Differences in crestal bone-to-implant contact following an under-drilling compared to an over-drilling protocol. A study in the rabbit tibia

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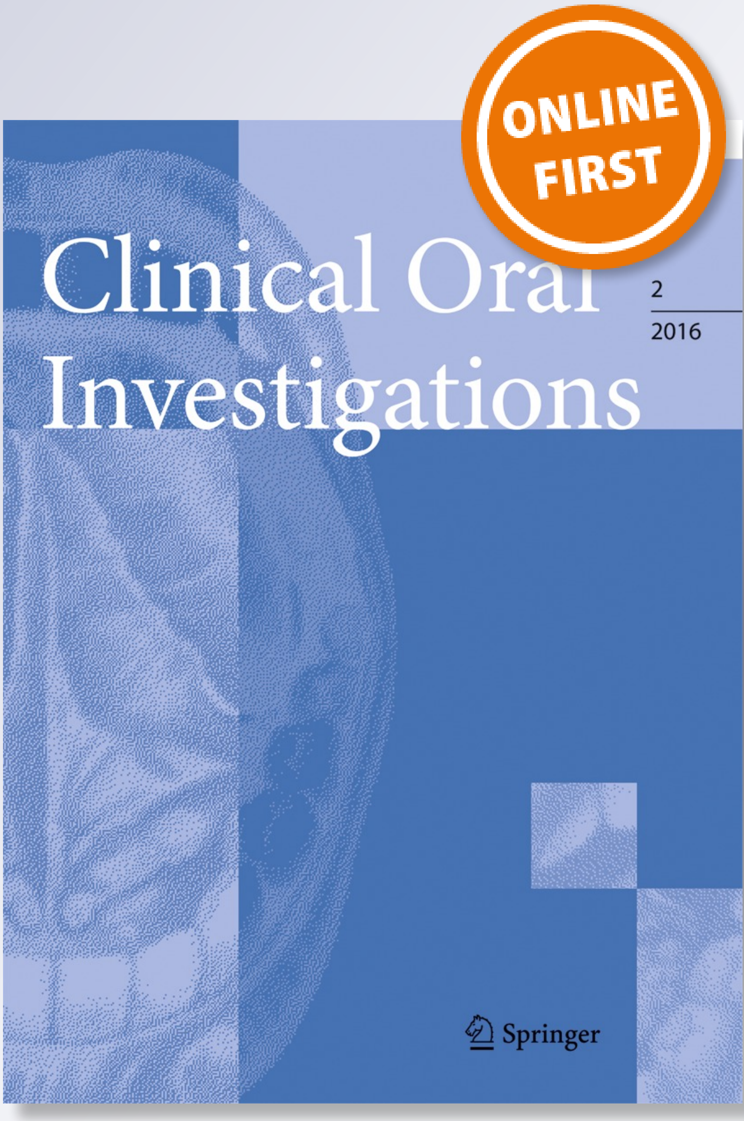

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ORIGINAL ARTICLE

Differences in crestal bone-to-implant contact following an under-drilling compared to an over-drilling protocol. A study in the rabbit tibia

Omer Cohen[1] · **Zeev Ormianer**[2] · **Haim Tal**[1] · **Daniel Rothamel**[4] · **Miron Weinreb**[3] · **Ofer Moses**[1]

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Abstract
Objectives The objective of this study is to compare bone-to-implant contact (BIC) between implants inserted at high torque due to under-drilling of the crestal bone to those inserted at low torque due to over-drilling of the crestal bone.
Materials and methods Forty implants with diameters of 3.75 mm (group A) or 3.55 mm (group B) were inserted in the proximal tibiae of NZW rabbits in two separate surgeries on day 0 or 21. Osteotomy of the crestal bone was finalized with a 3.65-mm drill. In group A, implants were inserted at torque ≥35 Ncm (under-drilling) and in group B with torque <10 Ncm (over-drilling). Implants and their surrounding bone were retrieved on day 42, thus creating 3- and 6-week observation periods, processed for non-decalcified histology and stained with toluidine blue. Crestal BIC (c-BIC) and total BIC (t-BIC) were measured. Wilcoxon test was used to evaluate differences between groups.
Results Three weeks post-surgery, the mean c-BIC in group A was 16.3 ± 3.3 vs 31.5 ± 3.4 % in group B ($P < 0.05$). At 6 weeks, a similar trend was observed (group A: 28.7 ± 3.6 %; group B: 38.4 ± 4.9 %) ($P > 0.05$). No differences in t-BIC were noted at 3 weeks and at 6 weeks between the groups.
Conclusions Insertion of implants with an over-drilling protocol of the crestal aspect of the osteotomy resulted in increased short-term crestal bone-to-implant contact.
Clinical relevance Insertion of implants with a high torque following an under-drilling protocol, commonly used for immediate loading, may reduce crestal bone-to-implant contact at early healing stages.

