not mean that implants would have increased crestal bone loss, as tissue thickness at alveolar crest seem to be more important, as the results of this study indicate.

There were attempts to determine the biotype of peri-implant mucosa. Kan et al proposed to evaluate the biotype by placing a periodontal probe into facial aspect of peri-implant mucosa. The peri-implant biotype was categorized as thin, if the outline of the probe could be seen through the gingiva, and thick if the probe could not be seen [261]. It can be concluded that the connection between mucosal tissue thickness before implant

placement and type of subsequently formed peri-implant mucosa biotype is not clear and needs to be research more.

According to the study protocol, implants were restored with a reduced healing time protocol, as implants were subjected to prosthetic treatment after 2 months in the lower and 4 months in the upper jaw. Traditional loading protocol, established by Brånemark et al already three decades ago suggests that sufficient osseointegration is achieved after unloaded healing period of 6 months in the maxilla and 3 months in mandibular bone [50]. However, it must be pointed out that these recommendations are based on use of machined surface titanium implants and have more empirical, than scientifically evidence-based background. In addition, recent Cochrane review by Esposito et al defined 2 months of healing, as conventional loading protocol [262]. Some in vitro and clinical studies show that process of osseointegration is associated with the morphology of the implants. Rough surface was shown to accelerate and increase bone-to-implant contact formation. Clinical investigations of sandblasted, large grit and acid-etched (SLA) implants, loaded after reduced healing periods demonstrate long-term success identical to conventionally loaded implants. Salvi et al has reported loading of titanium implants with SLA surface as early as 2 weeks did not appear to jeopardize the osseointegration healing process in the posterior mandible [263]. In addition other studies showed that implants with rough surface can be placed and loaded after 6 weeks in maxilla, thus contradicting traditional protocol, which allows occlusal force only after 18 weeks, i.e. 3 times longer, than approach with short healing period [264;265]. Recent retrospective study showed that implants with rough surface can be successfully restored and brought to function after 12 weeks of healing in the maxilla and after 6 weeks of unloaded period in mandible [266]. It appears that loading is at least not harmful, if not beneficial for implant healing with adequate primary stability. Furthermore, recent development of more advanced implant surfaces, such as chemically modified implant body covering (SLAactive, ITI, Straumann) have shown that reduced time healing protocol can be employed even in poor quality bone [267;268].

Implants used in current study had rough surface, therefore could be candidates for reduced healing protocol employment, although did not poses the surface, described in studies of extremely shortened healing periods to 2 weeks in the lower jaw and 6 weeks

in maxilla. As a consequence, study protocol did not employ healing time described previously; however did not use traditional approach either. Implants were restored after 8 weeks in mandible and 12 weeks in upper jaw. The primary stability was achieved and all implants had healing abutments connected at the end of the surgery. Reduced healing protocol did not impair implant success rate, as all implants integrated and were restored. Another debatable issue is the non-submerged implant placement, as implants are provided with healing abutments at the same intervention. Similarly to healing time, traditional approach seems very conservative, suggesting completely covering implant with soft tissues for undisturbed and uneventful healing, as a prerequisite for osseointegration. It was feared that healing abutment protrusion through sutured mucosa could raise the hazards of infection and premature loading for freshly positioned implant and could lead to failure to integrate. However, many studies have shown that one stage implant placement poses no threat for osseointegration. Becker et al reported no difference in survival rates and crestal bone loss between implants placed in one-stage and two-stage approach in an outcome of 3-year prospective clinical trial [269]. Analogous results were presented in other prospective trials [270-272]. It must be stressed that the absence of difference in crestal bone loss amounts between submerged and non-submerged techniques, which is demonstrated in described studies, is very important, as eliminates possible speculations, concerning the influence of implant placement in the current study on crestal bone stability. In conclusion it can be suggested that early implant loading and non-submerged placement are acceptable treatment modalities, which has no harmful effect on crestal bone loss and implant survival. Different implant positions in relation to bone level were used in many animal experiments. Jung et al used 3 positions of implants in relation to bone level: crestal or equal with bone, 1 mm below and 1 mm above bone level [273]. The same implant positions were used in other experimental animal studies, which measured amounts of crestal bone resorption [274-277]. Analysis of dental literature on marginal bone loss determined the study design focusing on different implant positions in relation to bone level, when one of study implants is placed equally with crest and other is left unsubmerged for about 2 mm. Similar study design was earlier described by Piattelli and co-workers in experiment on monkeys [278]. They reported no bone resorption if

