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Research Article

The Effects of Corona Stimulation on the Osseointegration of Dental Implants: An Experimental Study

Mustafa Ayhan, Humeyra Kocaelli

İstanbul University, Faculty of Dentistry, Department of Oral and Maxillofacial Surgery, İstanbul, Türkiye

Abstract

Aim: Currently, one of the most promising research areas in dental implantology is the exploration of additional procedures to reduce loading time for implants and enhance osseointegration in cases of poor bone quality. Various techniques have been researched and developed for stimulating bone production, including electrical stimulation of the jawbone and surrounding tissues. However, there is limited research on the direct relationship between electrostimulation and osseointegration. This experimental study aims to investigate the effects of corona stimulation (CS) on the rate and quality of osseointegration, as well as its potential to reduce the waiting period for dental implants.

Material and Method: In this experimental protocol, 32 dental implants were inserted into the tibia of four male sheep bilaterally. Implants on the right tibia of each male sheep underwent CS treatment, while the other side served as a control group without any stimulation. The animals were sacrificed on the 15th and 30th days after implantation. Bone segments containing the implants were processed using a noncalcified method. It assessed new bone formation and osseointegration around the dental implants using the undecalcified method and histomorphological analysis. An experienced blinded investigator measured percentages of mineralized bone-implant contact (BIC), bone area (BAr), and bone perimeter (BPm) to evaluate the bone-implant interface. Statistical analyses were performed using SPSS 21 for Windows, with a significance level set at $p<0.05$.

Results: The histomorphometric parameters revealed a significant increase in BIC, BAr, and BPm values in the CS group compared to the control group on both the 15th and 30th days ($p<0.05$). There was no statistically significant difference in BIC ratio between the second and fourth stimulation groups.

Conclusion: The findings of this experimental study suggest that CS may have a positive impact on the early osseointegration period of dental implants.

Keywords: Corona stimulation, dental implant, electrostimulation, histomorphometry, osseointegration

INTRODUCTION

Titanium implants placed in the jawbone typically achieve osseointegration within a few months of the latent phase, as demonstrated in Branemark's 1983 research (1,2). Presently, there is a significant focus within implant research on employing additional techniques to enable early loading of implants and enhancing osseointegration in cases of poor bone quality (3). Various bone-forming methods are under investigation to shorten the osseointegration period and improve success rates in such challenging cases (4). Strategies include enhancing the implant's surface properties, modifying its biochemical and morphological attributes, and boosting bone's inherent healing potential to achieve better bone-implant (BIC) contact both quantitatively and qualitatively (5-7).

Despite numerous studies in this field, current techniques aimed at accelerating postoperative bone healing, reducing prosthetic loading time, or facilitating early loading remain unsatisfactory (8). One such method involves the application of direct or transcutaneous electrostimulation to the bone and surrounding tissues (9). While electrostimulation has shown promise in

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Corresponding Author: Mustafa Ayhan, İstanbul University, Faculty of Dentistry, Department of Oral and Maxillofacial Surgery, İstanbul, Türkiye

E-mail: drmustafaayhan@gmail.com

wound healing and fracture treatments, there is a dearth of literature demonstrating its connection with osseointegration. Transcutaneous electrical nerve stimulation (TENS), a form of electrostimulation, has gained popularity in various treatments in recent years, including expediting wound healing, pain management, and reducing postoperative edema (10).

TENS devices have been shown to exert positive effects on wound healing by stimulating peripheral nerves and vascular structures, increasing blood flow, mitigating edema, providing analgesic effects, and accelerating regeneration. However, their potential impact on osseointegration following implant surgery has not been thoroughly investigated. Furthermore, TENS devices offer ease of use in clinical settings, which enhances patient convenience (11,12).

This research aims to experimentally examine the effect of the Corona Simulation device, a type of TENS device, on the postoperative osseointegration process of dental implants using histomorphometric analysis.

MATERIAL AND METHOD

The experimental protocol commenced following approval from the İstanbul University Animal Experiments Local Ethics Committee, under the reference number 2014/77, on July 18, 2014. Funding for this study was provided by the Scientific Research Project Unit of İstanbul University (BAP project no. 49665). The implants utilized in this research were sourced from Zimmer® (USA). The study comprised four groups: the experimental group and the control group, both of which were euthanized on the 15th and 30th days, respectively.