Keywords BIC · Insertion · Torque · Implants · Over-drilling · Under-drilling

✉ Omer Cohen
omerco2@gmail.com

[1] Department of Periodontology and Dental Implantology, The Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel

[2] Department of Oral Rehabilitation, School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel

[3] Department of Oral Biology, School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel

[4] Department of Oral and Maxillo-facial Plastic Surgery, University of Cologne, Cologne, Germany

Introduction

Primary implant stability is a prerequisite for achieving osseointegration and is indirectly related to implant micromotion [1]. Animal studies indicated that micromotion above a threshold of 50–100 μm results in fibrous instead of osseous integration to the implant [2, 3].

Primary stability depends on several factors; these include bone density and dimensions, implant geometry and size, and surgical technique. It has been suggested that implants should be inserted using an increased torque in order to increase their primary stability and enhance their integration [4, 5]. Insertion of implants using a torque measuring 32 Ncm or more is accepted for using immediate loading protocols of single implants [6, 7]. There is however no consensus regarding the optimal or maximal insertion torque permitted. It has been claimed that in tapered implant design, the use of a final drill that is slightly narrower than the implant elevates the final insertion torque, resulting in a higher success rate [8]. A histological study in rabbits has shown that the bone condensation peripheral to implants in underprepared osteotomies

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significantly improved peri-implant bone formation 2, 4, and 8 weeks after implantation [9]. If, however, localized stress is too great, it could lead to ischemia and bone necrosis at the implant-to-bone interface [10]. This phenomenon is generally considered to be limited to cortical bone. High compression caused by an insertion torque higher than 40–45 Ncm has been claimed to disturb the local microcirculation, leading to necrosis of the osteocytes, followed by bone resorption [11].

The aim of the study was to compare bone-to-implant contact (BIC) between implants inserted at high torque (≥35 Ncm) due to under-drilling of the crestal bone to those inserted at low torque (<10 Ncm) due to over-drilling of the crestal bone.

Materials and methods

Ten male New Zealand white (NZW) rabbits at 21–23 weeks of age (3–3.5 kg) were used in this study. Animals were anesthetized by intramuscular mixture of ketamine (35 mg/kg) and xylazine (5 mg/kg). Supplemental anesthetics were administered as needed during the surgery.

Before surgery, the shaved skin of the leg was carefully washed with 4 % chlorhexidine gluconate (Septal Scrub, Teva Medical, Ashdod, Israel) followed by 70 % isopropanol/0.5 % chlorhexidine solution (Alcoxidin, Vitamed, Binyamina, Israel). Analgesics were administered starting immediately post-operatively by subcutaneous injections of buprenorphine at a dose of 0.05 mg/kg twice daily for 3 days. Bone osteotomies were prepared with a final burr diameter of 2.65 mm at the posterior (apical) cortical bone and a final burr diameter of 3.65 mm at the anterior (crestal) cortical bone of the tibial metaphysis. Drills were replaced after every 10th osteotomy preparations. In each tibia, one implant of under-drilling (UD) and one of the over-drilling (OD) were inserted alternately. A total of four implants (two OD and two UD) were installed in each rabbit. X-rays of the tibiae were taken before and following surgeries to verify the implant location.

