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Clinical and histological efficacy of a new implant surface in achieving early and stable osseointegration: An in vivo study

Myron Nevins, Chia-Yu Chen, Wahn Khang, David M Kim

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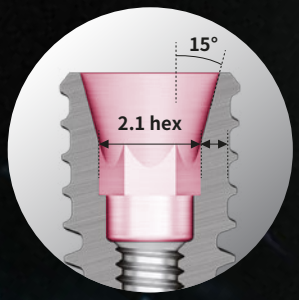

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Myron Nevins, Chia-Yu Chen, Wahn Khang, David M Kim

Clinical and histological efficacy of a new implant surface in achieving early and stable osseointegration: An in vivo study

KEYWORDS

acid-etched surface, bone–implant contact, dental implant, histology, histomorphometric analysis, nanohydroxyapatite, osseointegration, radiographs, SLActive, tooth extractions

ABSTRACT

An advantage of treated implant surfaces is their increased degree of hydrophilicity and wettability compared with untreated, machined, smooth surfaces that are hydrophobic. The present preclinical in vivo study aimed to compare the two implant surface types, namely SLActive (Straumann, Basel, Switzerland) and nanohydroxyapatite (Hiossen, Englewood Cliffs, NJ, USA), in achieving early osseointegration. The authors hypothesised that the nanohydroxyapatite surface is comparable to SLActive for early bone–implant contact. Six male mixed foxhounds underwent mandibular premolar and first molar extraction, and the sockets healed for 42 days. The mandibles were randomised to receive implants with either SLActive (control group) or nanohydroxyapatite surfaces (test group). A total of 36 implants were placed in 6 animals, and they were sacrificed at 2 weeks (2 animals), 4 weeks (2 animals) and 6 weeks (2 animals) after implant surgery. When radiographic analysis was performed, the difference in bone level between the two groups was statistically significant at 4 weeks ($P = 0.024$) and 6 weeks ($P = 0.008$), indicating that the crestal bone level was better maintained for the test group versus the control group. The bone–implant contact was also higher for the test group at 2 ($P = 0.012$) and 4 weeks ($P = 0.011$), indicating early osseointegration. In conclusion, this study underscored the potential of implants with nanohydroxyapatite surfaces to achieve early osseointegration.

Conflict-of-interest statement: *This research was funded by Hiossen, Englewood Cliffs, NJ, USA. The funders played no role in the collection, analysis or interpretation of data, in the writing of the manuscript or in the decision to publish the results. The authors declare there are no conflicts of interest relating to this study.*

Introduction

The biocompatibility of titanium or titanium alloy and its ability to achieve predictable osseointegration make it the material of choice for dental implants.[1,2] Attaining primary stability, which refers to the initial mechanical anchorage of the implant, is critical for the clinical success of osseointegrated dental implants. This stability is largely influenced by the implant macrogeometry, osteotomy preparation and bone density at the time of placement.[3] Subsequently, the long-term success of these implants relies on achieving secondary stability, which is mainly dependent on the biological integration of the implant with the surrounding bone. Although implant material and design, surgical condition, loading condition and the host responses may play an important role in osseointegration, the

secondary stability of the dental implant depends primarily on the implant surface characteristics, such as topography, wettability, coating, surface chemistry and modification.[4-6] Given that the bone response is closely related to the implant surface, research efforts since the discovery of osseointegration have focused on designing novel surface topographies for optimising osteoblastic migration, adhesion, proliferation and differentiation.[7] Until the 1990s, machined surface dental implants, fabricated following a turned, milled or polished manufacturing process, were dominant.[7] Since then, different implant surface modifications have been developed through additive and subtractive processing, including acid etching, grit blasting, electrochemical anodic oxidation, calcium-phosphate coatings and other combinations of these techniques.[5] A significant advantage of treated surfaces is their increased degree of hydrophilicity and wettability compared with untreated, machined, smooth surfaces that are hydrophobic.[7] Hydrophilic surfaces maintain the conformation and function of proteins, whereas hydrophobic implant textures trigger the denaturation of proteins by exerting conformational changes.[8] In addition, a high degree of hydrophilicity has been suggested to promote differentiation and maturation of osteoblasts, thus contributing to accelerated osseointegration.[9]

Rupp et al[10] reported that when nine screw-type implants made by eight manufacturers were evaluated for their hydrophilicity, the surfaces ranged from fully wettable and superhydrophilic to virtually unwettable and hydrophobic. Only three of the nine systems were hydrophilic during the initial wetting phase with contact angles below 90 degrees.[10] A water contact angle of 0 degrees is highly hydrophilic, whereas an angle greater than 90 degrees is hydrophobic.[7] The contact angles of hydrophobic implants ranged from 100 to 138 degrees.[9] As shown by Rupp et al,[10] initial hydrophobicity is unfavourable for most implants' initial biological response to blood contact.