microgap was located 1.0 – 2.0 mm above the alveolar crest, and a loss of 2.1 mm if microgap was present at the level of the alveolar crest. However, mucosal tissue thickness was not measured in later animal study, thus conclusions, in the light of the present study may be uncertain. It should be noted that no clinical trial was detected to use similar to animal studies study protocol for deepness of implant placement, therefore the novelty of this experiment is valuable.

The study design included the placement of test implants above the bone level. The decision to place test implant about 2 mm supracrestally was based on extensive literature search and analysis, performed before initiation of the study. By the opinion of the author, three main factors responsible for early crestal bone loss were identified, namely microgap, abutment micromovments and polished implant collar.

Microgap, if placed at bone level or subcrestaly, produces infiltrate of inflammatory cells in connective tissue facing implant/abutment connection, as a reaction to bacteria, present inside abutment. Ericsson called it “abutment-related inflammatory cell infiltrate” [279]. Inflammatory cells promote osteoclasts formation which are responsible for alveolar bone loss. Another factor associated with microgap is the instability of implant-abutment interface. It is suggested that micro-movements of abutment can be linked to bone loss around implants [280]. Some authors state that prosthetic abutment instability is more important, than microgap itself, or its size. Implant polished collar can stimulate crestal bone loss associated with “non-load” factor, as machined implant surface cannot effectively distribute occlusal stress to bone, “stress shielding” is created and results in bone resorption. This is the basis for clinical recommendations to leave smooth titanium surface out of contact with bone and positioning supracrestally seems reasonable. It must be remembered that in modern implants design smooth implants neck is replaced with moderately rough surface or micro-threads. This is done not only for better soft tissue adhesion, but also for bone maintenance, if implants are positioned below bone level. Therefore, major aim of present study design was to isolate influence of polished implant neck and microgap on crestal bone loss and that was performed by positioning implant-abutment connection supracrestally. This allowed testing the effect of mucosal tissues by isolating other factors as much as possible. Secondary tasks were to eliminate other factors as much as possible by formulating inclusion/exclusion criteria. Thus patients

were selected to have edentulous gap for at least 2 implants with minimum 3 mm distance in-between due to study by Tarnow et al, which showed that implants in closer proximity may experience additional bone loss [281]. For similar reason included implants should be surrounded for at least 1 mm of keratinized mucosa, as it was shown to have an impact on peri-implant tissue recession [282]. Chung et al has also showed that presence of immobile attached mucosa around implants may reduce crestal bone resorption, however, the difference with implants, surrounded by non- or less keratinized tissues was not statistically significant [283]. Kim et al in recent publication on influence of keratinized peri-implant mucosa on stability of tissue levels concluded that the risk of the increase of mucosal recession and the crestal bone loss is present, if there is absence of attached mucosal tissues around implants [284]. Therefore, it is thought that from the aspect of long-term maintenance and management, as well as for the area requiring esthetics, the presence of an appropriate amount of keratinized gingiva is required.
Patient exclusion criteria stated that samples with active symptoms or history of periodontitis treatment were not selected for the study. This was done due to available evidence that periodontitis patients more frequently develop crestal bone loss than implants in periodontally intact individuals. Karrousis et al, Hartd et al, Evian et al Rosenberg et al, have demonstrated strong relationship between periodontitis and further bone loss around implants [285-288]. Recent systematic analysis by Heinz-Mayfield has solidified history of periodontitis as one of the major factors for developing peri-implantitis in the future [289].
Analogous position was demonstrated towards patients with poor oral hygiene, although the issue seems controversial. It's been shown that infection and poor oral hygiene are factors, which greatly reduce implant survival, by increasing bone loss. Studies by Ferreira et al and Lindquist et al have shown the risk to loose bone around implants, if oral hygiene is neglected [290;291].
The placement of implants at the bone level is used as a common practice standard, recommended by majority of manufacturers and studies. Leaving implant-abutment connection above the bone level is not everyday routine. However, supracrestal implant placement cannot be considered as experimental, although not in agreement with traditional approach. Davarpanah et al and Holt et al proposed supracrestal implant

placement, as a possibility to reduce bone resorption and achievement of better clinical crown/implant relationship [292;293]. This approach also enhances longer implant placement. Martinez et al suggested avoiding crestal or subcrestal implant position in regions with limited bone height and poor quality, if only short implants can be used without difficult bone augmentation procedures, as crestal bone loss around short implant can significantly jeopardize percentage of bone-to-implant contact and result in unfavorable biomechanics. Author advised to place implants supracrestally and maintain stable crestal bone [294].

