The Effect of Bone Condensation and Crestal Preparation on the Bone Response to Implants Designed for Immediate Loading: A Histomorphometric Study in Dogs

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Purpose: *The aim of this study was to evaluate the influence of bone condensation and crestal preparation on the bone response of implants designed to promote osseocompression.* ***Materials and Methods:*** *In the first phase, the mandibular premolars of 6 dogs were extracted bilaterally. After 8 weeks, each dog received 8 Xive implants (4 per hemimandible). One hemimandible was randomly assigned to the experimental group and the other to the control group. The implant site was prepared using conventional standard drills. Prior to implant placement the crestal drill was used in the experimental group but not in the control group. After 12 weeks, the animals were sedated and sacrificed. The hemimandibles were removed and prepared for histomorphometric analysis of bone-implant contact (BIC) and bone density of areas adjacent to and further from the implant surface.* ***Results:*** *The mean ± SD percentages of BIC attained were 71.1% ± 11.8% and 45.1% ± 16.1% for the experimental and control groups, respectively. The bone density analysis revealed that in the control group, percentage BIC was a mean of 55.6% ± 11.3% adjacent to the implant and 50.7% ± 17.9% distant from the implant. In the experimental group, percentage BIC was a mean of 71.1% ± 8.6% adjacent to the implant and 55.6 ± 11.3 distant from the implant. The difference between the experimental and control groups was statistically significant for both parameters, BIC and bone density, in the adjacent areas (*$P < .0001$*).* ***Conclusion:*** *Crestal preparation is of fundamental importance for this implant system, since it led to better bone response, represented by the improved BIC and bone density.* INT J ORAL MAXILLOFAC IMPLANTS 2007;22:63–71

Key words: *bone condensation, bone density, bone-to-implant contact, clinical protocols, dental implants*

The highly satisfactory success rate obtained with dental implants in the treatment of edentulous patients depends on a number of factors, including the volume and quality of the bone.[1–5] Initial stability of the implants is, in effect, one of the fundamental criteria for obtaining osseointegration.[6] Achievement of initial stability depends on the bone density, on the surgical technique, and on the macro- and microstructure of the implant used.

According to Lekholm and Zarb,[7] bone density can be classified into 4 categories ranging from dense to spongy bone. Type 1 is dense, homogenous, compact cortical bone; type 4, on the other hand, consists of a thin layer of cortical bone surrounding a core of low-density trabecular bone. For all bone qualities, safe and gentle placement of the implants must be ensured. An atraumatic surgical technique requires the use of drills of increasing diameters and appropriate design and cutting efficiency, as well as abundant irrigation of the drill and surrounding bone during site preparation to avoid bone heating above 47°C, which could decrease the regenerative capacity of the bone.[8,9]

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Numerous animal studies confirm the importance of adequate implant anchorage to obtain osseointegration. Sennerby and coworkers[10] showed in rabbits that implants stabilized by only 3 threads in the cortical bone had a higher percentage of bone-to-implant contact (BIC) compared to implants which had been completely surrounded by trabecular bone. Furthermore, higher forces were necessary to dislodge the former implants compared with the latter implants. The results demonstrate that quality of bone is extremely important for optimal stabilization.

Different surgical approaches were suggested in the 1980s with the aim of achieving optimal osseous integration in poor-quality bone. For example, to improve primary stability, as well as to increase the chances of success in situations where it is necessary to place implants in bone of inferior quality, bone condensation with the use of osteotomes was developed.[11] The instruments, which are shaped like implants, are used to compress the bone laterally, with the aim of improving the quality and density of the bone. Lateral osseocompression during site preparation can improve the quality of type 4 bone so that it is similar to type 3 bone; the same technique can be applied to make type 3 bone seem more like type 2 bone.[12] When compared to the conventional technique of implant site preparation in an animal model, the osteotome technique showed increased bone formation and enhanced osseointegration of dental implants in trabecular bone.[13] Recently, a new system of implants was developed with implants for specific bone qualities and regions of the mouth. The macroscopic design of the implants and threads promotes considerable bone condensation during its placement, so that site preparation is specifically tailored to the region of the mouth where the implant is being placed and the type of bone usually found there. A special crestal drill capable of controlling the level of condensation was added to the drilling sequence. The drill, which is unique to the new implant system, is 0.2 mm wider than the drill that was previously the last in the sequence. The shape of this drill matches the shape of the implant, including the flare of its collar, and its use controls the degree of internal condensation achieved by the implant during placement. According to the manufacturer (Dentsply Friadent, Mannheim, Germany), depending on the bone quality the crestal drill should be used in depths varying between 2 mm (for bone type 4) and 6 mm (for bone of type 1, 2, or 3). Clinically, during the initial preparation with the pilot drill, bone density can be assessed by tactile perception.[3,14] For example, if there is little or no resistance, the bone density can be assumed to be low (type 4), and increased resistance to the pilot drill would correspond to bone types 1, 2, or 3. It is recommended that, when dealing with soft trabecular bone, the use of this drill be limited to the crestal 2 to 3 mm of the implant site; this allows the bone condensation provided by the implant at the time of insertion to occur in the remaining length of the site. However, if the drill were used for the full length of the osteotomy, it could possibly prevent bone condensation which could jeopardize the osseointegration.