Sandblasted, large grit, acid-etched (SLA) implant surfaces were introduced in 1998, and their surface roughness enhanced osseointegration through greater bone–implant contact (BIC). Airborne-particle abrasion achieves the optimal roughness for mechanical fixation, while etching, by raising the height of the roughness peaks, enhances the protein adhesion mechanism, which is crucial in the early stages of bone healing.[11] The microroughness of SLA surfaces is manufactured by large grit airborne-particle abrasion with 0.25- to 0.50-mm corundum particles at 5 bar.[11] The microtopographic surface structure results from a subsequent acid-etching process with HCL/H_2SO_4 at high temperatures, generating an active surface area with an even roughness and enhanced cell adhesion.[12] Studies on the predictability of successful long-term osseointegration have been published over the years, with Buser et al[13] reporting a 10-year success rate of 97.0% and a survival rate of 98.8% for 511 SLA implants in 303 patients, and a prevalence of peri-implantitis of just 1.8%.

In 2005, the SLActive surface was developed by Straumann (Basel, Switzerland) and launched to enhance osseointegration by preventing contamination from the ambient atmosphere and conserving an activated surface state by processing the implant after acid etching under protective gas and storing it in saline.[14] The surface energy of conventional titanium oxide surfaces is low due to the absorption of hydrocarbons and carbonates from ambient air and hydrophobicity resulting from the surface roughness.[9] SLActive is one of the most researched superhydrophilic implant surfaces and studies indicate that it improves initial healing, leading to accelerated integration.[5,11,15] Activated titanium implants are rinsed under nitrogen protection and stored in isotonic saline solution until insertion, and the high surface energy is sustained by a hydroxylated/hydrated surface that minimises the absorption of contaminating hydrocarbons and carbonates from the air.[9,15] The water contact angle of SLActive implants is 0 degrees, and it has been claimed that the hydrophilic SLActive surface improves cell adhesion, enhances bone apposition and density, promotes an ideal bone-forming environment and fosters neoangiogenesis.[11,14,16,17]

Hiossen (Englewood Cliffs, NJ, USA) recently introduced the EK implant system that has sandblasted and acid-etched (SA) surfaces with a nanohydroxyapatite (NH) coating (Fig 1). After the machining process, blasting is conducted with

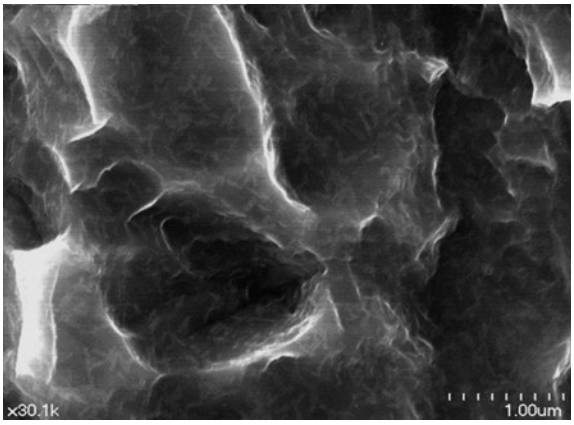

Fig 1 Scanning electron microscopy (SEM) image of NH coating.

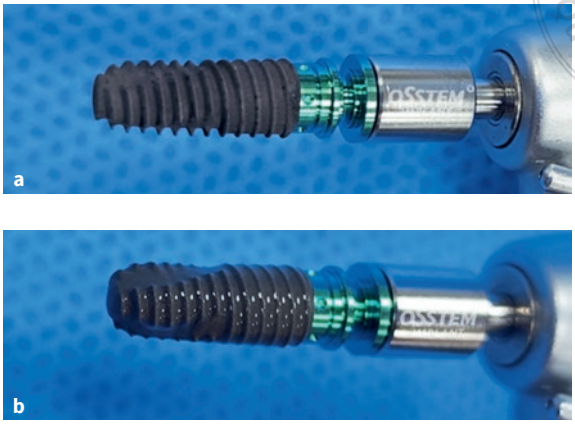

Fig 2a and b Implant with a hydrophilic NH surface after UV treatment.

aluminium oxide (Al_2O_3) with a particle size of 250 to 500 µm, followed by immersion in HSO_4/HCl solution. The implant undergoes two rounds of ultraviolet (UV) treatment, which makes the surface superhydrophilic (contact angle of 0 degrees) (Fig 2).[18] The hydroxyapatite (HA) coating is less than 10 nm in thickness, and the HA is absorbed during the bone remodelling process. An unpublished internal study conducted by the company reported a 39% improvement in osseointegration for NH surfaces compared to the SA surface alone. In addition, there was a 12% increase in platelet adhesion and cell differentiation for implants with NH surfaces.

