Descriptive Study of the Longevity of Dental Implant Surgery Drills

Olive F. L. Allsobrook, BDS;* Jonathan Leichter, DMD;† Douglas Holborow, BDS;‡ Michael Swain, PhD§

ABSTRACT

Background: Atraumatic preparation of the osteotomy site is critical for osseointegration.

Purpose: This study aimed to investigate the effects of multiple usages of dental implant drills on bone temperature changes and to examine the cutting surfaces of these drills under a scanning electron microscope (SEM).

Materials and Methods: The implant osteotomy procedure was adapted to the experimental setting to simulate wear on implant drills by preparing bovine ribs using a constant drilling force. Thermocouples were placed in the specimens to record temperature changes. SEM images of the drills were taken, and elemental spectroscopic analysis was performed.

Results: Temperatures measured in the bone adjacent to the implant site did not exceed 27.7°C during the experiment. Spectroscopic elemental analysis indicated that two of the drills were of a stainless steel composition, and the other drill consisted of a tungsten carbide-coated stainless steel. The tungsten carbide-coated bur had the lowest overall drilling temperatures and showed the least surface corrosion and plastic deformation. SEM analysis showed degradation of the cutting surfaces of the burs although the plastic deformation and surface wear did not appear to affect the cutting temperatures. Surface corrosion was observed on the cutting surfaces.

Conclusions: Drills used for up to 50 osteotomies do not appear to elevate bone temperatures to a harmful level. However, drill corrosion is potentially important in determining the life span of implant burs.

KEY WORDS: dental implant, drill, heat generation, irrigation, sterilization

INTRODUCTION

Reusable dental implant drills are widely used in clinical practice to perform osteotomies for dental implant placement. Manufacturers offer only loose guidelines as to the longevity of implant drills, and it is left to the clinician to determine the life span of the drills by subjectively evaluating the efficiency of the drill through a perceived increase in the force required to perform an osteotomy. The average number of implants placed during each surgical procedure is 2.5, and, with most dental implant manufacturers specifying drills as reusable for 10 surgical procedures, the drills would be expected to be used for 25 osteotomies.[1] Eriksson and Albrektsson have shown that temperatures of 47°C generated for 1 minute at the bone interface will induce osseonecrosis locally, which can compromise implant osseointegration.[2,3] Repeated use of implant drills can lead to degradation of their cutting surface and temperature elevation at the bone interface.[4] Matthews and Hirsch report that drill sharpness, irrigation, and the use of pilot drills will decrease temperature rise in the bone and speculate that the final osteotomy drill should perform a maximum of 40 osteotomies. Research has also focused on factors that affect the heat generated at the bone interface, including multiple uses of the drill, effects of sterilization processes, irrigation use, drilling technique, and intrinsic properties of the drills.[5–9] These studies fail to follow a consistent clinical protocol to determine the nature of clinical wear on implant drills. Most studies agree that access to copious irrigation is a major factor in preventing high temperatures at the

*BDS, Department of Oral Science, University of Otago, Otago, New Zealand; †senior lecturer, Department of Oral Science, University of Otago, Otago, New Zealand; ‡senior lecturer, Department of Oral Science, University of Otago, Otago, New Zealand; §professor, Department of Oral Science, University of Otago, Otago, New Zealand

Reprint requests: Dr. Jonathan Leichter, Department of Oral Sciences, School of Dentistry, P.O. Box 647, Dunedin, New Zealand; e-mail: jonathan.leichter@dent.otago.ac.nz

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bone interface.[4,5,10,11] The aims of this research were to analyze the effects of multiple usages of implant drills on temperature at the bone interface, to describe the effects of sterilization procedures and irrigation on the drill surfaces, and to determine the changes in composition of the burs after being subjected to multiple uses using electron microscopy-based elemental spectroscopy.

MATERIALS AND METHODS

Implant drills from three manufacturers, ITI (Straumann AG, Waldenburg, Switzerland), NB (Nobel Biocare AB, Göteborg, Sweden), and NE (Neoss Australia, New Farm, Queensland), were investigated in the research. Three successively larger pilot drills from each manufacturer were used to prepare an implant site, with the final preparation drill in each set evaluated.

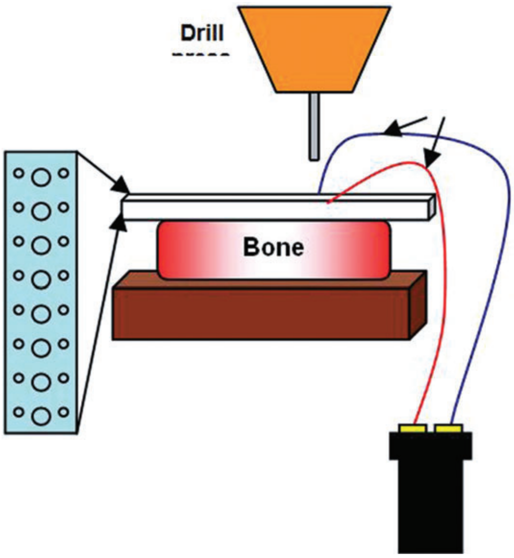


Figure 1 Setup of specimen with thermocouple attachment.