The Preoperative Preparation

The experimental phase of the study, including the electrostimulation process, took place at İstanbul University Faculty of Veterinary Medicine and involved four rams. Each ram weighed 55±5 kg and was between 12 to 14 months old. They were provided with a diet of concentrated feed (Eriş Fattening Feed - Türkiye) tailored to meet their daily caloric requirements, and they were housed in suitable indoor environments by the İstanbul University Faculty of Veterinary Medicine.

The animals were divided into two groups, with the first group euthanized on the 15th day and the second group on the 30th day of the study. In total, 32 Zimmer® (USA) 3.3×8 mm/Tapered Screw Vent (TSV) implants were applied, with four implants inserted into both the right and left tibias of each ram. The right tibia was designated as the experimental group, while the left tibia served as the control group.

General Anesthesia and Surgical Protocol

The animals were transported from their enclosures to the operating room at the İstanbul University Faculty of Veterinary Medicine Department of Surgery, with the assistance of support staff. For pre-anesthesia, Xylazine HCl (Rompun®, Bayer, Germany) was administered intramuscularly at a dosage of 0.2–0.5 mg/kg, along with intravenous ketamine hydrochloride (Ketalar®, Eczacıbaşı, Türkiye) at a dose of 5 mg/kg. General anesthesia was then induced using isoflurane (Forane®, Abbott. USA). Prior to the surgical procedure, the operative area was shaved and thoroughly cleansed with an antiseptic povidone-iodine solution (Betadine®, Purdue Pharma, USA).

Subsequently, a mid-crestal incision was made near the tibial diaphysis to access the bone, with the removal of both skin and periosteum. At 5 mm intervals, four implants were placed diagonally in the tibia, in proximity to the diaphysis, within the experimental animals. The implant positions were determined using a round steel bur attached to a contra-angle handpiece connected to a physio dispenser, operating at 800–1000 rpm and cooled with sterile saline. Implant cavities, each measuring 8 mm, were created using a 2-mm thick pilot bur followed by a 2.8-mm second bur. Four dental implants (TSV Zimmer®), featuring a diameter of 3.3 mm and a length of 8 mm, were inserted into the tibias of the four rams in bone level position.

Subsequent to the implant placements, subcutaneous tissue closure was achieved using absorbable polyglycolic acid sutures (4.0 Vicryl, Ethicon®, USA), while skin closure was performed with silk sutures (3.0 Doğsan®, Türkiye). All surgical procedures were carried out on the same day by the same surgical team, and the rams were subsequently relocated to a recovery area.

Postoperative Care

A half-dose of the antibiotic Ceftriaxone sodium (1 g) (Iesef®, Ulugay, Türkiye) at a rate of 22 mg/kg was administered intramuscularly every 12 h for 3 days. Subsequently, the sutures were removed one week following the surgical procedure. Throughout the 2 and 4-week recovery periods, the health status of the experimental animals was assessed on a weekly basis. The animals, which were provided with a diet of soft concentrated feed (Erişen Fattening Feed®, Türkiye), were monitored at 6-h intervals daily, post-operation, with particular attention to signs of infection, especially in the wound areas. As a result, all experimental animals completed their recovery period without encountering any complications.

Application of Corona Stimulation

Following the surgery, a postoperative procedure involved applying corona stimulation (CS) in a slow, impulsive mode to the right tibia of the experimental animals using an F3 electrode. This stimulation was administered for 10 min daily over 10 days. In contrast, the left tibia of the experimental animals was designated as the control group (Figure 1).