The purpose of the present in vivo preclinical study was to compare SLActive and NH implant surfaces in achieving early osseointegration. The authors hypothesise that NH surfaces are comparable to SLActive for early BIC.

Materials and methods

Ethics statement

The selection and management of experimental animals and the research protocol were approved by the Institutional Animal Care and Use Committee (IACUC), Pine Acres Rabbitry/Farm, Norton, MA, USA (approval no. 22-09). The Animal Research: Reporting of In Vivo Experiments (ARRIVE) guidelines were followed when reporting the findings.

Sample size calculation

Based on the difference in BIC from previous studies[19,20], a power calculation was performed with the significance level set at 5% and the power level at 80%, and it was estimated that at least five implants per group per time point would be needed. To account for unexpected events, six implants were allocated to each group per time point. Thus, to compare HA vs SLActive surfaces at three time points, 36 implants were necessary. With up to three implants per arch or six implants per animal, six animals were required for the study.

Housing and husbandry of the experimental animals

Six healthy male mixed foxhounds aged over 1 year and weighing 25 kg and above were prepared for this split-mouth study. The animals were properly nurtured and given a suitable diet under regular laboratory conditions, and were accommodated in an environment with a room temperature between 15°C and 20°C and a humidity level exceeding 30%.

Treatment group allocation and experimental materials

Based on a split-mouth design, each side of the posterior mandible of each animal was randomly assigned to one of the following two groups:

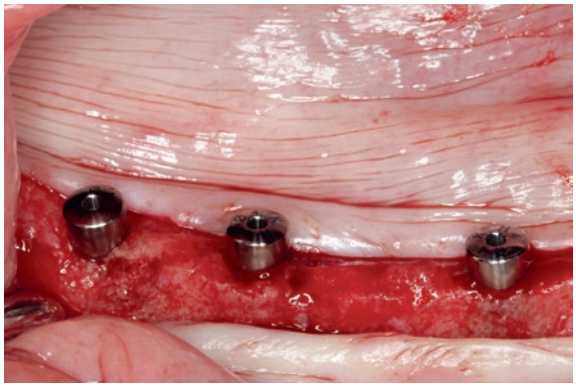

Fig 3 Clinical photograph of implants in the test group at 4 weeks after connecting healing abutments to dental implants at the time of surgery.

- Control group: bone-level tapered SLA implants (BLT Roxolid SLActive, 4.1 × 8.0 mm, Straumann) (n = 18 implants; 6 biopsy specimens taken at 2 weeks, 6 at 4 weeks, and 6 at 6 weeks).
- Test group: bone-level sandblasted and acid-etched implants with an NH coating (EK III NH, Hiossen) (n = 18 implants; 6 biopsy specimens taken at 2 weeks, 6 at 4 weeks, and 6 at 6 weeks).

Surgical procedures

Tooth extraction

General anaesthesia was administered using 0.005 to 0.5 mg/kg acepromazine (maximum dose 2 mg) and 1 to 4 mg/kg telazol, followed by inhalation of 1.5% to 2.0% isoflurane for the duration of the procedure. Local anaesthesia (two carpules of 2% xylocaine with 1:100,000 adrenaline, local infiltration, 3.6 ml) was administered intraorally. Clinical photographs were taken before the start of surgery. Sulcular incisions were made around the premolars and first molar with a #15 blade, and full mucoperiosteal flaps were subsequently reflected using an elevator. Following thorough plaque and calculus removal with dental scalers, the teeth from the second premolar to the first molar were hemisected, and both the mesial and distal roots of each tooth were extracted. The surgical site was closed with resorbable sutures (3-0 Vicryl Rapide; Ethicon, Raritan, NJ, USA) using the interrupted suturing technique. Clinical photographs were taken at the end of surgery. The animals underwent the standard postsurgical infection and pain control (20 mg/kg i.m. cefazolin sodium for a minimum of 3 days and 0.02 mg/kg i.m buprenorphine HCL BID or as needed for a minimum of 5 days). They received a diet of softened food (Purina Pro Plan dog food; Purina, St Louis, MO, USA) soaked in warm water for 45 minutes over the entire healing period and during the treatment phase. When the animals came off the surgical table, they were transported out of the surgical suite and placed on a heating pad where their vitals (heart rate, breathing rate, SpO2 and reflex responses) were checked every 15 minutes until they could maintain sternal recumbence. The animals were then transported back to their holding pens.