Bone Specimens

Bovine ribs with an average cortical thickness of 4 mm were used, as they were readily available and have a similar physical composition to the cancellous and cortical bone of the human mandible.[5] Bone specimens were stored at −20°C then, when needed, were thawed at room temperature by using a water bath. Holes were drilled in either end of the bone in order to attach an acrylic template, which marked the location of osteotomy site and enabled accurate placement of thermocouple holes to measure temperature adjacent to the cutting site. Thermocouple holes were drilled at a position 1 mm beyond the anticipated wall of the osteotomy. This was carried out to prevent damage to the thermocouple from the implant drill inadvertently contacting the thermocouple. The bone and template were screwed onto a wooden block fixed to the drill platform, which prevented horizontal movement of the specimen (Figure 1). K type thermocouples placed adjacent to the implant site measured the temperature produced during every fifth osteotomy. By using the template surgical guide, 1.5-mm-diameter thermocouple holes at depths of 4 and 12 mm on either side of the osteotomy site were prepared prior to the experiment, in accordance with Cordioli and Majzoub.[7] These depths provided temperature recordings at the inner surface of the cortical plate and at the final depth of the preparation in cancellous bones.

Apparatus and Cutting Procedure

A drill press was used to simulate the clinical osteotomy procedure. The revolutions per minute of the drill were set to ensure that the maximum recommended drill speed for each manufacturer was not exceeded (2000 rpm for Neoss and Nobel Biocare and 800 rpm for Straumann). The downward force was standardized with a 1,500-g weight attached to a 40-cm drill press spindle (Figure 2). 2.2- and 2.8-mm Straumann, 2.0- and 3.0-mm Nobel Biocare, and 2.2- and 3.0-mm Neoss pilot drills were used to initiate the osteotomy before the final preparation, with 3.5-mm Straumann, 3.4-mm Nobel Biocare, and 3.4-mm Neoss drills, which performed 20, 30, and 50 osteotomies respectively. The final preparation drills from each manufacturer were tested. The operator used a millimeter guide on the drill press to advance the drill to depths of 6, 10, and then 12 mm,

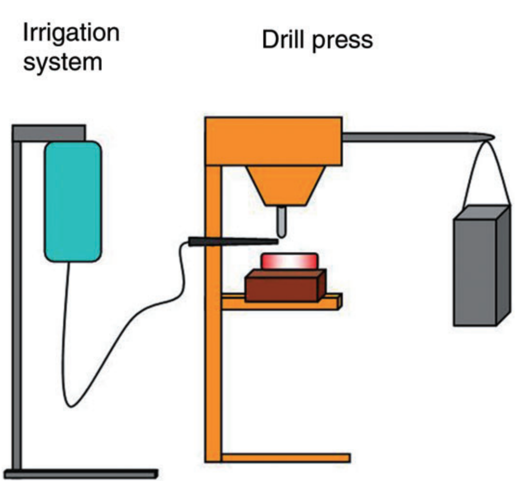


Figure 2 Setup of drill press with irrigation unit and load on spindle.

using an intermittent pumping motion. Thermocouple measurements of temperature at the implant site were recorded during the first, fifth, then every fifth osteotomy, up the fiftieth preparations. The thermometer (Digi-Sense DualLogR Thermocouple Thermometer Model no. 91100-50, Cole-Parmer, Vernon Hills, IL, USA) measured temperature at the preparation site at 1.0-s intervals, from the start of drilling until the completion of the osteotomy. An implant irrigation unit cooled the bone and provided lubrication for the removal of debris during the osteotomy to prevent the drills clogging. The irrigant was 0.9 M IV saline, which was refrigerated at 6°C prior to the experiment.

Sterilization Procedure

Sterilization processes can be detrimental to the cutting surfaces of implant drills.[6,8] The largest diameter drills were sterilized after every second osteotomy, in accordance with the standard sterilization protocol at the University of Otago – School of Dentistry. The drills were washed under tap water (chlorinated) and scrubbed with a small nylon brush and a detergent (Sonident, Whitely Corporation Pty Ltd, North Sydney, New South Wales, Australia) then immersed in an ultrasonic bath (also containing Sonident) for 10 minutes. Drills were then rinsed under warm tap water, dried with alcohol wipes, bagged, and autoclaved in a 25-minute cycle with 4-minute pressurized steam sterilization (134°C) and 8-minute drying.

Sterilizing and Irrigant Effects

To examine the effects of sterilization and irrigants alone, unused Straumann, Nobel Biocare, and Neoss drills were exposed solely to sterilization cycles, and scanning electron microscope (SEM) images were taken after 9, 14, and 24 cycles, equivalent to drills after 20, 30, and 50 osteotomies. Three more unused drills were solely immersed in saline irrigant solution for 17 minutes, equivalent to irrigant exposure after 50 osteotomies and imaged with the SEM.

SEM Spectroscopic Analysis

SEM (Cambridge S360, Cambridge Scientific Instruments Ltd, Cambridge, UK) images of the drills were taken in the unused state and then after the 1st, 5th, 10th, 20th, 30th, and 50th osteotomies. The gross images (16–300× magnification) were used to evaluate the wear, blunting, and plastic deformation of the drills' cutting surfaces. Higher magnification images (600–4,000×) were used to determine surface corrosion of the drills. A quantitative analysis of the drills' composition was performed by using JED 2300 Energy Dispersive Spectrometer to obtain energy dispersive X-ray spectra of the chemical composition of the drills.