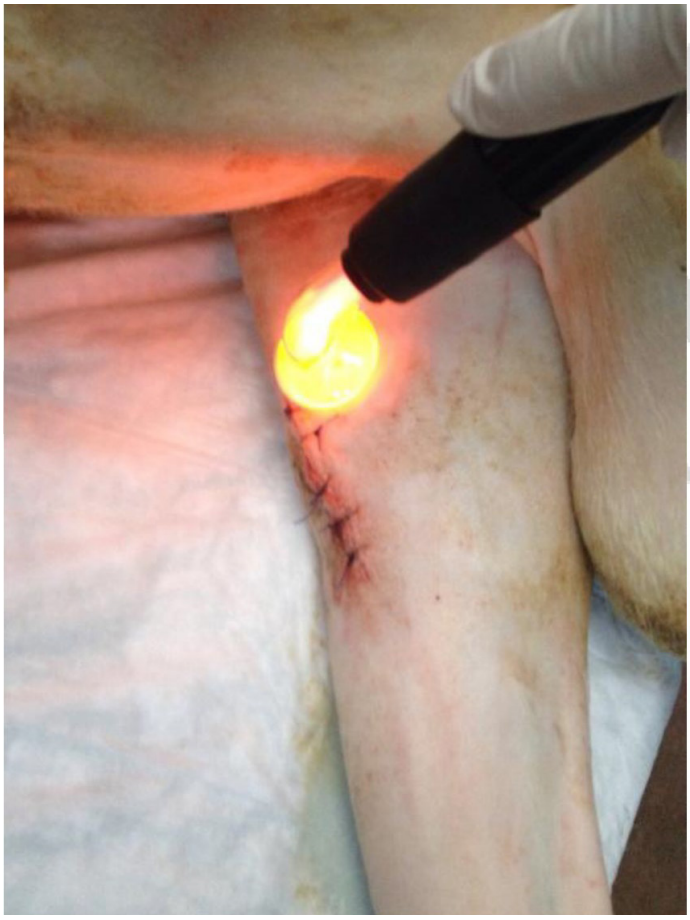

Figure 1. Application of CS in a slow, impulsive mode to the right tibia of the experimental animals

Technical Specifications of the Corona Device

The device in question is a high-voltage glass electrode available in various forms, designed for application on the skin or mucous membranes. These glass electrodes are essentially electron tubes filled with inert gas at low pressure following vacuum sealing. When the device makes contact with the skin, the high voltage at the electrode tips generates a corona discharge. This innovative device was developed by the İstanbul Technical University KOSGEB Technology Development Center.

The corona treatment device operates at a frequency of 22 KHz, boasts a maximum current intensity of 20 mA, a maximum current concentration of 5 mA/cm^2, and a maximum voltage rating of 1200 V. It operates on a 220 V alternating current input and delivers an output voltage ranging from 0.5 to 1.5 KV. This is a monopolar device with a total energy consumption of 40 W, an output energy range from 0 to 35 W, and it generates a sinusoidal current waveform.

Sacrification

Euthanasia procedures were carried out at the İstanbul University Faculty of Veterinary Medicine Department of Pathology. This involved administering intravenous sodium pentobarbital overdose to groups of two experimental animals on both the 15th and 30th days following the surgical procedure.

Before obtaining macroscopic samples from the experimental and control tibia, radiographic images were captured in anteroposterior (A/P) and mediolateral (M/L) projections (Figure 2). Subsequently, under a light microscope at 40× magnification (Olympus DP70, Tokyo, Japan), measurements were taken and recorded for the bone-to-implant contact (BIC), bone area (BAr), and bone circumference (BPm). This was accomplished using a semi-automatic image analysis program (Image Processing and Analysis in Java, Imaje J 1.46 j Version, Wayne Rasband, USA) after staining the sections with Toluidine blue.

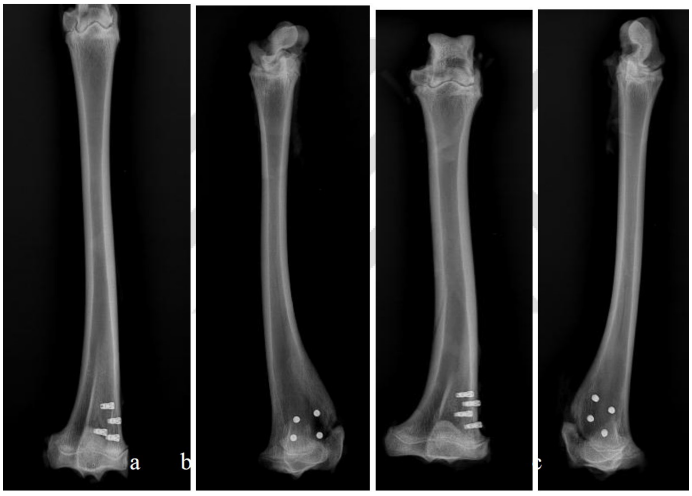

Figure 2. Radiographic images of tibia in experimental (left) and control (right) group

Histomorphometric Evaluation

The experimental and control groups were immersed in containers filled with 10% formalin to ensure thorough sample fixation. The bone thickness around the implant did not exceed 3–4 mm. After a 24-h fixation period, the implants underwent dehydration using ethyl alcohol, followed by plastic infiltration using a methylmethacrylate historesin solution (Technovit® 7200 VLC, Kulzer & CO. GmbH, Friedrickdorf, Germany).