The aim of this study was to evaluate in dogs the effect of crestal preparation on the osseointegration of dental implants, which promotes bone condensation by analyzing BIC and bone density.

MATERIALS AND METHODS

The study protocol was reviewed and approved by the the institutional review board on animal research.

Six young male mongrel dogs, weighing approximately 15 kg each, were used in this study. The animals had intact maxillae and atraumatic occlusion. They had no mucosal lesions and were in good general health, with contraindications to implant placement, as determined by clinical examination by a veterinarian.

The night before the surgery, the animals received a combination of 20,000 IU penicillin and 1.0 g streptomycin/10 kg body weight. Since each dose provides antibiotic coverage for 4 days, another dose was injected 4 days later, totaling 8 days of antibiotic coverage.[15,16] In the first stage of the study, the dogs were anesthetized after sedation with 1 mL/kg thiopental (20 mg/kg thiopental diluted in 50 mL saline). Full-thickness flaps were elevated bilaterally in the area of the first to fourth mandibular premolars. The teeth were sectioned in a buccolingual direction at the bifurcation so that the roots could be individually extracted without damaging the bony walls. After repositioning of the periodontal flaps, the wound was closed with resorbable sutures. The animals were maintained on a soft diet for 14 days. Healing was evaluated periodically, and the remaining teeth were cleaned monthly with ultrasonic points. In order to achieve bone with intermediate quality, a healing period of only 8 weeks was allowed before the next surgical intervention. The night before the second surgery, the animals received another dose of antibiotics, in the same manner as described before. The same method was used for anesthesia as well. Full-thickness flaps were elevated bilaterally in the area corresponding to the first to fourth mandibular premolars (Fig 1). Four rough-surfaced and acid-etched self-tapping screw-type implants 4.5 mm in diameter

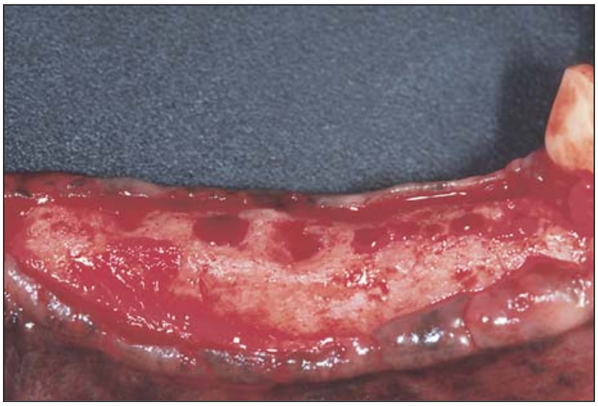


Fig 1 Clinical aspect before second surgery. Clinical aspect of the alveolar crest after elevation of a full-thickness flap.