Statistical Analysis of Temperature

SPSS version 13 (SPSS Inc., Chicago, IL, USA) was used to analyze the temperatures recorded in the experiment. Paired samples t-test analyzed the temperatures recorded at different thermocouple depths, and one-way analysis of variance (ANOVA) was used to compare the temperatures of the three manufacturers' drills at the different drilling sites and after specific drilling intervals. The parameters for statistical significance were $p < .05$. Mean and standard deviations of the elemental analysis of the drill surfaces were also calculated.

RESULTS

Statistical Analysis of Temperature Change Adjacent of Osteotomies

The mean temperature measured over the experiment was 20.0°C. The maximum temperature reached was 27.7°C, and the temperature seldom varied 2°C from the initial temperature. During the 50th osteotomies, the highest temperature recorded was 19.8°C, which was less than the mean temperature during the experiment (Table 1).

One-way ANOVA was performed for osteotomy 1, 20, and 50. Osteotomy 1 incorporated temperature measurements for all drills during the first osteotomy

TABLE 1 Mean Drilling Temperatures throughout the Experiment

Number of Holes Drilled	1	5	10	15	20	25	30	35	40	45	50
Total mean temperature of bone (°C) for all drill types	19.2	20.8	21.9	23.1	23.0	18.0	19.4	18.6	18.9	17.6	18.2

TABLE 2 *p*-Value Analysis for Temperatures Recorded at Osteotomy 1 Multiple Comparison Analysis of Variance

Drills	Mean Difference	Standard Error	Sig.	95% CI Lower bound	Upper Bound
Straumann (S; Straumann AG, Waldenburg, Switzerland)					
NB	−0.4996*	0.1427	0.001	−0.783	−0.217
NE	1.7130*	0.1299	0.000	1.455	1.971
Nobel Biocare (NB; Nobel Biocare AB, Göteborg, Sweden)					
S	0.4996*	0.1427	0.001	0.217	0.783
NE	2.2126*	0.1324	0.000	1.950	2.475
Neoss (NE; Neoss Australia, New Farm, Queensland)					
S	−1.7130*	0.1299	0.000	−1.971	−1.455
NB	−2.2126*	0.1324	0.000	−2.475	−1.950

*$p < .05$.

(including pilot drills). The results showed that the average temperatures of the drills from each of the manufacturers were significantly different from each other ($p < .05$) (Table 2). Analysis of temperature at Hole 20 showed that drilling temperatures with the Straumann drills were significantly different from Nobel Biocare and Neoss. The mean temperature measured after 20 holes for the Straumann drills was 23.0°C, 0.4°C higher than that of Nobel Biocare and Neoss drills. The temperatures measured at 50 osteotomies showed that none of the drill brands were significantly different from each other. The average drilling temperature was 18.2°C, and the maximum temperature reached was 19.8°C.

Paired sample *t*-tests of osteotomy 1, 20, and 50 showed a significant difference in the temperatures recorded at thermocouple 1 (12-mm depth) and thermocouple 2 (4-mm depth). Only one *t*-test of Straumann 3.5-mm drill failed to show a significant difference in the temperatures. However, the two other identical drills did show a difference. Thus, the bone temperature measured at 4-mm depth (the inner surface of the cortical plate) was significantly higher than that at 12-mm depth.

Descriptive Analysis of SEM Images

Images of the drills taken prior to the investigation provided a comparison for changes in the drills throughout the experiment (Figure 3). A comparison of the increasing wear on all cutting surfaces of each drill was not possible, as only one cutting surface was imaged at each stage and was chosen randomly, depending on the orientation of the drill to the electron beam in the SEM. The drills could, however, be examined in the viewing field, and it was concluded that none of the drills showed gross deformation of the cutting surface visible to the naked eye at any stage of the experiment.

Straumann drills showed cutting surface wear at 129× and 300× magnifications after five uses, approximately 100 μm in length. Plastic deformation of the cutting surface was present after 30 uses, and the surface wear was uniform across the cutting edge at 300× magnification after 50 uses (Figure 4A). Nobel Biocare drills showed virtually no visible wear throughout the experiment (see Figure 4B), apart from one instance when an area of plastic deformation was noted after the first use (30 μm long). Neoss drills appeared the most affected from multiple usage, as they were the only drills to show both wear and plastic deformation at the outer edge of the cutting tip. These drills showed the most extensive wear of the drills tested, with uniform wear present on the cutting edge after only 20 uses. At 50 uses, a large area of plastic deformation was observed on the outer edge of the cutting tip (see Figure 4C).

Magnification of the cutting tip of the drills showed differences in the manufacturing of the drills. Straumann drills showed milling lines, which corresponded with the surface preparation of the bur. Nobel Biocare drills had distinctive smooth dome-shaped ridges, which became more prominent with increased sterilization cycles. Neoss drills showed a smoothed surface, which gives the appearance of a coating on the drills.