Dental implant placement

After a healing period of 42 days, the same surgical protocol was utilised to place six implants in each animal (three implants on each side) according to a randomised distribution pattern generated for each animal prior to surgery. Clinical photographs were taken before the start of surgery. General anaesthesia using 0.005 to 0.5 mg/kg acepromazine (maximum dose 2 mg) and 1 to 4 mg/kg Telazol was administered, followed by inhalation of 1.5% to 2.0% isoflurane for the duration of the procedure. Local anaesthesia (two carpules of 2% xylocaine with 1:100,000 adrenaline, local infiltration, 3.6 ml) was administered intraorally. Implant osteotomies were performed with torque reduction rotary instruments following the implant manufacturer's recommendations using a sterile saline solution. Each animal's mandible was randomised to receive either control (BLT Roxolid SLActive 4.1 × 8.0 mm, Straumann) or test implants (EK III NH 4.0 × 8.5 mm, EK III NH, Hiossen). Implants were placed using an insertion device recommended by Straumann and Hiossen (insertion torque value [ITV] measured) and a hand rachet, according to the manufacturers' guidelines. Prior to insertion of healing abutments, implant stability quotient (ISQ) values were measured using an ISQ measuring device (IS3, Hiossen) (Fig 3).

Clinical photographs were taken prior to flap adaptation. The flaps were adapted around healing

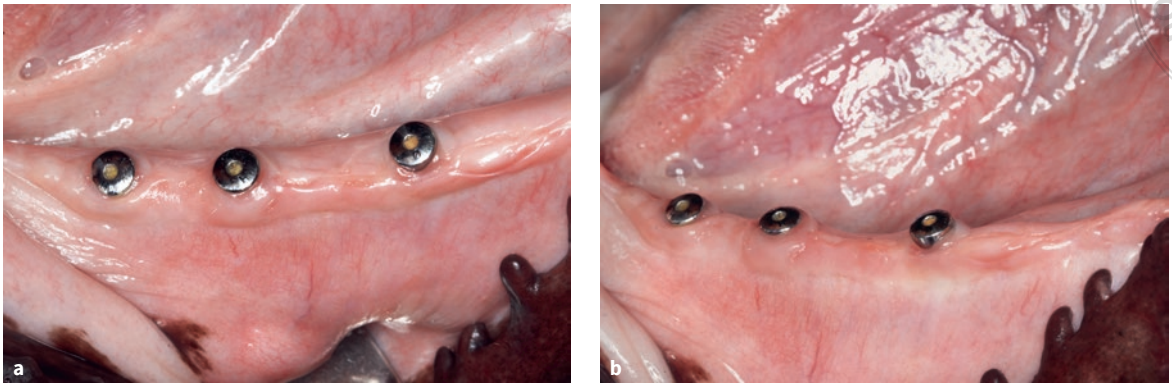

Fig 4a and b Occlusal and buccal views of implants in the test group at 4 weeks at the time of sacrifice. Healthy soft tissue supporting healing abutments was observed.

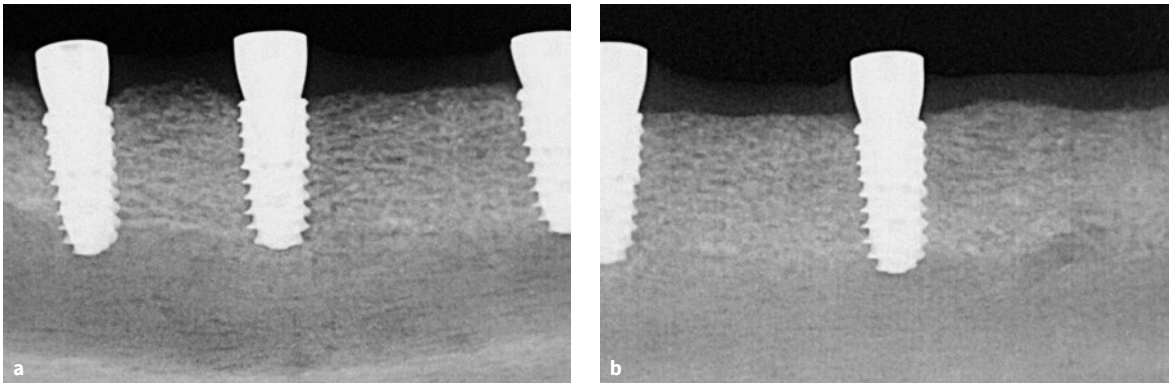

Fig 5a and b Radiographs of implants in the test group at 4 weeks revealing a stable bone level around dental implant threads.