Another question should be raised about the prognosis of test implants, placed above the bone in thin mucosal tissues. Because of crestal bone loss and subsequent mucosal recession, rough implant surface may denude and face oral environment. The surface of the implant and abutment (of varied textures and materials) may affect the behavior of soft tissues around the implant. Usually the implant has a smooth polished collar neck, ending with a platform for abutment connection. This was designed to accommodate possible future crestal bone loss and to avoid plaque accumulation on a roughened surface. If there is bone resorption, the polished titanium neck of the implant is exposed and becomes supracrestal. Research has shown, that less plaque adheres to polished titanium, than to rough surfaces [295], but only up to a threshold value (R_a=0.2μm), below which the bacterial adhesion could not be reduced [296]. Increased plaque accumulation and maintenance difficulties may predispose peri-mucositis or peri-implantitis[297]. In fact, when the microbiota adhering to the abutment was considered, rough surfaces harbored 25 times more bacteria, with a slightly lower density of coccoid organisms. However, the presence and density of periodontal pathogens submucosally were, however, more related to the patient's dental status than to the surface characteristics of the abutments.

The influence of rough implant or abutment surface is not completely clear, as Bollen et al [298] and Zitzmann et al [299] have shown that rough surface exposure did not result in increased plague accumulation, inflammation or bone loss. Wennerberg et al found no correlation between roughness of healing abutments and inflammation severity in human study [300]. In addition Bollen et al found that smooth surface abutments demonstrated deeper probing depths in the first year than rough surface abutments, which may indicate

that unstable soft tissue seal forms at the smooth surface. Roughened implant surface at neck portion in conventional viewpoint towards implant design is no longer considered inadequate, rather desirable, as it is suggested that irregular surface promotes better adhesion of soft peri-implant tissues [301]. Norton reported that 33 implants demonstrated a healthy soft tissue response around the exposed, roughened implant surface of Astra Tech single tooth implant with microthreads at conical neck (Astra Tech AB, Mönlndal, Sweden) during follow up of 1 year [302].

The problems of exposed implant threads to oral environment were addressed in retrospective clinical trial by Lekholm et al. The objects of research were implants that had not become completely covered with bone at implant placement or had developed marginal bone loss beyond the second thread, as judged radiographically at the first annual checkup. Initial marginal defects and fenestrations at implants did not lead to mucosal problems or progressive marginal bone resorption during the first 5 years of function. Moreover, bone resorption, seen after the first year of loading at initially completely bone-covered implants, did not lead to any specific soft tissue problems, nor did it result in any further progressive bone resorption during a subsequent 4-year period. Based on the observed low incidence of soft tissue pathology at implants with exposed threads, it is suggested that bone augmentation techniques in the situations studied be used with restriction [303].

Thus it can be assumed that, if good oral hygiene and maintenance will be delivered, supracrestal implants do not have risk for additional bone loss. It is worth mentioning, that absence of good oral hygiene and patient co-operation were exclusion criteria, consequently patients included into this research have low risk rate. At the end it can be concluded that placement of the implant above the bone level does not jeopardize success of treatment.