After preparing 50 osteotomies with irrigant and being subjected to 24 sterilizing cycles, the drills all showed varying degrees of pitting corrosion on the surface (Figure 5). Straumann drills showed pitting along the milling lines, and Nobel Biocare and Neoss

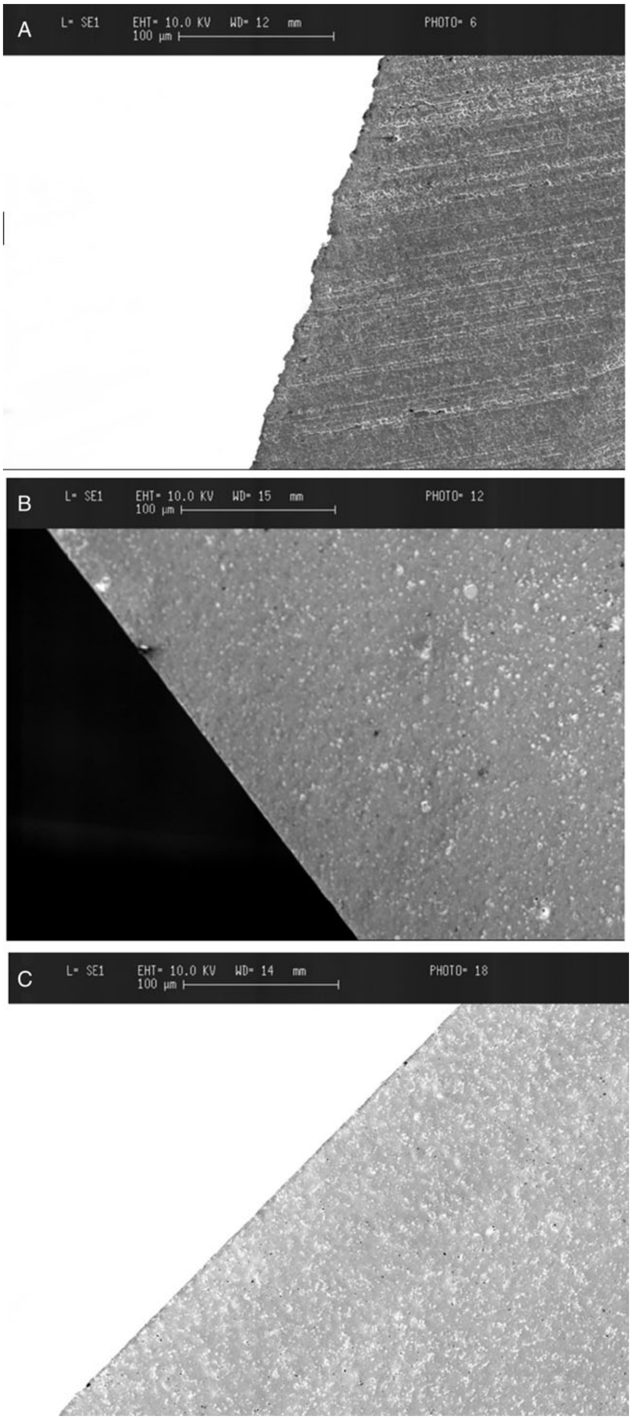


Figure 3 View of cutting edge of unused, untreated drills. *A,* Straumann (Straumann AG, Waldenburg, Switzerland) 300×. *B,* Nobel Biocare (Nobel Biocare AB, Göteborg, Sweden) 300×. *C,* Neoss (Neoss Australia, New Farm, Queensland) 300×.

showed a uniform pattern of pitting across the surface. New, unused drills were examined to compare the effects of the experimental variables on drill wear and corrosion (Figure 6A). Drills that were exclusively subjected to the sterilizing process (see Figure 6B) also showed a similar corrosion pattern and severity. Drills immersed in saline solution for 17 minutes showed a similar albeit lesser corrosion pattern (see Figure 6C). Pilot drills used solely for osteotomy preparation were then observed