In the UD group, SPI® (Alpha Biotech, Petah Tikva, Israel), implants with a coronal diameter of 3.75 mm were inserted with bicortical stabilization at torque ≥35 Ncm. In the OD group, ICE® (Alpha Biotech, Petah Tikva, Israel), implants with a coronal diameter of 3.55 mm were inserted with torque of <10 Ncm and only the most apical implant threads were engaged with cortical bone leaving a slight circumferential gap of 0.05 mm between the implant and the crestal cortical bone. Both implants were sandblasted and acid etched to create micropitting of 1–5 μm. Implant insertion torque (ITQ) was measured by the drilling unit with 3–5 NCm steps (W&H, Elcomed, Burmous, Austria). One implant from each group was first implanted in the right tibial metaphysis (Figs. 1 and 2). Twenty-one days following the first implantation, the left leg was subjected to the same surgical procedure. Implant shoulders were leveled with the surrounding bone, and the musculature, subcutaneous tissues, and skin were subsequently closed with 4/0 Vicryl sutures. Animals were euthanized 6 weeks following the first surgery by an intravenous overdose injection of pentobarbitone. This study protocol was approved by the ethical committee for Animal Experimentation of Harlan Laboratories Ltd. (Kiryat Weizmann, Rehovot, Israel) No. IL-12-02-032.

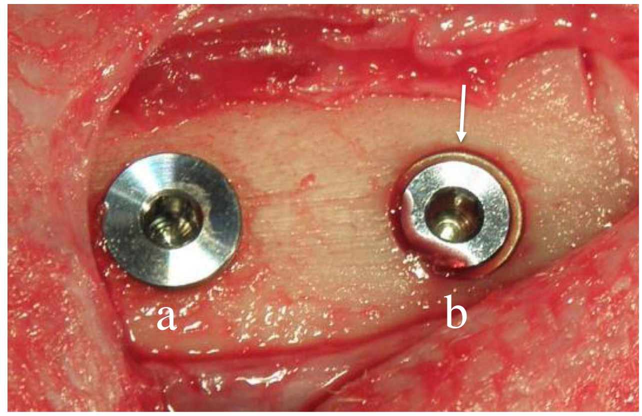

Fig. 1 Implants inserted in the tibial metaphysis. **a** SPI® implant inserted with an under-drilling protocol (UD). **b** ICE® implant inserted with an over-drilling protocol (OD). The *arrow* marks the 0.05-mm circumferential gap

After sacrifice, the tibiae were dissected and blocks containing the surgical sites with one implant each were retrieved and fixed in 10 % neutral-buffered formalin for at least 10 days. The blocks were dehydrated through an ascending ethanol series and xylene and were finally infiltrated and embedded in methyl-methacrylate (Technovit 9100 NEU, Heraeus Kulzer, Wehrheim, Germany) at 4 °C for non-decalcified sectioning. By means of a diamond saw (Exakt Apparatebau, Norderstedt, Germany), the blocks were cut along the longitudinal axis of the implant at 200-μm

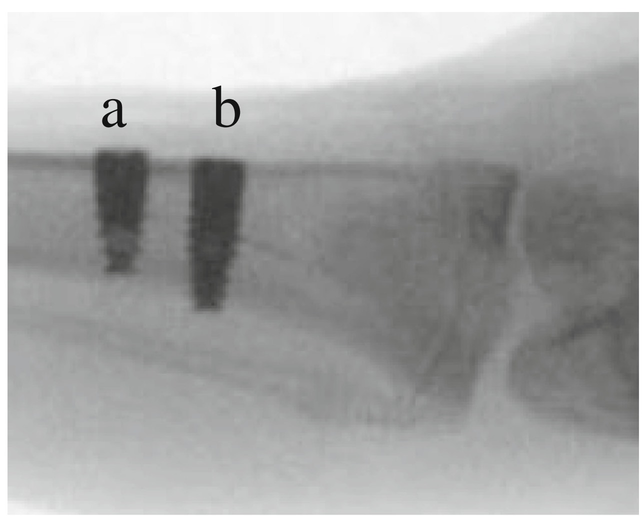

Fig. 2 Radiograph confirming the position of the implants in relation to the cortical bones. **a** SPI® implant inserted with an under-drilling protocol (UD). **b** ICE® implant inserted with an over-drilling protocol (OD)

thickness. The sections were glued to silanized glass slides (Super Frost, Menzel GmbH, Braunschweig, Germany) using acrylic cement (Technovit 7210 VLC, Heraeus Kulzer) before being ground down to a final thickness of 40 μm [12].