Following the embedding of the samples and acrylic polymerization, parallel surfaces were prepared for the initial cutting of the blocks. The implant sections were then split using the Exakt 300 CP and a diamond saw, resulting in a final thickness of 200 µm. These sections were subsequently stained with Toluidine blue and examined under a light microscope at 40× magnification (Olympus DP70, Tokyo, Japan). Measurements for BIC, bone area (BAr), and bone circumference (BPm) were obtained using a semi-automatic image analysis program (Image Processing and Analysis in Java, Imaje J 1.46 j Version, Wayne Rasband, USA) (Figure 3).

The BIC value represents the ratio of the entire implant surface length to the length of the bone tissue in contact with the implant surface, expressed in percentage (%). The BAr value is the sum of bone areas located between the implant threads, measured in square millimeters (mm²). Additionally, the BPm value corresponds to the total

circumference of the bone tissue formed between the threads of the implants, measured in millimeters (mm).

For the histopathological assessment of the sections, the preparations used in the histomorphometric analysis of the experimental protocol were examined at the İstanbul University Faculty of Medicine, Department of Basic Medical Sciences, Department of Pathology. Upon comparing the 5 µm thick preparations used for histomorphometric analysis with the 100 µm thick sections containing implants, it was determined that the latter were not suitable for histological evaluation to obtain statistically significant results. Therefore, the study included only the results from histomorphometric analysis.

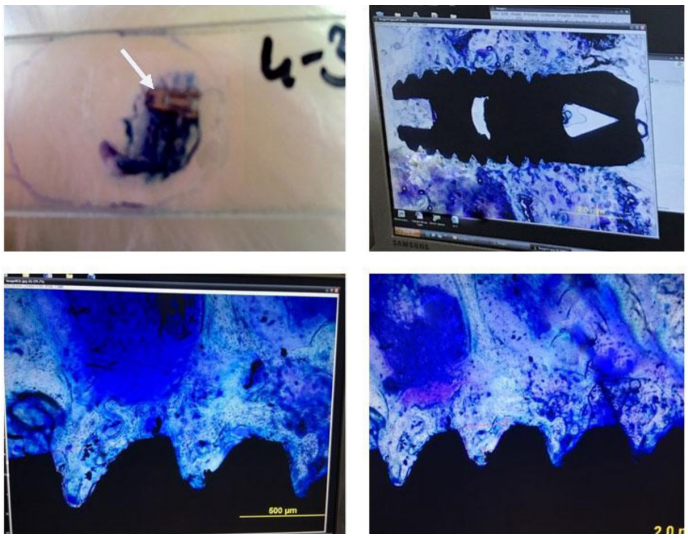

Figure 3. The implant sections were split resulting in a final thickness of 200 µm and examined under a light microscope at 40× magnification

Statistical Evaluation

Statistical analyses were conducted at the İstanbul University Faculty of Medicine, Department of Basic Medical Sciences - Public Health, using IBM SPSS (Statistical Package for Social Sciences for Windows, Version 21.0, Armonk, NY, IBM Corp.). In this study, descriptive statistical methods, including median, minimum-maximum, and standard deviation, were employed and assessed through the Mann-Whitney U test.

To compare parameters that did not exhibit a normal distribution, as well as quantitative data, the groups were analyzed based on median, mean, ±standard deviation, and minimum-maximum values. In the Mann-Whitney U test, the significance level was determined by the median value, and statistical significance was considered at the $p<0.05$ level.

RESULTS

In this research, the impact of coronal stimulation on the osseointegration process of 32 dental implants was investigated. It conducted histomorphometric assessments of the osseointegration process, with implant samples being sacrificed on both the 15th and 30th days. The study comprised four primary groups, each containing eight implants: the 15th-day experimental group (n=8), the 15th-day control group (n=8), the 30th-day experimental group (n=8), and the 30th-day control group (n=8) (Figures 4 and 5).