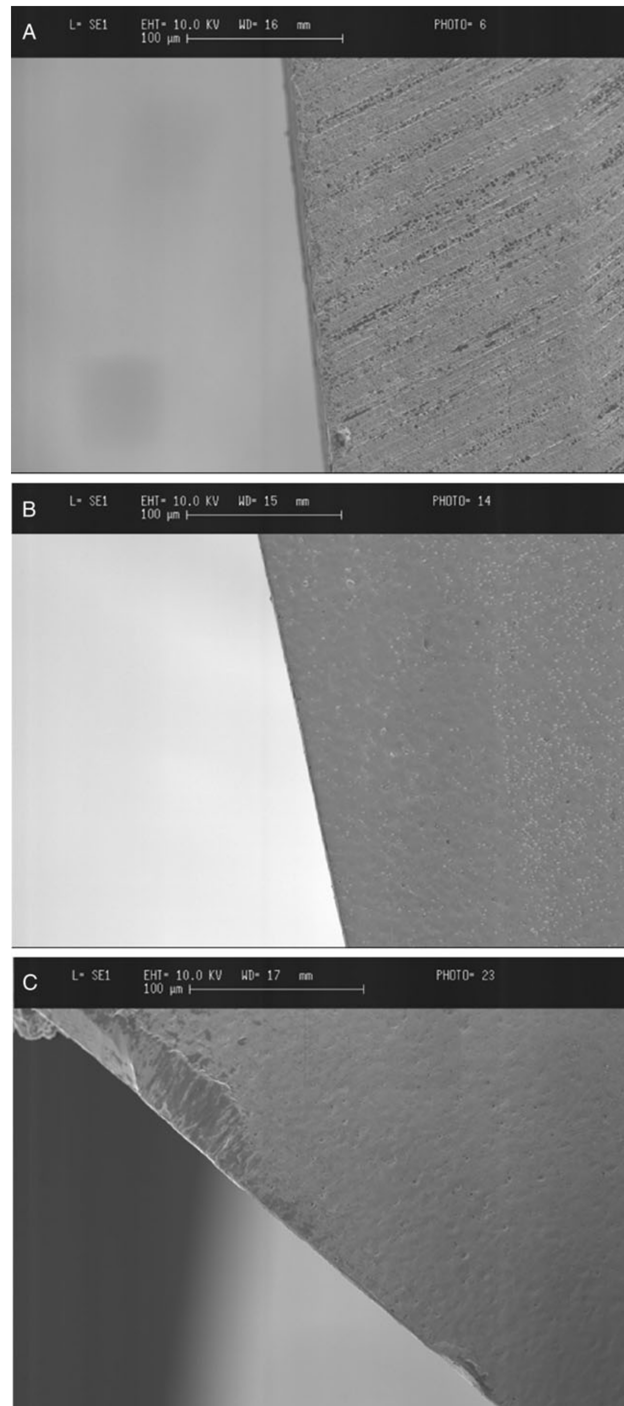
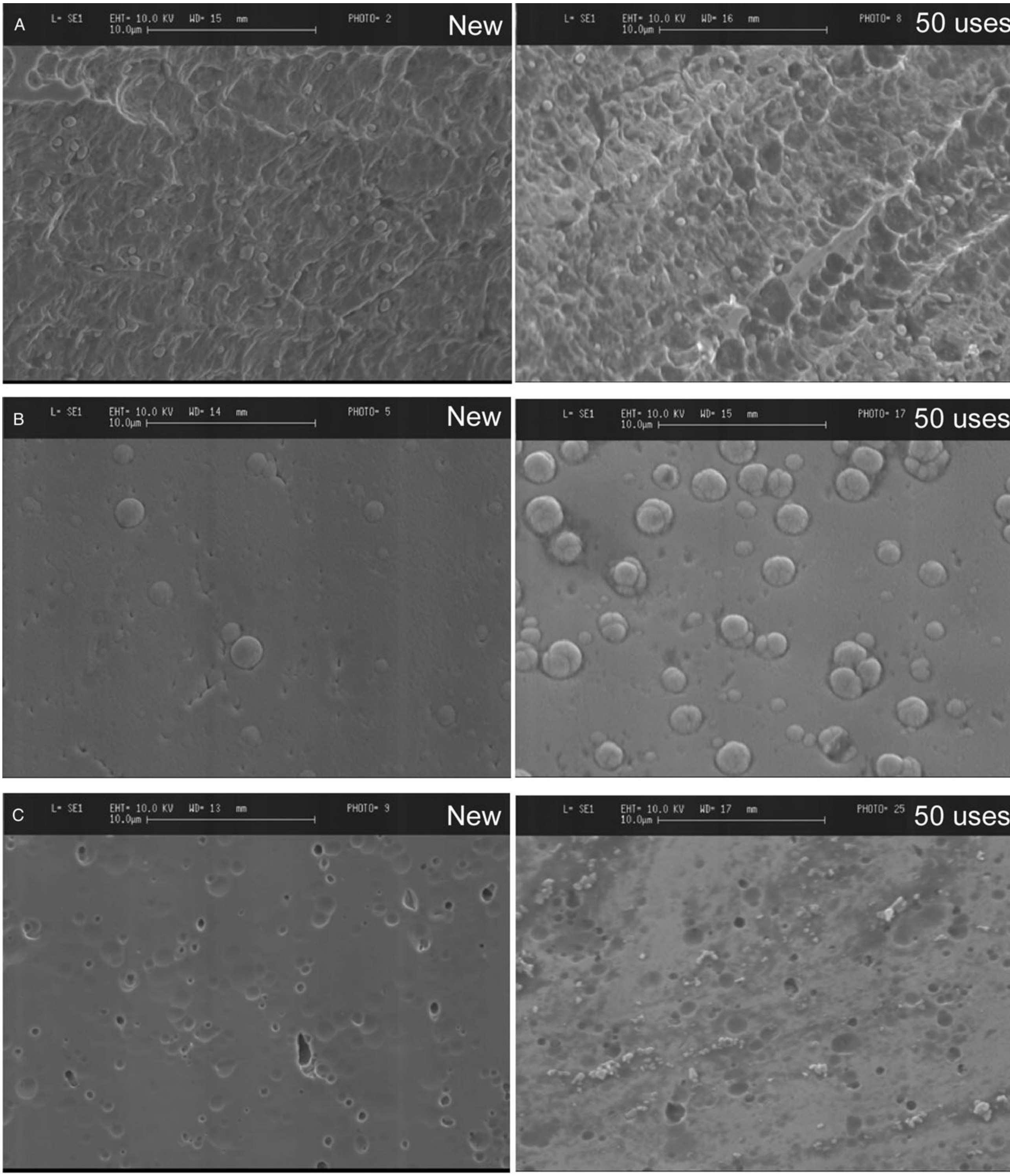


Figure 4 View of cutting edge after 50 osteotomies. *A,* Straumann (Straumann AG, Waldenburg, Switzerland) 300×. *B,* Nobel Biocare (Nobel Biocare AB, Göteborg, Sweden) 300×. *C,* Neoss (Neoss Australia, New Farm, Queensland) 337×.



Figures 5 Comparison of new and used drill cutting edge surfaces showing differences in surface corrosion after multiple osteotomies and sterilization cycles (4000×). *A,* Straumann (Straumann AG, Waldenburg, Switzerland). *B,* Nobel Biocare (Nobel Biocare AB, Göteborg, Sweden). *C,* Neoss (Neoss Australia, New Farm, Queensland).