Sections were stained with toluidine blue for the evaluation of new bone formation. Crestal bone-to-implant contact (c-BIC, within the crestal compact bone) and total BIC (t-BIC, along the entire implant) were calculated with ImageJ at a magnification of ×100 (Fig. 3). Data are presented as mean ± standard error (se). SPSS software v.22 (IBM, Armonk, NY) was used for the statistical analysis of the data. A paired non-parametric test (Wilcoxon test) was used to evaluate differences between groups. $P < 0.05$ was set as the significance level.

Results

Histological examination revealed that at 3 weeks, implants inserted with an under-drilling (UD) protocol presented areas of bone resorption along the thread pitch while areas of new bone formation were observed within the thread valleys

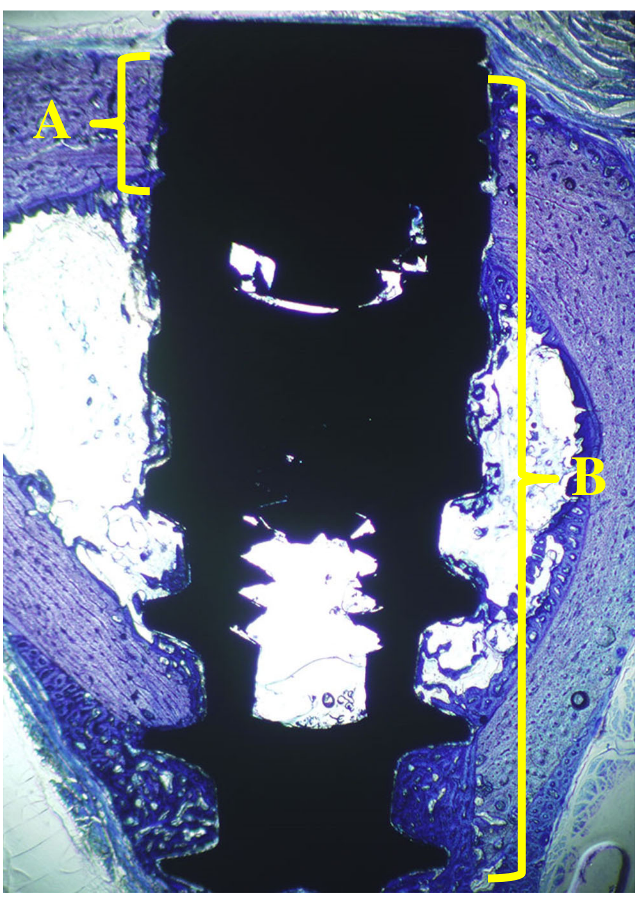

Fig. 3 Micrograph of a whole implant. *A* represents the region of crestal cortical bone-to-implant contact (c-BIC). *B* represents the region of total bone-to-implant contact (t-BIC). Magnification ×10

(Fig. 4). Also, some microcracks in the peripheral bone were identified. Implants inserted with an over-drilling (OD) protocol presented extensive new bone formation along the implant surface. Mean c-BIC in the OD group was 31.5 ± 3.4 vs 16.3 ± 3.3 % in the UD group ($P < 0.05$, Fig. 5).

At 6 weeks, histological sections of both groups presented extensive bone remodeling. In both groups mature remodeled bone was observed (Fig. 6). Mean c-BIC was higher in the OD group (38.4 ± 4.9 %) compared to the UD group (28.7 ± 3.6 %); however, the difference between groups was not statistically significant (Fig. 7).

No differences in t-BIC were noted at 3 weeks (18.3 ± 1.6 vs 14.6 ± 1.3 %) and at 6 weeks (21.8 ± 1.9 vs 23.8 ± 2.0 %) between the OD and UD groups, respectively.