Recent histological [304;305] and clinical studies [306-308] have questioned the role of occlusion in etiology of bone loss. While still there are reports, which show the capacity of occlusal stress to overload dental implants, their applications to early crestal bone loss seem doubtful. Wiskott and Belser suggested that horizontal overload cannot be the cause for limited bone loss [309]. Yet in the overload concept, the supracrestal lever would continually increase, while resisting level would be reduced until fracturing implant from

its bony housing. But apparently early crestal bone loss is prone to stabilize itself after 1-year of prosthesis loading. Oh et al in narrative review has hypothesized that marginal bone loss can be induced by occlusal overload and excessive stress on immature bone-to-implant interface in early stages of loading. Bone loss stops, as bone matures and is more resistant to stresses. However, it must be noted that traditional reviews are susceptible to publication selection bias [310], therefore conclusions should be evaluated cautiously. The role of loading on early crestal bone loss also can be evaluated in studies on single-stage implant placement, when healing abutment is connected to implant at the time of surgery. It was discussed earlier that there is no difference in survival rates between one- and two-stage surgery implants and overall bone loss lower in one-stage implants. It should be mentioned that Cochrane database systematic review of implantation types recommended using one-stage approach, whenever possible [311]. Similarly, implant placement with immediate provisional reconstruction within few hours or days was shown to be beneficial and minimized lateral bone loss, compared to delayed loading concept. These are the reasons why occlusion was not taken into consideration in this study and formed a basis to use different prosthetic configuration for implant restoration. Thus, the results showed that crestal bone loss around implants restored with single crowns, splinted crowns or FPD's did not have statistically significant difference in test and control groups. This shows that occlusal loading and different prosthetic solutions are not the reasons for early crestal bone loss.

Bone loss around implants can be reported in two different ways. Some studies state separate measurement of distal and mesial sites of implant, others show combined numbers per single implant. Reporting bone loss mesially and distally seems more precise, as measurements between sites can vary. The reason for such disparity might be the shape of alveolar ridge. Flat ridge is optimal; however not available in most of the cases. Sometimes implants are placed on ascending bone crest, therefore different implant-abutment junction position mesiodistally in relation to the bone level may occur. Thus bone loss also can differ between mesial and distal sites.

On the other hand, the combined measurement is more convenient to understand, to relate and to compare with outcomes of other studies. However, it must be noted that statistically calculation of mean bone loss around single implant may not be correct, as

only two measurements are combined. From statistical point of view, report of separate distal and mesial measurements would be more precise.

Therefore, the decision to measure bone loss separately on mesial and distal sites and statistically evaluate the correlation between them is reasonable. If correlation is significant, mean bone loss per implant can be counted, but if correlation would be unreliable – study should report split measurements of distal and mesial sites of the implant. It appeared that Pearson's correlation coefficient showed significant strong correlation between the mesial and distal sites, therefore the mean bone loss per implant was calculated. For the sake of accuracy, crestal bone loss was reported in both ways – on mesial and distal sites and combined measurement per implant. Additionally, both methods of reporting data could be compared. It was interesting to see that there was difference between bone loss around mesial aspect of test implants and overall bone loss of test implants, when 3 groups of tissue thickness were analyzed. Error bar graphics showed that there was no statistical difference between mesial aspects of test implants, placed in thin and medium tissue, while depicturing of bone loss around all test implants revealed statistically significant difference between thin and medium thickness tissue (fig?). Thus, it can be concluded that separate measurement and reporting of bone loss on mesial and distal aspects looks more valid than reporting of combined figures.

Metal-ceramic single crowns, splinted crowns or 3-unit fixed partial dentures were used for restoration of implants, and the type of prosthesis did not affect the magnitude of hard peri-implant tissue loss. Loading stress, which differs in all 3 prostheses configurations, was not the aspect to change the bone response. Some studies, which used finite element analysis tests show that 2 implants supporting 3-unit fixed partial denture experience additional stresses in the neck area, compared to single implants [312]. Splinted crowns, conversely, have shown reduced damage evolution on bone tissues [313]. Therefore, some speculate that increased loading in implant neck area may result in actual bone loss, however, the current study shows that mathematical loading enlargement did not induce clinical bone changes. This clearly highlights the difference between finite element analysis and clinical studies, and that should always be kept in mind, when relating in vitro findings to clinical practice. In addition, patient gender and jaw or implant restoration type did not have noteworthy influence on bone changes in both groups.

While patient distribution between sexes was similar (12 male and 14 female), allotment between jaws was uneven, as mandible received 27 cases (54 implants) and maxilla – 5 cases (10 implants) or only 13% of all implants. It is well recognized that the upper jaw has lower bone quality compared to mandible; however, there is no data that crestal bone loss is dental arch dependant.