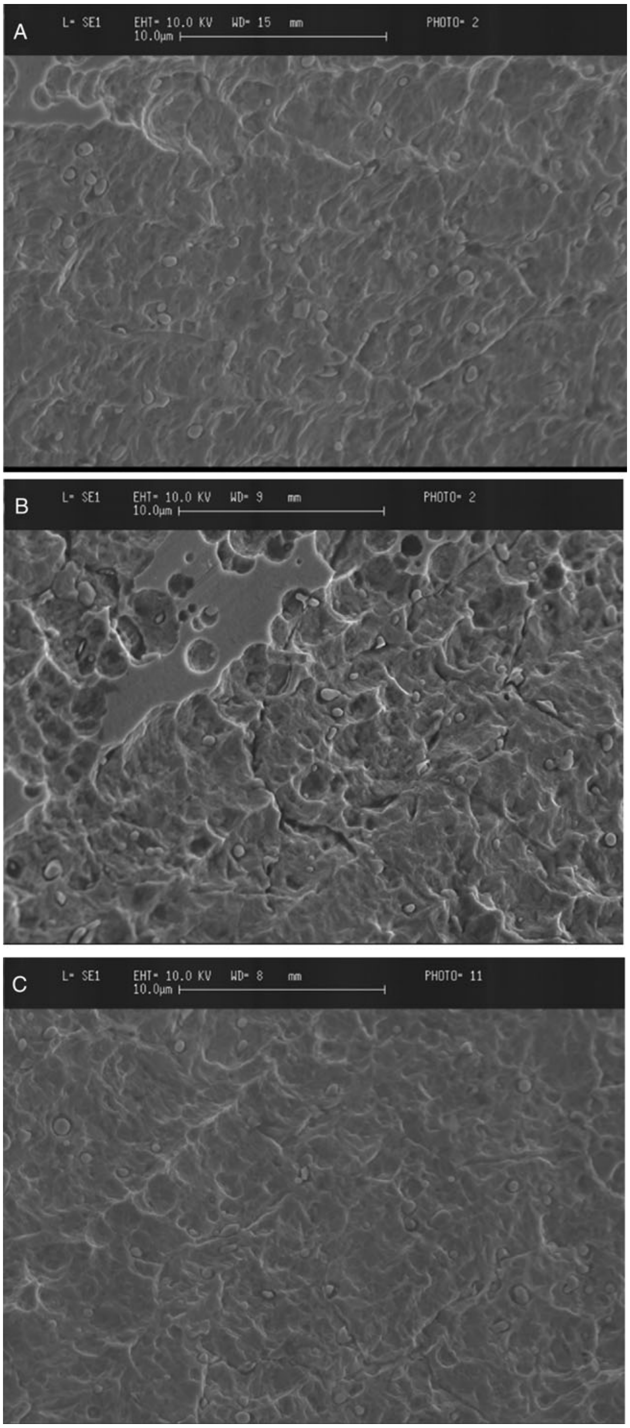


Figure 6 Straumann drills (Straumann AG, Waldenburg, Switzerland) showing variables for comparison of corrosion effects. *A,* 4,000× new. *B,* 4,000× sterilization only. *C,* 4,000× saline only.

under the SEM. These drills also displayed corrosion although they were not sterilized.

SEM Spectroscopic Analysis

The implant drills used in this study were from leading implant drill manufacturers. The manufacturers suggested that the drills were composed primarily of stainless steel alloys and that spectroscopic analysis allowed for the precise composition of the drills to be determined for comparison with each other. The results showed Straumann and Neoss drills to be composed of a stainless steel alloy with a high iron and chromium composition. Nobel Biocare drill appeared to be coated with a tungsten carbide alloy, and although where there were defects in the coating, the underlying structure was of a stainless steel alloy (Figures 7 and 8). The spectroscopic analysis of the cutting and adjacent surface in some instances shows different elemental analysis after usage and sterilization. Table 3 lists the comparative energy dispersive x-ray spectra compositions. For the Nobel Biocare drills, the major change has been in the C (carbon) and W (tungsten) contents. After 50 uses, the flat area 2 showed a 10% reduction on C and a comparable increase in W, whereas, after sterilization, the outcomes were almost exactly the opposite, that is, a decrease in W but an increase in C. For the Neoss drills, there is a significant increase in C, again, in area after 50 uses and a reduction in Fe. After sterilization, there is also an increase in C and a lesser reduction in Fe, again in area 2. For the Straumann drills, there was an increase only in C in area 2 after 50 uses associated with a slight decrease in Fe. There was minimal influence of sterilization for Straumann drills. From the SEM images of the surfaces before and after drilling and sterilization, it is apparent that, despite the cleaning process, debris appears to still be attached to the area 2. It is also evident that Straumann drills were the ones that showed the

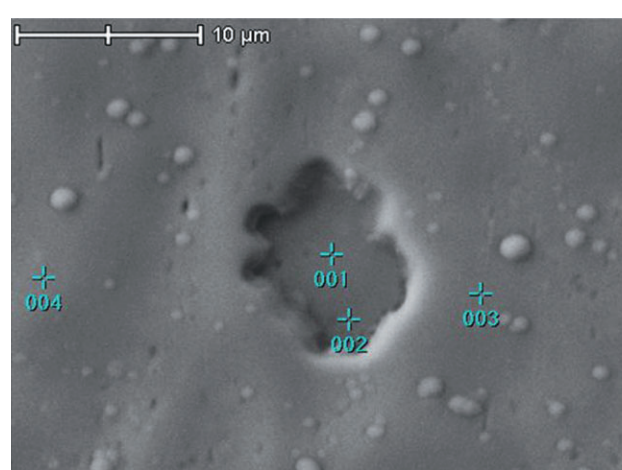


Figure 7 Scanning electron microscope image of Nobel Biocare drill (Nobel Biocare AB, Göteborg, Sweden) surface with deficiencies in the coating.