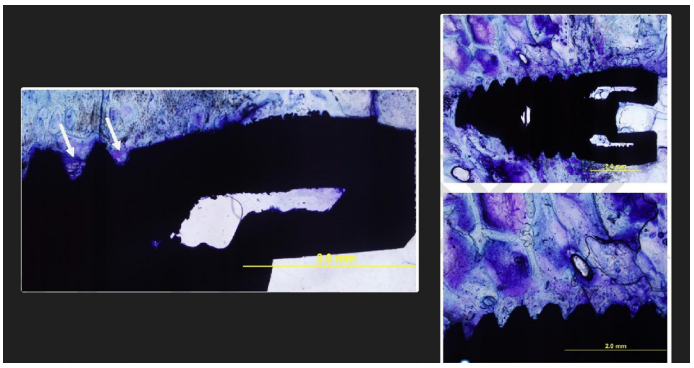

Figure 4. 15th day control (left) and experiment (right) group

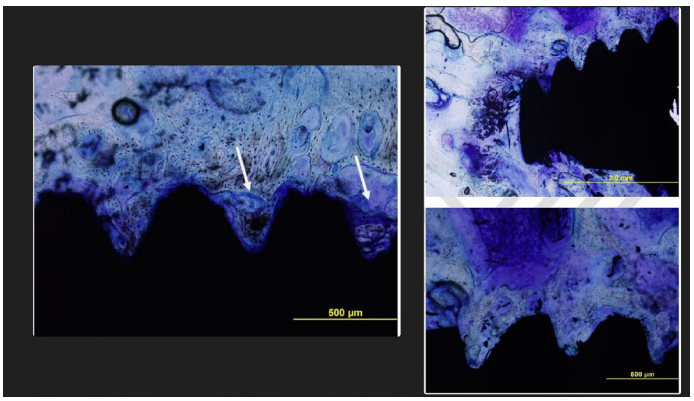

Figure 5. 30th day control (left) and experiment (right) group

In this histomorphometric analyses, three key parameters were assessed: BIC, bone area (BAr), and bone circumference (BPm).

The measurements derived from histomorphometric sections were computed using a specialized computer-aided image analysis program, specifically Image Processing and Analysis in Java, Imaje J 1.46j Version, developed by Wayne Rasband in the USA.

The BIC value represents the percentage obtained by dividing the entire implant surface area by the area of bone tissue in direct contact with the implant surface.

The BAr value quantifies the area of bone formation located between the implant threads, and its unit of measurement is square millimeters (mm^2).

The BPm value, on the other hand, signifies the cumulative length of the bone tissue circumference formed between the implant threads, and its unit of measurement is millimeters (mm).

The exponent symbols {a, b, c, d, e, f, x} used in group comparisons are presented, with significance values determined for {a, b, c, d, e, f} being $p<0.05$, while the significance value for x is $p>0.05$.

When the BIC values between the experimental and control groups on the 15th day were compared, a notable

difference in significance values emerged. Specifically, the BIC value on the 15th day was statistically higher in the experimental group that underwent CS (p=0.001) compared to the control group.

Similarly, when the BIC values between the experimental and control groups on the 30th day were compared, it observed a significant difference. Specifically, the BIC value on the 30th day was statistically higher in the experimental group that underwent CS (p=0.001) compared to the control group.

Similarly, when the BAr values between the experimental and control groups on the 15th day were compared, a significant difference was observed. Specifically, the BAr value on the 15th day was statistically higher in the experimental group that underwent CS (p=0.005) compared to the control group.

Likewise, when the BAr values between the experimental and control groups on the 30th day were compared, a significant difference in significance values emerged. Specifically, the BAr value on the 30th day was significantly higher in the experimental group that underwent CS (p=0.001) compared to the control group.

In a similar vein, when the BPm values between the experimental and control groups on the 15th day were compared, a notable difference in significance values emerged. Specifically, the BPm value on the 15th day was statistically higher in the experimental group that underwent CS (p=0.001) compared to the control group.

Similarly, when the BPm values between the experimental and control groups on the 30th day were compared, a significant difference in significance values was evident. Specifically, the BPm value on the 30th day was statistically higher in the experimental group that underwent CS (p=0.002) compared to the control group (Table 1).

Table 1. Histomorphometric analysis of groups

Groups	n	BIC (%)	BAr (mm²)	BPm (mm)
Day/groups	32	**Mean±SD;med; (min-max)**	**Mean±SD;med; (min-max)**	**Mean±SD;med; (min-max)**
15th day experiment	8	67.71±5.07, 67.50 (61.73-76.25)[ax]	0.56±0.23, 0.47 (0.32-0.91)[b]	6.94±1.22, 6.70 (5.51-9.20)[c]
15th day control	8	35.99±6.09, 35.81 (29.27-48.40)[a]	0.24±0.16, 0.18 (0.13-0.65)[b]	4.07±0.84, 3.99 (2.73-5.20)[c]
30th day experiment	8	68.33±7.97, 70.04 (55.47-78.15)[dx]	0.84±0.27, 0.89 (0.49-1.14)[e]	8.83±1.08, 8.67 (7.54-10.85)[f]
30th day control	8	45.63±8.48, 41.96 (36.72-56.80)[d]	0.34±0.06, 0.35 (0.21-0.43)[e]	5.60±1.51, 5.73 (3.31-8.18)[f]