Different methods for mucosal thickness measurement have been described in the literature. The thickness of masticatory mucosa is evaluated by invasive methods using injection needle or probe, as it was described by Olsson et al [314]. Histological sections and cephalometric radiographs were additional methods to measure the width of the gingiva in various regions of mouth [315;316]. The thickness of masticatory mucosa has also been evaluated by non-invasive methods such as ultrasonic devices. Briefly, a piezo-crystal is set oscillating by a pulse generator at 5 MHz. Ultrasonic pulses are transmitted through the sound-permeable mucosa at an assumed velocity of about 1520 m/s and reflected in part at the surface of the alveolar bone or tooth. 1000 signals per second are transmitted, received and analyzed. This method seems reliable, however, have been demonstrated that may be deficient, if very thick tissue is present. Although the ultrasonographic method of assessing mucosal thickness is non-invasive, drawbacks included the relative unavailability of the instrument, difficulty in maintaining the directionality of the transducer, and non-reliable results when the thickness of gingiva exceeds 2–2.5 mm.

Thus, in the current trial mucosal thickness was measured directly with periodontal probe. Compared to ultrasonic or radiographic measurement this approach could be considered rather novel, however can be considered adequate for tissue thickness assessment. It was shown that direct visibility, which was achieved in the current study, is crucial for measurement [317]. Lawson and Jones conducted an interesting study to compare different methods of mucosal tissue thickness measurement and their reliability [318]. Authors have evaluated ultrasonic device, radiographic evaluation, ridge mapping method and direct measuring. Results have shown that direct measuring can be considered as a “gold standard”, as it was most reliable and reproducible. Radiographic method of evaluation was also precise, however with slight tendency to underestimate mucosal thickness. Ultrasound and ridge mapping device with rubber stop showed much

greater negative bias, than other methods, probably due to compressibility of the mucosa, which yielded easily to the pressure of application of the ultrasound probe tip and the ridge-mapping probe rubber stopper. In addition, probing is considered a reliable measuring procedure in evaluation of soft periodontal and peri-implant tissues [319;320]. This study as any experiment has its limitations. Sample size of patients, especially in the test group with initially thin mucosal tissues could have negatively influenced the results. However, patient selection and implant placement was random, therefore the amount of each test group could not be increased or reduced by the researchers. It must be remembered that clinical trials, involving dental implants are very expensive and hard to proceed. Not so large sample size can be accepted, if results show very strong statistical significance. ANOVA tests revealed that in two tissue thickness groups ($F_{[1,30]} = 138.2$; $P = .000$) and in three thickness group ($F_{[2,29]} = 37.3$; $P = .000$) statistical significance was very strong. On the other hand, a number of earlier published and widely cited clinical trials used very similar [321;322] or even smaller sample size [323], and it seems that sample size of the current experiment can be acceptable.

Bone loss measurement was performed on digital radiographs with magnification of 6 times. Morner-Svalling et al has proved that digital radiographs are at least as reliable as conventional diagnostic tools for evaluation of peri-implant bone levels [324]. Other advantage, e.g. radiation doses, time saved, the elimination of darkroom procedures, the pedagogical approach with the patient and opportunities for tele-consultations with radiologists are well known to be cost-effective and reliable. Validity of digital radiography was shown by other authors [325;326], thus it can be considered that this diagnostic device is suitable for crestal bone measurements. In addition, it was shown that Trophy RVG system, which was used in the current experiments can be considered reliable or even superior among other digital radiographic sensors [327].

The radiographs were taken using a parallel long-cone technique with film holders. It can be admitted that the use of standardized radiographs with individually manufactured devices, firmly connected to implant, would provide highest precision and accuracy and are usually referred as “gold standard”. However, Sewerin has shown that in clinical reality true standardization radiographs is very difficult to achieve, as factors like implant and abutment angulations, restoration position and retention method, jaw may influence