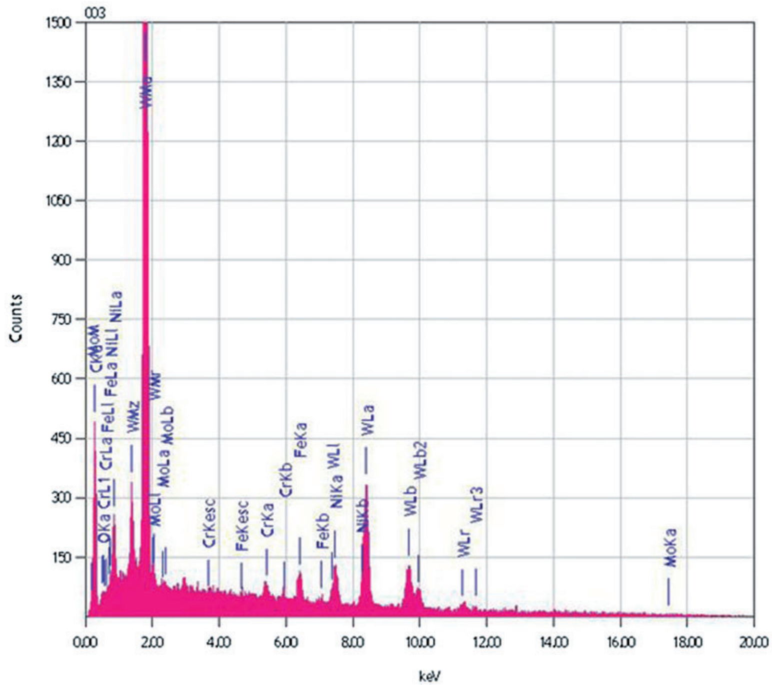


Figure 8 Spectra showing elemental peaks of surface coating of Nobel Biocare drill (Nobel Biocare AB, Göteborg, Sweden).

most discernable changes after sterilization, indicated by a corrodedlike surface, whereas this was not seen for the other drills.

DISCUSSION

This experiment employed techniques used in previous research in order to describe the effects of clinical use on dental surgical implant drills.[5–8] The aim was to develop an understanding of the effects of standard clinical use of surgical implant drills. Previous research did not provide an overall evaluation of the burs, as, in some cases, the drills were not sterilized,[5] the material used was not similar to human bone,[6] or only one type was evaluated.[7] In many experiments, the osteotomies were prepared by handheld equipment, so the force on the drills was not standardized despite early experiments by Matthews and Hirsch,[4] showing force exerted on the drills to be a key factor in the wear of the drills. Unlike in previous experiments, in this study, a protocol was developed that closely simulated clinical use of the drills in a setting that controlled the experimental variables. This enabled degradation or relative temperature changes of the drills to be evaluated and be related to the wear of the drills in clinical practice.

The results of the temperatures generated during drilling indicate that, even after 50 osteotomies, in no instance did the temperature generated approach the critical value 47°C associated with necrosis. There were statistically significant differences in temperature increase between the different manufacturers' drills at the first osteotomy site, but the differences were not clinically significant. At osteotomy site 50, there was no statistically significant difference in the temperature increase between the different manufacturers' drills. The results obtained suggest that the drills generally did not induce high temperatures and, in fact, had lower drilling temperatures at the final osteotomy than the mean for the experiment. Temperatures measured at the bone interface, 1 mm from the preparation site, showed significant difference between the temperatures measured at 4- and 12-mm depths. The temperature at 4 mm was significantly higher than that at the deeper thermocouple, suggesting that the denser cortical plate induces higher frictional forces, which produce more heat in the drills. The deeper thermocouple measured lower temperatures despite having decreased irrigant penetration, which aimed to cool the cutting surface, as less force would have been required to penetrate the spongy cancellous bone. Clinically, the operator should be aware of the increased heat of bone in the cortical plate of the mandible and use a cooled irrigant and a sharp drill to prevent elevated heat in the bone.