Discussion

In the present study, the effect of high insertion torque (due to under-drilling) and low insertion torque (due to over-drilling) on crestal BIC was evaluated. While several studies reported on (mostly cancellous) BIC of implants inserted with high torque, only a few studies investigated the effect of the high insertion torque on the crestal compact bone, which is the main load/strain bearing region. In the present study, at 3 weeks, implants inserted with an under-drilling protocol presented areas of bone resorption adjacent to the implant surface and also regions of new bone formation. Implants inserted with an over-drilling protocol presented extensive new bone formation with no signs of bone resorption. Overall, c-BIC of implants inserted with a low torque due to over-drilling was significantly higher.

Previous studies on healing chamber model reported that implants with deep circumferential trough provide void spaces between the implant and the osteotomy after implant placement. These voids were filled immediately after implant placement with a blood clot, which was replaced by woven bone through an intramembranous ossification without prior bone resorption. In contrast, implant regions that were in direct contact with the bone and provided initial fixation had undergone bone resorption prior to subsequent bone formation [13]. As a result, the time needed to achieve osseointegration was shorter for implants with a substantial contact-free surface compared with implants with a large surface in contact with bone at the time of installation [13, 14]. Hence, the lower crestal BIC observed at 3 weeks in implants inserted with the UD protocol may be related to the presence of an initial bone resorption phase prior to bone formation. However, at 6 weeks of healing, the differences between groups were possibly diluted.

In a previous study, Duyck et al. [15] compared BIC of implants inserted with high torque (above 50 Ncm due to under-drilling) to that of implants inserted with a low (up to

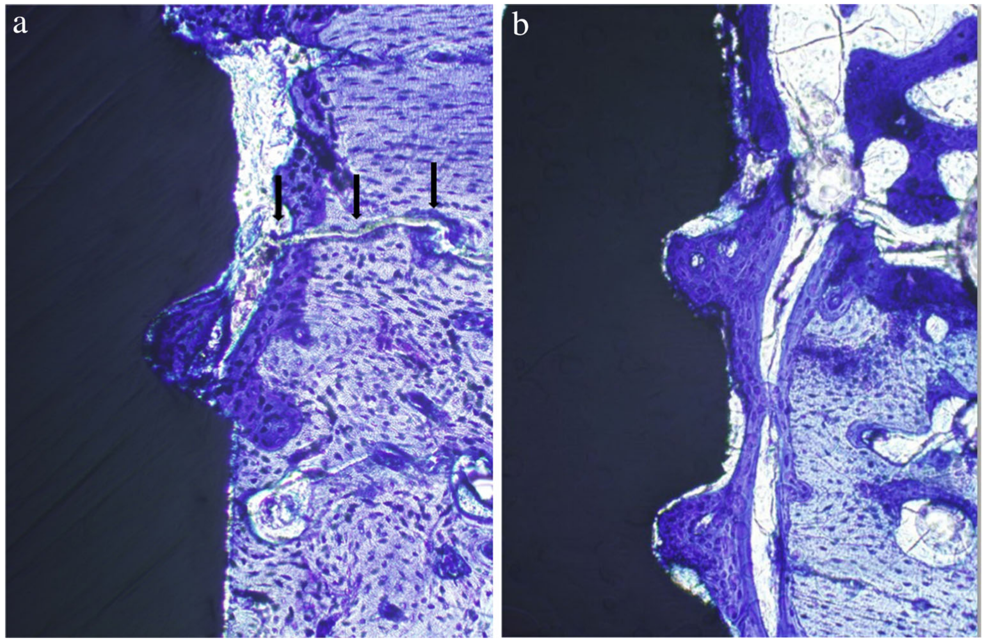

Fig. 4 Micrographs of a 3-week site. **a** Representative section of an implant from the UD group. Bone resorption is seen in areas of the thread pitch while new bone formation is evident in the threads valley. A microcrack (marked by *arrows*) can be observed. **b** Representative section of an implant from the OD group. Extensive new bone formation along the implant surface can be identified. Magnification ×100

10 Ncm torque due to over-drilling) in the rabbit tibia. After 2 weeks, implants inserted with a high torque demonstrated significantly higher host BIC compared to implants inserted with a low torque. At 4 weeks, no difference in BIC was found between the groups. However, concomitantly, it was found that de novo bone, which represents a true osseointegration and not mere mechanical compression of bone, was significantly higher around implants inserted at a low torque. This was also supported histologically as only little newly formed bone was observed around implants placed with high insertion torque while substantial new bone formation was observed around implants placed with a low insertion torque [15].