the failure to identify extent of bone loss as precise as possible [328]. Therefore costs and technical difficulties, related to thickness of digital x-ray films precluded employment of standardized radiographs in this trial. It was admitted that appropriate positioning of film holders can satisfy the requirements for acceptable radiographic image.
Instead, certain means were undertaken to increase the reliability of measurements. First, parallel long-cone technique was used with film holders, firmly attached to x-ray machine tube. Secondly, a careful examination of images for clear parallel visibility of implant threads was performed and 3 cases with 6 implants were excluded as not parallel enough to calculate bone changes. It is stressed in the literature that implant thread evaluation is basis for defining the parallel radiographs, suitable for precise bone loss calculation [329]. Another step to increase the precision of the bone loss measurements was calibration of digital images, which were performed within the software. As the diameter of the implants used were known, they were used for calibration. It was shown, that calibration of the digital images results in statistically more accurate measurements, compared to raw data [330]. Further, it must be admitted that a number of published articles, also used the same technique, therefore described measurement of bone loss seems acceptable [331;332].
In addition, Cameron et al demonstrated that film position did not significantly influence the accuracy of measurements of the image if tube head was maintained to less than 20 degrees from perpendicular to the long axis of the implant [333]. Correspondingly, Hollender and Rockler have stated that 9 degrees deviation from strict parallel line is reasonable and still proper diagnostic x-ray image can be obtained [334].

5.2. Influence of thin mucosal tissues on crestal bone stability around implants with platform switching.

In nowadays dentistry implants with platform switching are considered to represent newest concepts in avoiding of crestal bone remodeling. The use of prosthetic abutments with reduced width in relation to the implant diameter seems to have the greatest potential to limit the marginal bone resorption. The effects of platform switching have clear clinical relevance in some certain clinical situations. If bone height appears to be

limited and anatomical structures like maxillary sinus cavity or mandibular nerve preclude placement of implant with adequate length, the platform-switching concept may be beneficial in reducing crestal bone loss, thus improving implant/crown ratio and increases biomechanical support for the implant. Additionally, employing such kind of implants has shown to stabilize soft peri-implant tissues and warrants the presence of a papilla. It was shown that if two implants are positioned too close to each other, bone loss may occur and limit the presence of the papilla interproximally. Therefore, the use of platform switching implants in esthetic zone was advocated, especially if implants are placed side by side.

However, the results of this pilot study indicate that altered horizontal relationship between outer edge of the implant and a smaller-diameter abutment (platform switching) does not prevent crest bone loss, if mucosal tissues at the time of implant placement were thin e.g. 2 mm or less. All implants in the test group, which was formed of implants with platform switching, overcome mean bone loss of about 1.76 mm, which is a little less than control group implants (1.88 mm), however this difference was not statistically significant. It can be suggested that this bone loss resulted from BW formation, as primary tissue thickness was not sufficient for peri-implant seal to form without hard tissue resorption.

It was postulated that implant-abutment displacement can reduce crestal bone loss, as the source of inflammation is kept away from bone. Marginal resorption in different studies varies from 0.06 mm to 1.6 mm [335;336], thus composing about 0.76 mm after 8 years of loading [337]. The outcome of this pilot trial showed that implant-abutment connection is not the only factor in crestal bone loss etiology and bone resorption can occur not only around implants with regular matching I-A connection, but also around implants with platform switching modification. As mucosal tissue thickness was not bigger than 2 mm in this particular patient sample it could be hypothesized that bone loss resulted due to inadequate tissue thickness for peri-implant seal formation. It was stressed earlier that peri-implant seal tends to be about 4 mm in humans [83], thus initial mucosal tissue thickness and crestal bone loss around test implants would comply similar quantity. It can be concluded that anatomical condition, like mucosal tissue thickness plays a major role, probably more important than implant-abutment connection type.