Fig 2 The crestal drill.

and 9.5 mm in length (Xive; Dentsply Friadent) were placed bilaterally in each dog. One side of each mandible was randomly designated the control side and the other the experimental side. The crestal drill was used in experimental sites but not in control sites. The implant sites were sequentially enlarged to 4.5 mm in diameter with pilot and spiral drills according to the standard surgical protocol. After the completion of implant site preparation, crestal preparation of the bone was performed in a vertical direction in the experimental sites. A crestal drill (Fig 2) with a cutting depth of 6 mm was used for this purpose. The crestal preparation of 6 mm, the entire length of the drill, was chosen to obtain a more representative field for histomorphometric analysis. In sequence the implants were placed according to the manufacturer's instructions (Fig 3). The animals were maintained on a soft diet for 14 days. Healing was evaluated periodically, and the teeth were cleaned monthly with ultrasonic points. The animals were sedated and then sacrificed with an overdose of thiopental after sedation 12 weeks after implant placement. Hemimandibles were removed, dissected, and fixed in 4% phosphate-buffered formalin (pH 7) for 10 days. They were then transferred to a solution of 70% ethanol until processing. The specimens were dehydrated in a graded series of alcohols up to a concentration of 100%. They were then infiltrated, embedded in methylmethacrylate resin, and hard-sectioned using the technique described by Donath and Breuner.[17] The sections were prepared for histomorphometry and stained with Stevenel's blue and alizarin red S for optic microscopic analysis.

Histomorphometric Analysis

Two longitudinal histologic sections 20 to 30 µm thick from each implant were captured using a video camera (Leica DC 300F; Leica Microsystems, Nussloch, Germany) joined to a stereomicroscope (Leica MZFL

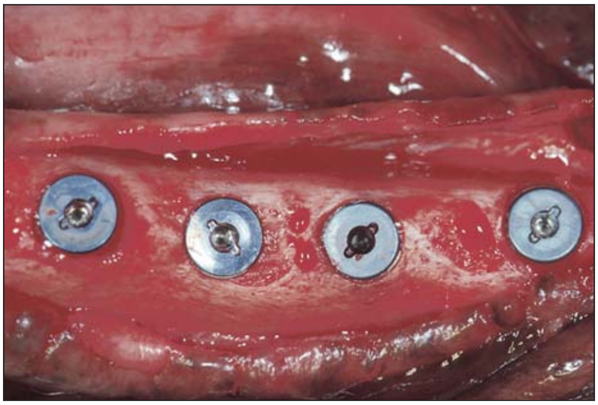


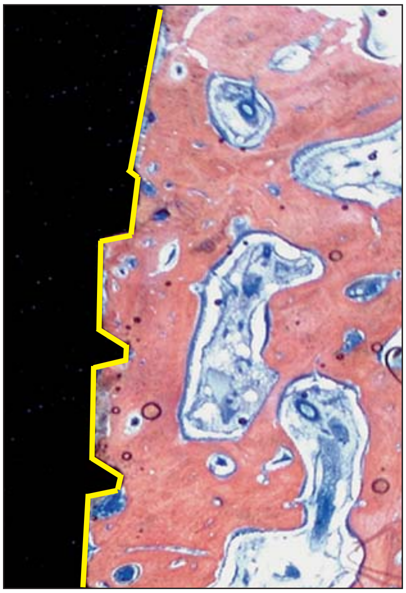
Fig 3 Implants in position (occlusal view).

III; Leica Microsystems). The images were analyzed through the Image J program (National Institutes of Health, Bethesda, MD), which determined the percentages of BIC and the bone density around the implants. Through linear measurements, in the cervical 6 mm of the implant the percentage of mineralized bone in direct contact with the implant surface (BIC) was determined (Fig 4).

Bone density was determined as the percentage of bone found within 6 squares measuring 0.61 mm^2 each. BIC was measured in these same regions. Three squares were placed adjacent to the implant surface (adjacent areas) and three were placed in a mirror image of the first (distant areas), as seen in Fig 5. A single blinded examiner with no knowledge of the group assignment made the measurements.

Statistical Analysis

The data were grouped using both the implants and dogs as units for analysis. The mean differences in BIC between the groups were examined with the Mann-