abutments (4.5 × 4.0 mm RC healing abutment [Straumann] for the control and 4.0 × 4.0 mm EK healing abutment [Hiossen] for the test implants) for tension-free wound closure with resorbable interrupted sutures. Again, the animals underwent the standard postsurgical infection and pain control (20 mg/kg i.m. cefazolin sodium for a minimum of 3 days and 0.02 mg/kg i.m buprenorphine HCL BID or as needed for a minimum of 5 days). They received a soft diet of softened food soaked in warm water for 45 minutes over the entire healing period and treatment phase. When the animals came off the surgical table, they were transported out of the surgical suite and placed on a heating pad where their vitals (heart rate, breathing rate, SpO2 and reflex responses) were checked every 15 minutes until they could maintain sternal recumbence. They were then transported back to their holding pens.

Sacrifice of the experimental animals

The animals were sacrificed at 2 weeks (two animals), 4 weeks (two animals) and 6 weeks (two animals) after the implant surgery (Fig 4a and b) based on previous publications.[21–23] Euthanasia was performed using 0.005 to 0.5 mg/kg acepromazine (maximum dose 2 mg), 1 to 4 mg/kg Telazol and 10 mg/lb IV Euthasol. The mandibles were resected en bloc using an oscillating autopsy saw, and the recovered specimens were immediately immersed in fixative for histological preparation and evaluation.

Radiographic assessment

Standardised periapical dental radiographs were taken at implant placement and at the time of sacrifice (2, 4 and 6 weeks) (Fig 5a and b). The radiographs

were saved in JPEG format. The images were standardised based on known implant diameter and length and measured digitally using ImageJ software (National Institutes of Health, Bethesda, MD, USA). A built-in digital calliper in the software was used for all measurements, and pixel values of a given linear measurement were converted to millimetres. The implant platform and the first radiographic implant–bone contact were identified on the mesial and distal surfaces. Baseline and follow-up radiographs were used to calculate the changes in the level of the first BIC.

Histology and BIC analysis

The fixed samples were dehydrated in a graded series of ethanol (60%, 80%, 96% and absolute ethanol) using a dehydration system with agitation and vacuum. The blocks were infiltrated with Technovit 7200 VLC resin (Kulzer, Hanau, Germany). Infiltrated specimens were placed in embedding moulds, and polymerisation was performed under white and blue light. Polymerised blocks were sectioned in a mesiodistal direction and parallel to the long axis of each implant. The slices were reduced by microgrinding and polishing using an EXAKT grinding unit (EXAKT, Norderstedt, Germany) to an even thickness of 60 to 70 µm. Sections were stained with Sanderson rapid bone stain and counter-stained with acid fuchsin and examined using a Leica MZ16 stereomicroscope and a 6000DRB light microscope (Leica, Wetzlar, Germany). Histomorphometric measurements were performed by using software (ImageAccess, Imagic, Opfikon, Switzerland) to calculate BIC.

Statistical analysis

The data were represented as mean ± standard deviation (SD) and analysed statistically using SPSS software (version 23.0, IBM, Armonk, NY, USA). Parametric and non-parametric pairwise comparisons with a Student *t* test and a Wilcoxon signed-rank test were conducted between the control and test groups. The level of statistical significance was set at $P < 0.05$.

Results

Clinical findings

A total of 36 implants were placed in six animals. Clinically, all implants seemed stable and achieved clinical osseointegration without signs of peri-implantitis or implant failure.