Bone loss around control implants is no surprise, as many studies have shown bone resorption around 2-piece implants with microgap at bone level.
Study design aimed at patients, with thin tissue biotype, as previous trials with larger sample of subject showed the potential of tissues with thickness of 2 mm or less to evoke marginal bone recession. Conclusion of this pilot study opposes current opinion that implants with platform switching do not experience crestal bone loss, or does it only in minimal amounts. The decision to evaluate behavior crestal bone around platform-switched implants positioned in thin tissues was based on results of previous animal trials [338;339] and previous study with implants, placed in different relation to the bone crest. Pilot study is described as a small-scale methodological test intended to ensure that proposed methods and procedures will work in practice before being applied in a large, expensive investigation. Pilot studies provide an opportunity to make adjustments and revisions before investing in, and incurring, the heavy costs associated with a large study. Thus the results of this trial should be carefully read, as small sample size precludes stronger conclusion formulation. Sample size in pilot studies is the object of discussion. Recent pilot investigation by Schwarz and co-authors used 8 implants placed in 4 dogs for primary evaluation of new implant design and crestal bone measurements [340]. Even less implants were tested in animal experiment, which evaluated flapless implant placement and simultaneous per-implant defect correction – 5 implants placed in 5 mongrel dogs [341]. In contrast pilot study by Shahidi et al involved 37 patients and 54 implants to test new papilla regeneration technique in implant dentistry [342]. Thus it can be considered that sample size in current pilot study is adequate.
Reported outcome of this trail is not in agreement with previous clinical study by Vela-Neblot et al [343]. This study compared regular connection implants, assigned to control group with platform switched fixtures, which formed test assembly. Implants in both groups were positioned equally with bone crest and later restored with single crowns. After 6 months of loading mean value of bone loss observed in the mesial and distal measurements for the control group was 2.53 and 2.56 mm and for the test sample 0.76 and 0.77 mm respectively. This difference was found to be statistically significant and supported recommendation to use implants with platform switching for crestal bone preservation. However, authors mentioned that some of test implants had about 1.3 mm

bone loss, but no further explanation for this was provided. Having in mind that material and method section did not include mucosal tissue measurement before implant placement, it could be suggested that this unusual bone loss occurred due to possibly present thin tissue. It is possible that major part of test platform switching implants were positioned in thick tissue, therefore could experience less bone loss, than control implants. This study has many similarities with the current experiment. First, both studies used two types of implants – platform switched and with regular implant-abutment junction. Secondly, in both studies implants were placed at the bone level. Finally, follow-up period was the same. Of course, there were some obvious disparities. Implants in Vela-Neblot et al study were restored with single crowns, while test and control implants in the current study were rehabilitated with splinted metal-ceramic restorations. Additionally, implants in the other study were placed in split-mouth manner, however pilot investigation explored implants positioned side by side. Of course it should be noted that sample size was much bigger in clinical trial, than in pilot study.

A similar speculation can be attributed to another clinical study, which retrospectively evaluated Ankylos implants. It was reported bone loss around implants with platform switching to be only 0.2 mm within 3 years of loading, although bone resorption after implants uncovering ranged from 0.5 to 2 mm on average [232]. Again, as initial tissue thickness before implant placement was not registered or reported it can be assumed that bone loss up to 2 mm could be a consequence of thin tissues.

Other clinical trials, including retrospective studies by Norton evaluated bone loss of Astra Tech implants, which also poses platform switching modification showed minimal amounts of crestal bone loss, however, did not explore mucosal tissue thickness factor [344;345]. Hurzeler et al controlled clinical trial also poses the drawback discussed – no mucosal thickness evaluation was performed before implant placement [346]. Authors have reported that mean bone loss around implants with platform switching at a time of restoration delivery was only 0.09 mm. This period of time between implant placement and beginning of the prosthetic treatment usually represents the formation of peri-implant seal and such minimal bone resorption could be explained, if thick tissues were present. Studies by Cappiello and co-authors, Canullo and Rasperini and Calvo-Guilardo with co-workers also did not describe measurements of mucosal tissue thickness before implant

placement [347-349]. Not all studies have reported no or minimal bone resorption around implants with smaller-size abutments. Some interesting evidence can be found in animal studies. Becker et al conducted an animal study to compare crestal bone loss around wide diameter implants, connected with smaller diameter healing abutments, thus creating platform switching effect to implants with horizontally matching healing abutments [350]. Results showed that both groups experienced similar amounts of bone resorption and extension of soft tissue structure was also similar. This shows that platform switching is not the precondition to reduce bone loss around implants. As implants in this animal trial were not loaded, bone loss can be attributed to BW formation, which sometimes can involve bone resorption. It should be added that this animal experiment used actually used regular connection implants fitted with smaller diameter healing abutments.