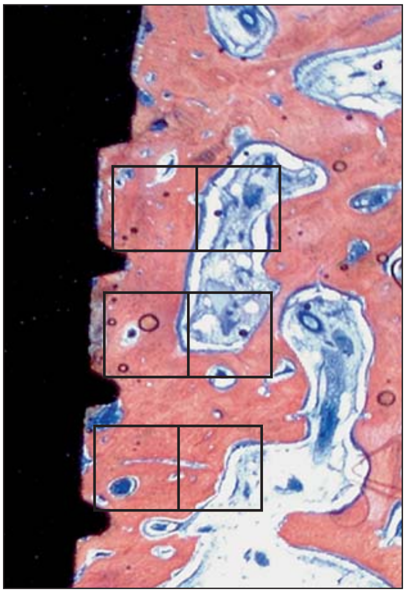
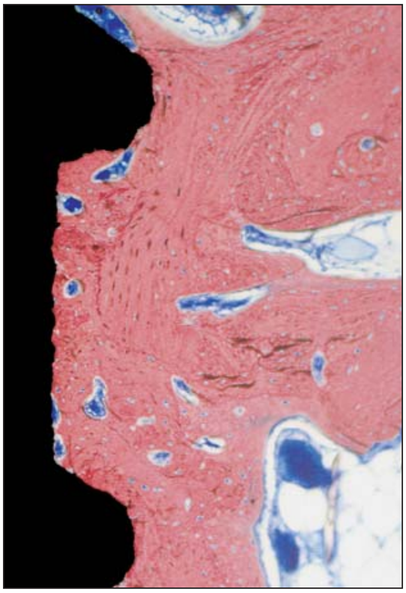


Fig 4 *(left)* BIC in the cervical 6 mm of an implant.

Fig 5 *(right)* Bone densities were determined by measuring the percentage of bone within the squares. The same squares were used for BIC calculation.



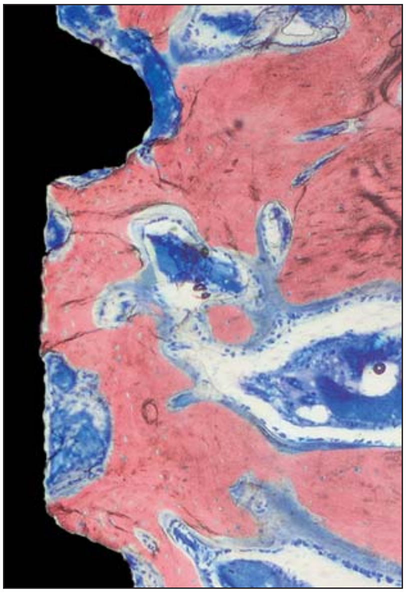


Fig 6 *(left)* BIC in an experimental group specimen (Stevenel's blue and alizarin red S stain; original magnification ×25).

Fig 7 *(right)* BIC in a control group specimen (Stevenel's blue and alizarin red S stain; original magnification ×25).

Whitney nonparametric test, with a significance level of 5%. The differences in bone density were examined with the Kruskal-Wallis nonparametric test, with a significance level of 5%.

RESULTS

Clinical Findings

Postextraction healing was uneventful in all animals. At the implantation surgeries 8 weeks later, the extraction sites had healed, and the alveolar ridge showed evidence of remodeling (Fig 1). During site preparation resistance to the pilot drill indicated the presence of bone of intermediate quality (type 2 or 3). All the implants osseointegrated well, as evidenced by clinical and radiographic examination at the time of sacrifice.

Histologic Observations

The bone-implant interface had mineralized bone matrix in intimate contact with the implant surfaces in both the experimental and control groups. The bone tissue was characterized by concentric or parallel formations. Central canals of different diameters were seen, covered by an active endosteum. At some points these canals were in close contact with the implant surface (Figs 6 and 7). During the bone density analysis, higher densities were observed adjacent to the implants.

Histomorphometric Findings

The percentages of direct BIC around the cervical 6 mm of the implants are given in Table 1. The average percentage of direct BIC in the experimental group was 71.1% ± 11.8% (range, 45.1% to 86.2%); in the experimental group, average BIC was 45.1% ± 16.1% (range, 17.6 to 74.3). The difference between the experimental and control group was significant when the implants were used as the experimental unit (*P* < .001).

Statistical analysis was also carried out with the dog as the experimental unit; it showed that the mean percentage of BIC was 71.1% ± 8.8% (range, 60.7% to 80.8%) for the experimental group and 45.1 ± 9.6% (range, 28.2% to 54.9%) for the control group (Table 2). The differences were also statistically significant (*P* < .05).