Table 1 The ITV value was significantly higher for the test group versus the control ($P < 0.0001$), but the ISQ value was similar for both groups

Variable	Mean ± SD (median)		*P* value
	Control	Test	
ITV value	45.000 ± 7.276 (50)	47.500 ± 5.752 (50)	< 0.0001
ISQ value	81.111 ± 1.833 (82)	80.444 ± 4.275 (82)	0.747

Table 2 Analysis of the periapical radiograph revealed statistically significant differences in bone level between control and test implants at weeks 4 and 6. Negative values at baseline indicate subcrestal placement of implants. Positive values indicate crestal bone loss where the first BIC was apical to the implant shoulder

Variable		Mean ± SD (median)		*P* value
		Control	Test	
First BIC, mm	Baseline	−0.577 ± 0.332 (−0.690)	−0.855 ± 0.262 (−0.935)	0.408
	2 wk	−0.541 ± 0.720 (−0.743)	−0.577 ± 0.404 (−0.596)	0.671
	4 wk	−0.110 ± 0.449 (−0.341)	−0.531 ± 0.466 (−0.526)	0.024
	6 wk	0.417 ± 0.408 (0.503)	−0.020 ± 0.320 (−0.165)	0.008

ITV, ISQ and radiographic analysis

All implants achieved an ITV of at least 40 Ncm, and some had to be hand-torqued. The ITV value for test implants was higher than that for the control implants ($P < 0.0001$), but the ISQ value at baseline demonstrated no statistical difference between the groups (81.111 ± 1.833 for the control and 80.444 ± 4.275 for the test group, $P = 0.747$) (Table 1).

Radiographic analysis revealed that the implants were placed subcrestally for both groups with no statistical significance ($P = 0.408$) (Fig 6). Furthermore, the changes in bone level were not statistically significant between the two groups at 2 weeks ($P = 0.671$), but became significant at 4 weeks (control group −0.110 ± 0.449 mm, test group −0.531 ± 0.466 mm; $P = 0.024$) and 6 weeks (control group 0.417 ± 0.408 mm, test group −0.020 ± 0.320 mm; $P = 0.008$) (Table 2). Negative values at baseline indicate the subcrestal placement of implants. Positive values indicate crestal bone loss where the first BIC was apical to the implant shoulder. The significant differences between the control and test groups at 4 and 6 weeks demonstrate that test implants experienced less coronal bone remodelling than control implants during those evaluation time points.

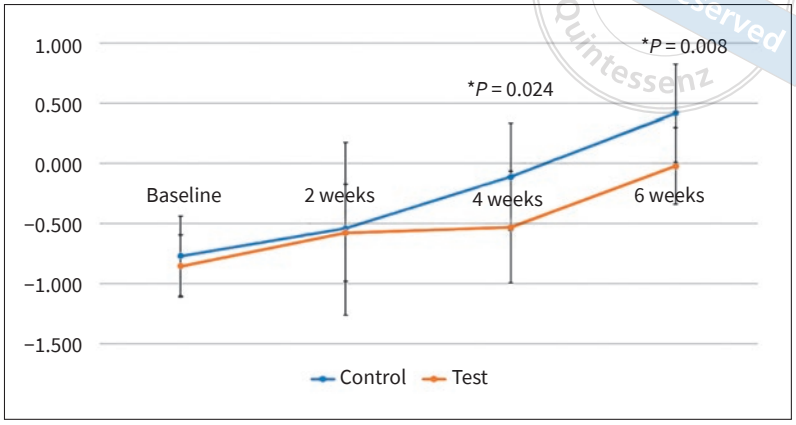

Fig 6 Change in crestal bone level for both control and test implants at 2, 4 and 6 weeks. Negative values at baseline indicate subcrestal placement of implants. Positive values indicate crestal bone loss where the first BIC was apical to the implant shoulder.