TABLE 3 Mean % Elemental Composition

COLUMN		1	2			1	2			1	2
NB NEW	C	39	33.6	S NEW	C	5.1	4.7	NE NEW	C	12.1	5.6
	O	1.6	1.6		O	0.2	0.24		O	0.46	0.12
	Cr	1	0.38		Si	0.68	0.58		Si	0.34	0.36
	Fe	2	1.54		Cr	15.6	16		Cr	12.4	12.8
	Ni	3.6	4.2		Fe	77.4	77.2		Fe	72.6	79
	W	54	59		Mo	0.84	1.26		Ni	1	1.02
	Mo	0.6	0.28						Mo	1.24	1.4
NB 50×	C	36	33.6	S 50×	C	9.4	6.2	NE 50×	C	6.8	7.3
	O	1.4	1.48		O	2.32	0.8		O	0.04	0.74
	Cr	1	0.4		Si	0.74	0.6		Si	0.46	0.28
	Fe	2	1.52		Cr	14.8	14.8		Cr	13	13
	Ni	3.4	4.36		Fe	70.2	76		Fe	77.4	76.2
	W	57	58.8		Mo	1.88	1.26		Ni	1	1
	Mo	0.5	0.5		Cu	1.4	0.5		Mo	1.4	1.38
					Zn	0.3	0				
NB Saline	C	37	34.4	S Saline	C	7.7	5	NE Saline	C	9.2	9.2
	O	1.3	0.84		O	0.56	0.1		O	0.28	0.36
	Cr	0.8	0.86		Si	0.62	0.62		Si	0.36	0.36
	Fe	2.1	2		Cr	15.2	15.6		Cr	12.8	12.8
	Ni	3.4	3.6		Fe	75	77.6		Fe	75.2	75.2
	W	55	57.4		Mo	1	1.38		Ni	1	0.94
	Mo	0.4	0.6						Mo	1.2	1.16
NB Ster	C	34	32.4	S Ster	C	5.8	6	NE Ster	C	4.5	4.4
	O	1.2	1.06		O	0.62	0.54		O	0.44	0.32
	Cr	0.7	0.78		Si	0.62	0.54		Si	0.2	0.3
	Fe	1.9	1.98		Cr	16.4	15.6		Cr	13.2	13.4
	Ni	3.7	3.94		Fe	75.8	76.2		Fe	79.4	79.6
	W	58	59.2		Mo	0.86	1.06		Ni	0.86	0.92
	Mo	0.4	0.68		Mo	0.86	1.06		Mo	1.2	1.34

C = carbon; Cr = chromium; Fe = iron; 1 = cutting surface; 2 = flat surface; NB = Nobel Biocare (Nobel Biocare AB, Göteborg, Sweden); NE = Neoss (Neoss Australia, New Farm, Queensland); S = Straumann (Straumann AG, Waldenburg, Switzerland); Ni = nickel; M = Molybdenum; W = tungsten.

The SEM analysis showed that Neoss and Nobel Biocare drills appeared to have a smooth, polished surface, while the Straumann drills had a ground and rougher surface. After 50 osteotomies, Neoss and Straumann burs showed substantial wear and plastic deformation on the cutting edge, whereas the Nobel Biocare drills had no such wear behavior.

After exposure to saline or sterilization for the equivalent to 50 osteotomies, the Straumann drills showed the most extensive change, with pitting discernible on the surface. This appeared more evident after sterilization, where etch-like grooves were evident. A possible interpretation is that the deformation from the initial machining damage may have caused locally high-enough temperatures to modify the C distribution within the stainless steel. If stainless steel is exposed to temperatures of 600°C or higher, C diffuses to Cr, and forms Cr_2C_3 precipitates that reduces the availability of Cr within the stainless steel, thereby making it prone to corrosion. This would explain the uniform corrosion patterns seen.

The spectra of the implant drills revealed that Straumann and Neoss drills were both stainless steel alloys, while the Nobel Biocare drill had a thin tungsten carbide alloy coating over stainless steel. The composition of the drills has not shown any alloy to be superior in regard to the temperature changes at the drilling site or the wear patterns on the drilling surface. There were slight differences in the chemical compositions of the drills at different regions of the drill (see Table 1). The Neoss drills that were used 50 times and those that were sterilized only showed a marked decrease in iron composition on the inner, flat aspect of the drill. The tungsten carbide coating appears to show minimal change. Tungsten carbide alloys are much harder than stainless steel and so are expected to provide greater wear and plastic flow resistance induced by the cutting of the bone.

The overall experiment has given a unique view of implant drill wear, with the variables tested allowing a replicated clinical protocol. The results here confirm that wear occurs during osteotomy preparation and that irrigant use and sterilization processes combined compound the problem.

Nobel Biocare showed the least corrosion and wear and had the lowest mean drilling temperatures after 20 osteotomies, which may be attributed to the different elemental composition of the drills. Nobel Biocare drills appear to have intrinsic properties, which appear to protect them from the mechanical, thermal, and corrosion failure evident in the Straumann, and Neoss drills.

CONCLUSIONS

Low temperatures at the bone interface during implant osteotomies are extremely important for successful osseointegration. The following conclusions were drawn from the study:

- After 50 successive osteotomies (twice the recommended number), the temperatures in the cortical plate and the cancellous bone never varied more than 5°C from the start temperature.
- The highest recorded temperatures for each osteotomy did not last more than 9 seconds.
- These results conform to similar studies that analyze temperature during multiple osteotomies.[5,8]
- Suggested usage of drills for up to 40 osteotomies appears a conservative and safe estimate from the results obtained in this study.[3,8]
- The temperatures measured at the two thermocouple locations were significantly different from each other as were the mean temperatures of drills from each of the different manufacturers, contradicting previous research that found no difference in temperature readings.[5,8]
- Sterilization processes and saline irrigant were shown to increase corrosion of the implant burs and, in combination with the heat and stresses produced in the cutting of bone, increased the corrosion of the drills.
- Deformation and corrosion did not appear to have an effect on temperature increases at the adjacent bone sites.
- Nobel Biocare showed the least corrosion and wear and had the lowest mean drilling temperatures after 20 osteotomies.

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