The effect of static bone strain on implant stability and bone remodeling was investigated in female rabbits [16]. After 24 days, implants inserted in the proximal tibia with undersized preparation of 0.15 mm exhibited significantly

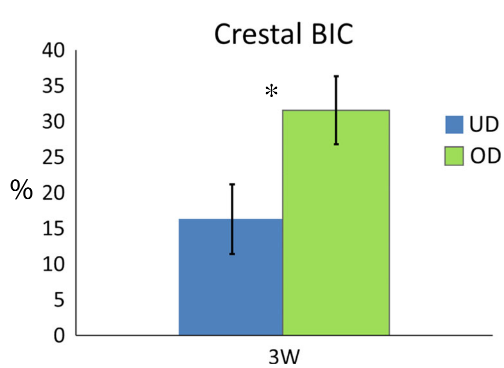

Fig. 5 Mean (±se) c-BIC at 3 weeks (*3W*) of implants inserted with an over-drilling protocol (*OD*) and implants inserted with an under-drilling protocol (*UD*). * denotes p <0.05

more old bone compared to control implants, which were inserted with no static strain. These authors concluded that increased condensation did not adversely affect the amount of the old bone [16]. In the current study, implants inserted with 0.1 mm under-drilling demonstrated after 3 weeks extensive bone resorption and a lower BIC compared to implants inserted with over-drilling. The different results may be due to differences in animal gender. While Halldin conducted the study on female rabbits, the current study was conducted on male rabbits. It is known that estrogen is an inhibitor of bone resorption that decreases both osteoclast numbers and activity. Apart from the direct regulation of osteoclasts, which it achieves through its receptors, estrogen can inhibit the release of osteoclast stimulatory factors or enhance the release of osteoclast inhibitory factors [17]. In a canine model, 4-mm-diameter implants inserted into undersized 3.2- or 3.5-mm osteotomies presented at 1 week extensive necrotic bone areas at the first three implant threads. At 3 weeks, these regions evolved to remodeling sites with a restricted amount of new bone [18]. Implants inserted with high torque (mean 110 Ncm) in the sheep mandible, composed of a thick (3–4 mm) cortical bone, demonstrated intrabony pockets around the implant neck as early as 6 weeks after placement [5].

One limitation of the present study is the use of two different implant types: SPI® and ICE®. These implants differ in their threading pattern in addition to their coronal diameter. However, it is unlikely that this fact affected the results for the following reasons: Both SPI® and ICE® have identical surface characteristics. It is established that implant surface properties are those that affect osteoblast differentiation and mineralization by influencing the level of bone-related genes and