Figures 8 and 9 show implant distribution in relation to the BIC percentage for the experimental and control groups, respectively. The experimental group showed a higher number of implants (12) with values between 75% and 85% BIC. In this group, BIC percentages of less than 45% were not found. Another 6 implants showed BIC values from 65% to 75%. In the control group, the BIC ranges with the greatest number of implants (n = 5) were 35% to 40% and 50% to

Table 1 Percentage of BIC

	BIC (%)	
Implant	Experimental group	Control group
1	65.9	51.1
2	77.3	19.6
3	52.7	24.4
4	68.9	17.6
5	68.3	61.1
6	73.0	39.1
7	48.3	37.3
8	53.3	54.7
9	75.7	62.1
10	81.7	54.7
11	86.2	60.4
12	75.4	35.5
13	81.9	36.2
14	55.7	39.5
15	45.1	51.8
16	68.9	47.0
17	76.4	30.5
18	82.2	65.4
19	80.3	32.3
20	84.3	42.6
21	76.2	22.9
22	80.1	52.2
23	75.2	70.4
24	72.9	74.3
Mean ± SD	71.1 ± 11.8	45.1 ± 16.1

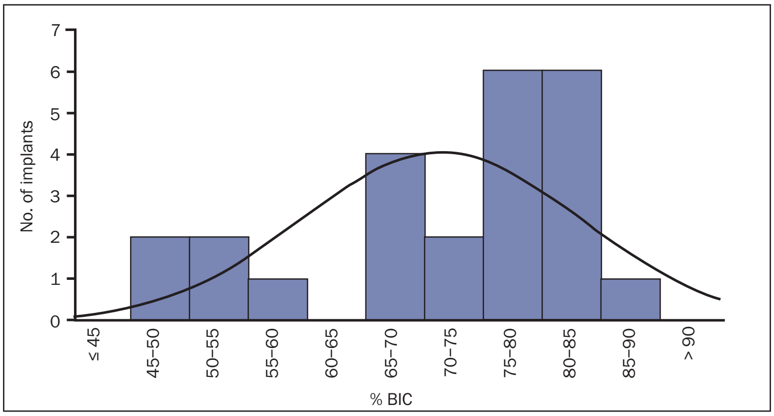


Fig 8 The histogram shows a normal distribution, with the majority of the values for the experimental group concentrated around the mean.

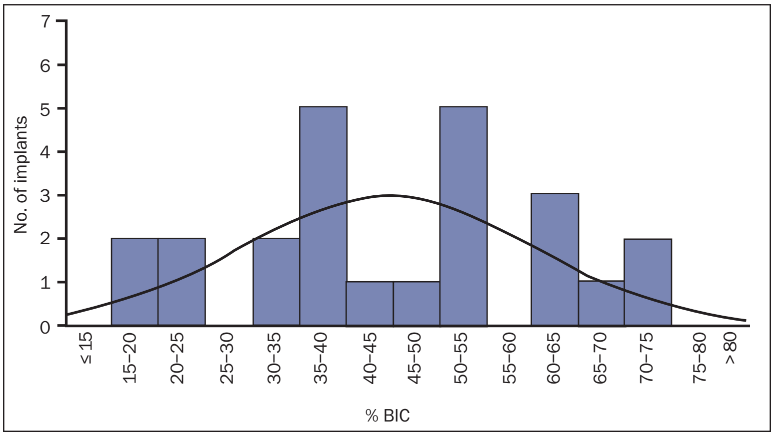


Fig 9 The histogram shows dispersion of the osseointegration values for the control group.

Table 2 Percentage of BIC—Dog as the Experimental Unit

	BIC (%)	
Dog	Experimental group	Control group
1	66.2	28.2
2	60.7	48.0
3	79.7	53.2
4	62.9	43.6
5	80.8	42.7
6	76.1	54.9
Mean ± SD	71.1 ± 8.8	45.1 ± 9.6

Table 3 Percentage of Bone Density in the Adjacent and Distant Areas—Implant as the Experimental Unit