DISCUSSION

Various forms of electrical stimulation have been utilized for several years to expedite wound healing in both soft and hard tissues (13). Furthermore, they have found application in post-surgical pain and edema control, neuralgiform pain treatment in the craniofacial region, acute fracture management, correction of non-union fractures, periodontal disease treatment, dental procedure anesthesia, and the management of chronic and acute pain in the maxillofacial region (14-17). In recent years, they have also been employed to enhance the osseointegration of dental implants, thus reducing healing time, with ongoing research continually adding to the existing literature (18-21).

In particular, research dedicated to enhancing bone integration through electrostimulation has brought about notable advancements in this field. An initial study by Bassett et al. (22) posited that weak electrical currents could initiate osteogenesis and provided evidence of the beneficial impacts of direct electrical currents on bone formation. Subsequent studies have consistently affirmed the effectiveness of direct electrical currents in stimulating and augmenting osteogenesis (23-25).

In addition to direct electrical currents, non-invasive techniques such as alternating current, electromagnetic fields, and TENS have also displayed positive effects on bone healing. A study by Ciombor et al. (26) underscored the advantageous impact of electromagnetic fields on bone formation, highlighting the potential of non-invasive approaches. Schwartz et al. (27) conducted research on stem cells and demonstrated that pulsed electromagnetic fields (PEMF) enhanced the osteoblastic differentiation of mesenchymal cells, particularly in the presence of BMP-2. Similarly, Sun et al. (28) observed that the application of electromagnetic fields accelerated the proliferation and differentiation of bone marrow stem cells.

The favorable influence of electrical stimulation on mesenchymal cell proliferation has garnered popularity in the context of improving the osseointegration of dental implants. In their study, Gittens et al. (29) examined the impact of electrical stimulation on cell differentiation within an experimental cell culture model. Their results revealed that electrical stimulation augmented the differentiation of MG63 osteoblasts and the production of local factors. Additionally, they observed that the effect of applied polarized electricity was voltage-dependent, with a more pronounced increase in osteoblast differentiation noted at higher potential differences.

Diniz et al. (30) conducted research on the impact of electromagnetic field stimulation on osteoblast maturation in a cell culture setting. Their study demonstrated that electromagnetic fields expedited osteoblast proliferation and differentiation but hindered the formation of bone-like tissue during the mineralization phase. Jansen et al. (31) explored the initial effects of electromagnetic fields on the metabolism and differentiation of human bone marrow stromal cells. Their findings suggested

that electromagnetic fields enhanced mineralization and promoted cell proliferation.

As a consequence, electrostimulation has emerged as a prominent area of research for enhancing the osseointegration of dental implants, particularly during the initial phases of healing. The results indicate that electrostimulation expedites healing in the early stages and fosters osseointegration. Nevertheless, the long-term effects are intricate and warrant further investigation.

In this study, the results revealed that the experimental groups exhibited significantly higher values in comparison to the control groups, thus reinforcing the favorable impact of coronal stimulation on the osseointegration of dental implants. When comparing the experimental groups at 2 and 4 weeks, the absence of significance in BIC values indicates that coronal stimulation expedites early-stage healing and osseointegration. These findings align with prior studies that have similarly identified electrostimulation as having a substantial influence on wound healing and early-stage osseointegration (30-33).

CONCLUSION

This study marks the inaugural experimental exploration of employing the Coronally Stimulated Implant Device (CSID) in dental implant procedures. In this study, results have statistically substantiated the efficacy of CSID during the initial phases of osseointegration. Specifically, the absence of statistical disparities in BIC values between the experimental and control groups at 15 and 30 days implies that CSID exerts a favorable influence on both the early osseointegration's quality and quantity.

Based on these findings, the utilization of CSID could prove advantageous in scenarios where early implant loading is under consideration, particularly for patients with systemic health concerns. Given the straightforward application of this device in oral and maxillofacial surgery, its translation into clinical settings appears practicable. Moreover, owing to its ability to alleviate edema and pain effectively, it may help diminish the necessity for post-implantation medication.

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Conflict of Interest: *The authors have no conflicts of interest to declare.*

Ethical approval: The experimental protocol commenced following approval from the İstanbul University Animal Experiments Local Ethics Committee, under the reference number 2014/77, on July 18, 2014.

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