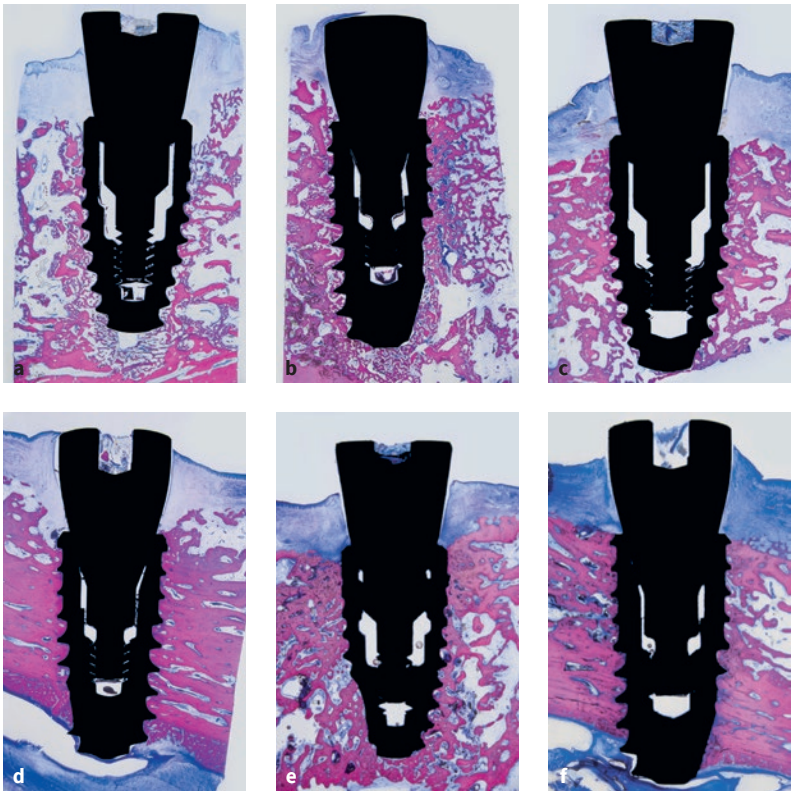

Fig 7a to f Representative histological images of control **(a, c and e)** and test implants **(b, d and f)** for each evaluation time point: 2 **(a and b)**, 4 **(c and d)** and 6 weeks **(e and f)**.

Histomorphometric and BIC analysis

Histological results demonstrated that all implants had achieved osseointegration, and a histomorphometric analysis was performed for all implants (Fig 7). Light microscopy revealed close bone apposition with the combination of newly formed and native bone. There were areas where mineralised bone was in contact with the implant surface and where bone marrow spaces were adjacent to the surface. For the 2-week specimens, de novo bone formation was observed along the implant threads. For the 4- and 6-week specimens, bone formation continued to occur in all specimens, primarily observed by way of the increased bone volume fill inside and around the implant threads. The BIC appeared to be sufficient to provide a clinically stable implant.

The BIC was significantly higher for the test group compared to the control group at 2 weeks (76.40% ± 15.33% versus 51.31% ± 13.14%; $P = 0.012$) and 4 weeks (87.33% ± 5.92% versus 74.45% ± 8.26%; $P = 0.011$) (Fig 8 and Table 3); however, the BIC between the test and the control group was similar at 6 weeks (89.50% ± 9.83% versus 83.37% ± 8.21%; $P = 0.268$), indicating that both implant surfaces achieved a high degree of BIC by 6 weeks.

Table 3 Statistical analysis demonstrating a significant difference in BIC between control and test implants at weeks 2 and 4

Variable		Mean ± SD (median)		*P* value
		Control	Test	
BIC (%)	2 wk	51.31 ± 13.14 (51.09)	76.40 ± 15.33 (79.56)	0.012
	4 wk	74.45 ± 8.26 (73.96)	87.33 ± 5.92 (87.00)	0.011
	6 wk	83.37 ± 8.21 (84.83)	89.50 ± 9.83 (94.30)	0.268

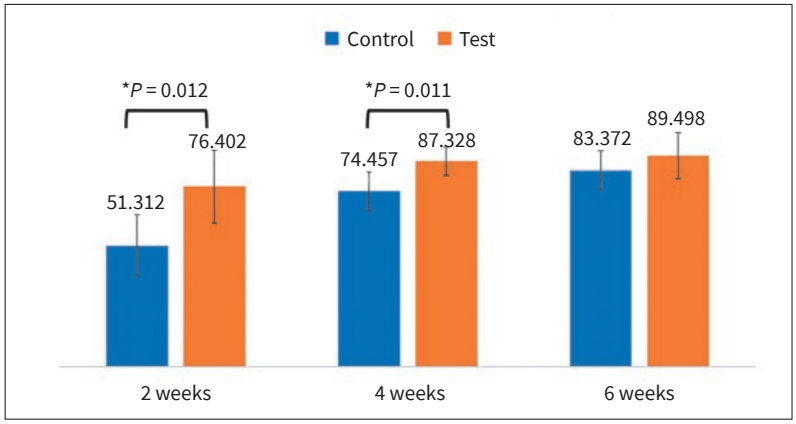

Fig 8 BIC (%) increased for all groups from 2 to 6 weeks.