Jung et al. in animal histological study have shown that implants with non-matching implant-abutment diameters experienced very little bone loss. Implants were positioned in three different positions: 1 mm subcrestally, at the bone level and 1 mm above the crest. Amount of bone loss was not statistically different between tested groups, however most of the bone loss occurred around subcrestally placed implants. This shows that even with platform switching implants the deepness of microgap location is important.

It must be pointed out that this animal experiment did not have a proper control group, composed of implants with matching implant-abutment diameters; therefore, the conclusions have limited relevance. The ability of platform switching to reduce bone loss around implants has been explained by Lazzara et al. It was suggested, that if abutment diameter matches with implant, the inflammatory cell infiltrate is formed in the connective tissue, contacting microgap, created by implant-abutment interface. If abutment of narrower diameter is connected to wider neck implant, the implant-abutment interface is shifted away from outer edge of the implant, thus distancing inflammatory cell infiltrate away from bone. Hypothetically less crestal bone loss is expected and increased implant/ abutment surface allows more stable peri-implant soft tissue integration. However, all studies describing platform switching have similar feature – initial mucosa thickness was not recorded before implant placement.

6. CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. If at the time of implant insertion the mucosal tissue thickness was 2 mm or less supracrestally positioned implants with horizontally matching implant-abutment interface overcome bone loss. If tissue thickness is more than 2 mm, placement of implant-abutment connection above the bone level can reduce crestal bone loss.
2. According to crestal bone loss around studied implants, mucosal tissue could be classified as thin (up to 2 mm), medium (2.1 – 3.0 mm) and thick (3.1 and more).
3. Implants with platform switching modification experience crestal bone loss, if at a time of implant placement the tissue thickness was 2 mm or less.
4. Implant placement 2 mm supracrestally can reduce bone loss, if implants are positioned in thick mucosal tissue. If tissue thickness is 2 mm or less, supracrestal implant position does not preclude significant bone remodeling in apical direction.
5. Bone loss on mesial and distal aspects may be different, compared to combined measurement per implant.
6. Prosthetic construction (single crowns, splinted crowns, FPD), patient gender and jaw did not influence the amplitude of bone resorption around implants.

7. PUBLICATIONS

1. Linkevicius T**,** Apse P, Grybauskas S, Puisys A. The influence of soft tissue thickness on crestal bone changes around implants. A 1-year prospective controlled clinical trial. Int J Oral Maxillofac Implants in press.

2. Linkevicius T, Apse P, Grybauskas S, Puisys A. Reaction of crestal bone around implants to mucosal tissues of different thickness. A 1-year prospective clinical trial. Stomatologija, Baltic Dental and Maxillofacial Journal in press.

3. Linkevicius T**,** Apse P, Grybauskas S, Puisys A. The influence of thin mucosal tissues on crestal bone stability around implants with platform switching. Clin Oral Impl Res 2008; 19(9):879

4. Linkevicius T, Apse P, Grybauskas S, Puisys A. The influence of thin mucosal tissues on crestal bone stability around implants with platform switching. A 1 – year pilot study. Stomatologija, Baltic Dental and Maxillofacial Journal 2008, Suppl. 5:11-12.

5. Linkevicius T, Apse P. BW Around Implants. An Evidence-Based Review. Stomatologija, Baltic Dental and Maxillofacial Journal 2008;10(1):27-35.

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8. PRESENTATIONS IN INTERNATIONAL CONGRESSES

1. "The influence of thin mucosal tissues on crestal bone stability around implants with platform switching". Poster presentation in the 17th annual Scientific Meeting of EAO, Warsaw, Poland, 2008.

2. "The influence of thin mucosal tissues on crestal bone stability around implants with platform switching. A 1-year pilot study". III Baltic Scientific Conference of Dentistry, Vilnius, Lithuania, 2008.

3. "Effect of soft tissue thickness on crestal bone changes around implants. A 1 year prospective controlled randomized study". II Baltic Scientific conference of Dentistry. Riga, Latvia, 2007

4. "The influence of soft tissue thickness on crestal bone stability around implants". Poster presentation in 16th Annual Scientific Meeting of EAO, Barcelona, Spain, 2007.

5. "Soft tissue around implants". 1st Baltic Scientific Conference in Dentistry. Parnu, Estonia, 2006

6. "BW around implants". 6th Baltic workshop on osseointegrated implants. Riga, Latvia, 2006.

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