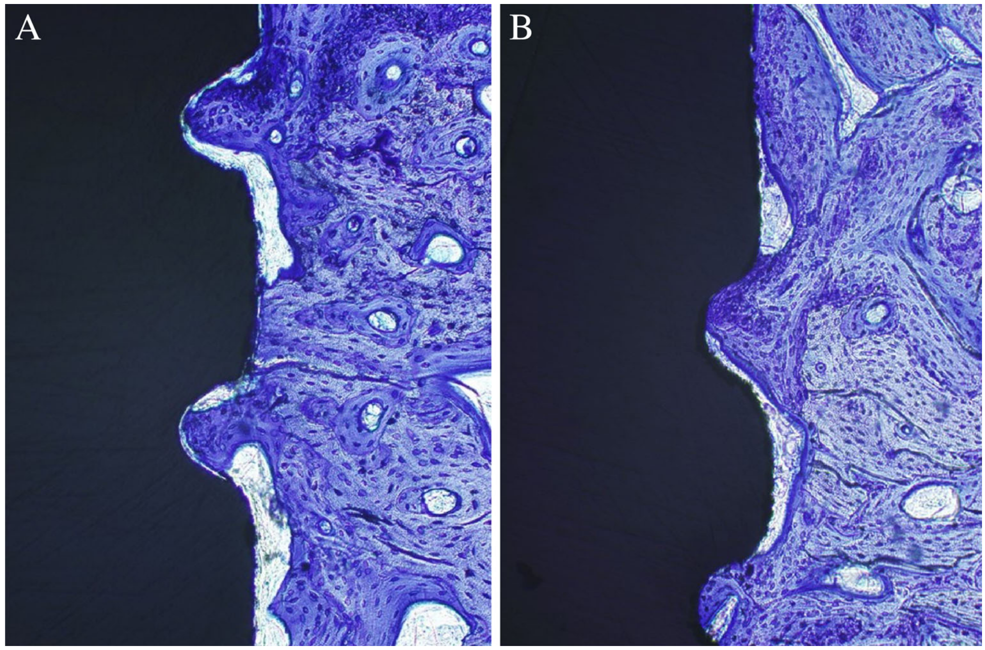

Fig. 6 Micrographs of 6-week sites. **a** Representative section of an implant from the UD group. **b** Representative section of an implant from the OD group. Bone remodeling and maturation are apparent in both sections with a more mature bone in the OD group section. Magnification ×100

transcription factors [19, 20]. The different microtheading at the coronal aspect is probably not relevant to the results since only the SPI® threads of the UD group were engaged in the crestal bone, while in the OD group, microthreads of the ICE® implants were not and therefore did not influence the results.

Moreover, previous studies suggested that microthreads up to the crestal aspect of the implant dissipate some forces and may aid in preserving crestal bone and potentially increase BIC [21, 22, 23]. With this notion, it was therefore expected that the UD group (SPI® implants) will have higher BIC than the OD group where crestal microthreads were not engaged; however, the opposite was found.

This study looked at effects of over- and under-drilling on early stages of osseointegration and the establishment of bone-to-implant contact, which is a major and obligatory factor in the long-term existence of a dental implant. Obviously, future studies should test the later (post-loading) effects of the insertion method on BIC.

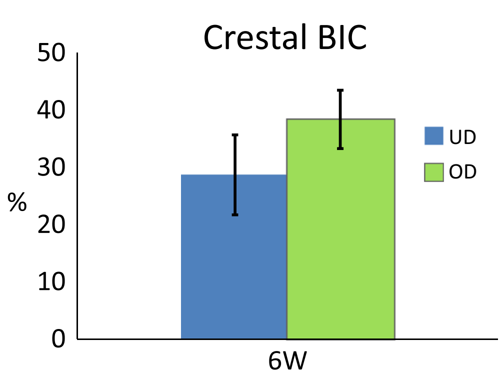

Fig. 7 Mean (±se) c-BIC at 6 weeks (*6W*) of implants inserted with an over-drilling protocol (*OD*) and implants inserted with an under-drilling protocol (*UD*)

Conclusions

Within the limitations of the present study, insertion of implants with a high torque following an under-drilling protocol (commonly used for immediate loading) may reduce short-term crestal bone-to-implant contact. On the other hand, over-drilling of the crestal aspect of the osteotomy may result in increased crestal bone-to-implant contact. Further studies using other implant systems and animal models should be conducted to confirm these results.

Compliance with ethical standards This study protocol was approved by the ethical committee for Animal Experimentation of Harlan Laboratories Ltd. (Kiryat Weizmann, Rehovot, Israel) No. IL-12-02-032.

Conflict of interest Author A declares that he has no conflict of interest. Author B declares that he serves as an external advisor of Alpha Biotech Ltd. Author C declares that he has no conflict of interest. Author D declares that he has no conflict of interest. Author E declares that he has no conflict of interest. Author F declares that he serves as an external advisor of Alpha Biotech Ltd.

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Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Informed consent This study is an animal model study. For this type of study, informed consent is not required.

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