Discussion

Implant surface characteristics, particularly surface roughness and hydrophilicity, are considered critical factors in achieving a high degree of BIC.[24,25] With enhanced surface energy and wettability, hydrophilic surfaces have been reported to promote superior bone healing and osseointegration.[26] SA surfaces are considered the gold standard in dental implantology for achieving high and predictable osseointegration. In the present preclinical study, two implant surfaces (SLActive and NH) were compared with regard to their capacity to achieve early osseointegration. Historically, implant surfaces coated with HA were reported to have a higher incidence of complications, possibly due to delamination of the thick HA layer and the uncontrolled rate of dissolution of deposited phases.[27]

Tallarico et al[28] conducted a 5-year prospective clinical study on implant failure and marginal bone remodelling with Hiossen ET III implants with an SA surface. Despite COVID-19 resulting in not all patients being able to return for follow-up appointments, they reported a cumulative implant survival rate of 97.5% and mean marginal bone loss of 0.41 ± 0.30 mm.[28] The same group conducted a split-mouth, randomised controlled trial to compare early implant failure and implant stability of one-stage Hiossen ET III implants with SA and NH surfaces.[29] Although both SA and NH implants achieved a high ISQ value and osseointegration, the NH implants did not demonstrate a typical physiological decrease in ISQ value between the second and fourth week after implant placement, but they did demonstrate stable ISQ values compared to SA implants during remodelling.[29] A follow-up multicentre randomised controlled trial comparing Hiossen ET III implants with SA and NH surfaces also confirmed that those with NH surfaces seem to avoid a decrease in ISQ value during the bone remodelling phase.[30]

The present study aimed to investigate the effects of NH implants' ability to achieve early osseointegration, directly compared to SLActive implants. The implants used were standard size, and the study was carried out using a large animal model to mimic clinical situations. ITV and ISQ value were recorded and radiographs were obtained at the time of implant surgery, and conventional histological and histomorphometric analyses were utilised to investigate the early BIC for both implant surfaces in detail.

The study results demonstrated that the initial ITV was significantly higher for the test group than the control group, but the baseline ISQ value at insertion was the same for both groups. The unique design features of the EK implant, such as aggressive corkscrew threads, triple helix cutting edge and deep apical threads, could have resulted in a high ITV. The present authors decided not to measure the ISQ during observation to avoid disrupting the osseointegration process. The radiographic bone level during the early osseointegration stages (2 and 4 weeks) revealed a statistical difference in the maintenance of the crestal bone level at 4 and 6 weeks for the test group versus the control group. Histological and histomorphometric analyses were conducted to investigate the early BIC formation in detail, and the histomorphometric analysis revealed statistically higher BIC for the test group versus the control group both at 2 and 4 weeks, demonstrating that the NH surface seemed to be effective in early osseointegration.

The observed BIC values of 76% at 2 weeks and 87% at 4 weeks for NH surfaces are notably high, especially when compared to other implant surfaces examined in the literature. These results underscore the effectiveness of NH surfaces in promoting early osseointegration. A review of studies investigating various implant surfaces typically reported BIC values ranging from 50% to 80% at similar time points,[31,32] highlighting the superior performance of NH surfaces in the present study. This enhanced osseointegration can be attributed to the unique combination of superhydrophilicity and the presence of low crystalline NH on the NH surface, which likely facilitates increased wettability, platelet adhesion and rapid formation of woven bone. The resorption of NH and the subsequent formation of new bone integrated into the SA surface further contributed to the high BIC values observed. These findings suggest that NH surfaces may offer a significant advantage in clinical settings, particularly in scenarios where rapid and robust osseointegration is desired.

To the best of the present authors' knowledge, this is the first in vivo study to utilise histological and histomorphometric methods to investigate the efficacy of NH surfaces in promoting early osseointegration. Although articles have demonstrated the stability of ISQ values for implants with NH surfaces, the present study validated the clinical findings via radiographic, histological and histomorphometric investigations.

The present study has some limitations that should be considered when interpreting the findings. Firstly, the small sample size may limit the generalisability of the results. Additionally, the study implants were not loaded, as the focus was on investigating the wound healing process during the early osseointegration phase. Furthermore, detailed histomorphometric quantitative analysis was not performed for the percentage of osteoid, old bone and other components along the BIC surface, and microcomputed tomography analysis was also not conducted to provide 3D volumetric data.

Despite this, the study demonstrates the potential of NH surfaces in achieving early osseointegration. Future research should aim to address these limitations by including larger sample sizes, loading the implants to assess their performance under functional conditions and conducting comprehensive histomorphometric and microcomputed tomography analyses. Such studies would provide a more complete understanding of the osseointegration process and the role of different implant surface characteristics in promoting bone healing and integration.

Conclusion

In conclusion, this preclinical study validates the efficacy of early osseointegration of NH implant surfaces. Despite the small sample size, NH implants demonstrated superior early osseointegration and reduced crestal bone remodelling.

Acknowledgments

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