	Adjacent area (%)		Distant area (%)	
Implant	Experimental group	Control group	Experimental group	Control group
1	85.5	57.8	60.6	81.5
2	76.3	52.6	84.2	55.2
3	79.4	47.3	49.3	55.8
4	52.4	44.7	47.3	57.8
5	72.6	71.0	54.2	68.4
6	69.4	60.5	44.7	65.7
7	80.5	39.2	60.5	50.0
8	78.4	39.4	58.3	26.3
9	63.1	71.0	55.2	78.9
10	71.0	63.1	58.4	68.4
11	57.8	49.1	47.3	36.8
12	74.7	60.5	51.9	44.7
13	60.5	63.5	47.3	47.3
14	65.7	55.2	44.7	26.3
15	71.0	73.6	47.3	55.1
16	82.8	51.2	66.3	34.2
17	65.7	57.8	55.2	52.6
18	78.0	76.3	31.0	81.5
19	65.7	44.7	42.1	47.3
20	68.5	36.8	44.2	26.3
21	80.5	55.2	60.7	60.4
22	72.1	68.4	63.1	38.8
23	59.0	50.0	39.4	39.4
24	76.8	44.7	28.4	18.4
Mean ± SD	71.1 ± 8.6	55.6 ± 11.3	51.7 ± 11.8	50.7 ± 17.9

Table 4 Percentage of Bone Density in the Adjacent and Distant Areas—Dog as the Experimental Unit

	Adjacent area (%)		Distant area (%)	
Dog	Experimental group	Control group	Experimental group	Control group
1	77.8	50.6	54.9	56.8
2	75.2	52.5	54.4	52.6
3	66.7	60.9	53.6	57.2
4	70.0	60.9	51.4	40.7
5	69.5	53.9	43.1	51.9
6	72.1	54.6	47.9	39.2
Mean ± SD	71.9 ± 4.0	55.6 ± 4.3	50.8 ± 4.5	49.7 ± 7.8

55%. Six implants showed BIC ≤ 35%, and only 2 implants showed values between 70% and 75%. None of the control implants had BIC higher than 80%.

Bone density analysis revealed that the percentage of bone in adjacent areas was 71.1% ± 8.6% (range, 52.4% to 85.5%) for the experimental group and was 55.6% ± 11.3% (range, 36.8% to 76.3%) for the control group (Table 3). The difference was statistically significant ($P < .0001$). The average bone density in areas distant from the implants was 51.7% ± 11.8% (range, 28.4% to 84.2%) and 50.7% ± 17.9% (range, 18.4% to 81.5%), for experimental and control groups, respectively. The difference between the 2 groups was not statistically significant ($P > .05$). The statistical analysis described was conducted using the implants as the experimental units (Table 2). When the experimental unit was the dog, the mean bone densities for the adjacent areas were 71.9% ± 4.0% for the experimental group and 55.6% ± 4.3% for the control group; the difference between the 2 groups was statistically significant ($P < .05$; Table 4). For the distant areas, the mean bone densities were 50.8% ± 4.5% for the experimental group and 49.7% ± 7.8% for the control group; the difference between the 2 groups was not statistically significant ($P > .05$). The results were similar whether the dog or the implant was used as the experimental unit.

DISCUSSION

Presently implant dentistry's high level of predictability is well documented.[1–5] Time of loading, quantity and quality of bone, and macro- and microstructure of implants, including design and length, have been extensively discussed over the past few years. The extensive research on the subject has permitted the evolution of this therapy.

Primary implant stability is 1 of the main factors influencing implant survival rates. It is a prerequisite to establish mechanical rest, which seems to be essential for undisturbed healing and osseointegration.[18,19] Primary stability depends upon the surgical technique, the geometry of the implant, and the local amount and density of the bone.[20] If an implant is placed in the soft spongy bone with poor initial stability, a frequent result is connective tissue encapsulation.[21] Micromovements of more than 100 μm are sufficient to jeopardize healing with direct BIC.[22] This observation was also reported by Szmukler-Moncler and coworkers,[21] who indicated that micromotions at the bone-implant interface beyond 150 μm resulted in fibrous encapsulation instead of osseointegration.

Implant configuration has long been considered an essential requirement for implant success. As a general concept, the screw implant design develops higher mechanical retention, minimizes micromotion of the implant, and improves initial stability, the principal requirement for immediate loading success.

With respect to the self-tapping implants, it is known that they must utilize a specific thread design in order to offer good cutting performance and, as a result, more BIC when placed in spongy bone sites. The thread design has been shown to be more of a determinant of primary stability than the surface characteristics in softer type 4 bone.[23] On the other hand, in cortical bone, reduced resistance in cutting performance is required. High insertion torques lead to increased friction that could overcompress the surrounding bone or even cause heating necrosis. To fulfill these requirements a new approach associating a self-tapping implant with a crestal site preparation independent of the bone density was developed.

The aim of the present study was to evaluate in dogs the effect of crestal preparation, followed by the placement of osseocondensating Xive implants on BIC and bone density. For this purpose, the 4 bilateral premolars of 6 dogs were extracted. After 8 weeks of healing, each dog received 8 implants (4 per hemimandible); 1 hemimandible was randomly assigned to be the experimental group (ie, the one in which the crestal drill was used), while the other was designated the control group. The animals used in this study probably did not present with type 4 bone in the sites of implantation. However, by reducing the healing period following extraction to 8 weeks, a less compact bone was obtained. Caution should be used in extrapolating the results to either animals or humans with type 4 bone.

Analysis between the groups showed statistically significant differences in BIC, with significantly greater BIC in the experimental group (71.1% in the experimental group and 45.1% in the control group). In the experimental group, 18 implants had BIC of 65% to 85%, and no implant had BIC inferior to 40%. In the control group, only 11 implants demonstrated a BIC of 50% to 75%, and 11 other implants presented BIC values inferior to 40%. The better distribution achieved in the experimental group demonstrates the advantages of adequate and controlled crestal preparation. The combination of the condensation thread of the implant and the crestal drill offers high primary stability in all types of bone. However, it must be noted that excessive torques, which may occur during implant placement, can traumatize the peri-implant bone and jeopardize osseointegration. In a previous study, the importance of the crestal drill to reduce crestal resorption was demonstrated.[24] In this study it was demonstrated that the proper use of the crestal drill in association with this implant design can improve BIC and bone density in bone of intermediate quality. Therefore, recommendations for the correct use of the crestal drill can be extrapolated. Penetration of 2 mm in bone type 4, 3 mm in bone type 3, and 6 mm in bone types 1 and 2 are recommended for the crestal drill. The internal condensation effect induced by the thread design is particularly desirable in spongy bone. In contrast, internal condensation is not required to increase primary stability in more cortical bone. The effect of internal condensation is controlled by the crestal drill as a result of the vertical preparation. Very high torques may occur, particularly in the mandible, because of the high proportion of cortical bone. The macrodesign of the implant, with its core and thread pattern, is intended to achieve high primary stability.

Another important observation is the histomorphometric findings in the areas adjacent to the implant surface compared with areas further from the implant surface. In the region adjacent to the implant surface, a mean bone density of 71.1% (range, 52.4% to 85.5%) was achieved for the experimental group, and a mean bone density of 55.6% (range, 36.8% to 76.3%) was achieved for the control group. The average bone densities achieved in the areas distant from the implant surface were 51.7% (range, 28.4% to 84.2%) and 50.7% (range, 18.4% to 81.5%), respectively, for experimental and control groups.

In order to achieve primary stability, a clinical alternative is to underprepare the implant site by 1 drill size to create osseocompression during implant insertion. Another way to obtain similar results is through the use of osteotomes. Both of these techniques can lead to osseocondensation and improve bone density. However, one technique is a clinical maneuver to attempt to improve specific clinical situations, and the other requires a specific set of instruments, has limited indications, and involves some amount of discomfort to the patients.

It has been claimed that implant placement by the osteotome technique not only improves primary stability but leads to accelerated bone healing compared to conventional implant placement in trabecular bone, as can be found, for example, in the human posterior maxilla.[13] However, in a study of implants placed in the maxillae of minipigs, there were no statistically significant differences between sites prepared using osteotomes and those prepared with spiral drills.[25,26] The results obtained in this study reinforce the benefits provided by crestal preparation in obtaining better bone response to the selected implant system. Previous animal studies have demonstrated the importance of the marginal bone density on implant stability.[27,28] A statistically significant correlation between the cutting torque resistance of the implant penetrating the crestal portion of the implant site and resonance frequency analysis has been demonstrated.[29] Improved bone density in bone closer to the implant surface may also lead to improved primary stability of the implants,[30] a decisive factor in the achievement of osseointegration.[18,19] In conclusion, for this implant system, crestal preparation led to better bone response, represented by the improved BIC and bone density.

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