Development of a new guided sleeve made of zirconia dioxide

Application for surgical guides in dental implantology

Literature

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The field of dental implantology has developed enormously over the last 50 years. Not only the actual dental implants but also the placement techniques and the possibilities of predictable planning have changed and improved greatly. In order to make implant placement in the jaw safer and as accurate as possible, methods have been developed to use 3D data obtained in advance. This technique became possible after the development of CT by Hounsfield in 1972 and the introduction of reduced-radiation CBCT.[1–3]

With the help of the data obtained, surgical guides can be produced with appropriately incorporated guided sleeves. This enables the most precise implantation possible.[5] In this regard, Schnutenhaus et al. found that implants placed with surgical guides were positioned more precisely than those placed freehand.[6]

Generally, metal drills paired with metal guided sleeves are used in dental implantology.[7] However, this can cause abrasion during guided drilling and contamination of the surgical site.[8] Experience in hip arthroplasty shows that metal–metal pairings are unfavourable in their abrasion behaviour. The metal particles can cause inflammation of the surrounding tissue, abrasion disease or particle disease.[9] In dentistry, the abrasion in the surgical area also poses risks in terms of wound healing and eventual peri-implantitis.[10, 11] Titanium ions from the titanium particles indirectly evoke an inflammatory reaction, and it is assumed that the osteoblasts are damaged.[12, 13] In orthopaedics, a ceramic–ceramic pairing offers an alternative with lower biological activity and a 27-fold reduction in abrasion. The following article presents the development of a new guided sleeve of zirconia for surgical guides for accurate drilling while avoiding chipping or particle abrasion that can cause peri-implantitis or particle disease.

Fig. 1: Lower jaw preparation before drilling. (© Leonard Vollmer)

Objective

The objective of the research was to test the chip abrasion of a combination of a zirconia sleeve with a zirconia drill and compare it with that of a titanium guided sleeve used in combination with a steel drill in order to prevent or minimise the risks associated with chip abrasion. For this purpose, test drillings were carried out on an anatomical specimen and subsequently compared histologically and by means of energy-dispersive X-ray spectroscopy (EDS).

Materials and methods

Ten drillings with the combination of a zirconia guided sleeve and zirconia drill and one drilling with a titanium guided sleeve and steel drill were carried out and subsequently examined (Table 1).

Bone material

An anatomical edentulous macerated mandibular specimen fixed in paraformaldehyde was used for the experiment (Fig. 1). This preparation was chosen to simulate an *in vivo* situation. The portions of the cortical bone were broad and the cancellous structures dense. The


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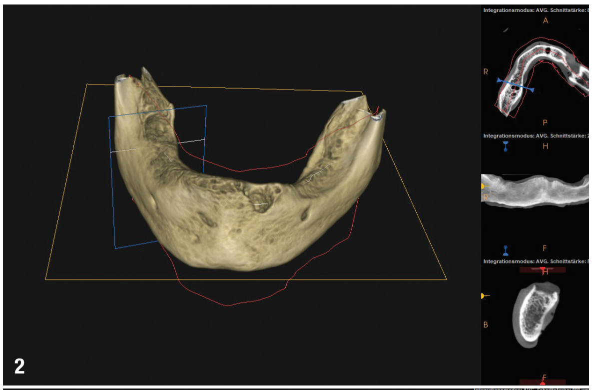
bone quality corresponded to the D2 classification according to Lekholm and Zarb.[14] The ramus of the mandible was separated from the body of the mandible to keep the drilling of the steel drill in conjunction with the titanium guided sleeve and the zirconia drills in conjunction with zirconia guided sleeves separate and to exclude contamination.

CBCT scanning of mandibular bone for planning and positioning of the drills

The fixed jaw sections were scanned in a CBCT unit (CS 9300, Carestream Dental; Fig. 2). This was followed by digital planning (CS 3D, Version 3.8.6, Carestream Dental). Eleven implants were planned and positioned in the bone, ten in the body of the mandible (Fig. 3) and one in the ramus. The data was then imported into the coDiagnostiX technical program (Dental Wings) to produce both the jaw model and the bone-supported surgical guides.

Fabrication of the jaw model and the guides

The model and guides were fabricated using the NextDent 5100 printer (3D Systems). NextDent Model 2.0 in grey was used for printing the jaws, and NextDent SG was used for the surgical guide. Since surgical guides are made of plastic and direct drilling through plastic leads to extremely strong abrasion of this by sharp implant drills, the guided sleeves must be made of a



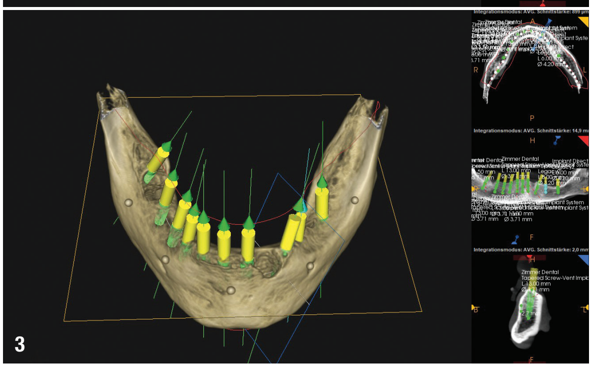


Fig. 2: CBCT scan of the body of the mandible in the planning program, showing broad portions of cortical bone and dense cancellous structures.
Fig. 3: CBCT scan of the body of the mandible in the planning program showing ten implants positioned. (© Leonard Vollmer)

Implant planning	
CBCT device	CS 9300 (Carestream Dental)
Planning program	CS 3D, Version 3.8.6 (Carestream Dental)
Design program	coDiagnostiX (Dental Wings)
3D-printing	
Printer	Nextdent 5100 (3D Systems)
Model material	Nextdent Model 2.0/grey (3D Systems)
Guide material	Nextdent SG (3D Systems)
Guided sleeves and drills	
Titanium guided sleeve	M.27.31.D200L5 (Steco)
Zirconia guided sleeve	Utility model no. 202020103184.8
Adhesive for sleeves	BLUE FIX (FLUSSFISCH)
Steel pilot drill	210L16.204.020 (Komet Dental)
Zirconia pilot drill	K210L19.204.020 (Komet Dental)
Histological examination	
Separation unit (large diamond disc)	333C450 (HORICO)
Plastic infiltrate	2-hydroxyethylmethacrylate
Plastic infiltrate	Technovit 7200 VLC (Kulzer)
Light polymerisation unit	EXAKT
3-component resin	Technovit 4000 (Kulzer)
Vacuum precision adhesive press	EXAKT
Grinding machine	EXAKT 400 CS
Diamond bandsaw	EXAKT 300 CP
Light microscope	ZEISS Axioscope 2
Video camera	ZEISS AxioCam MRc
Dye	Toluidine blue

Table 1: Overview of the materials used.

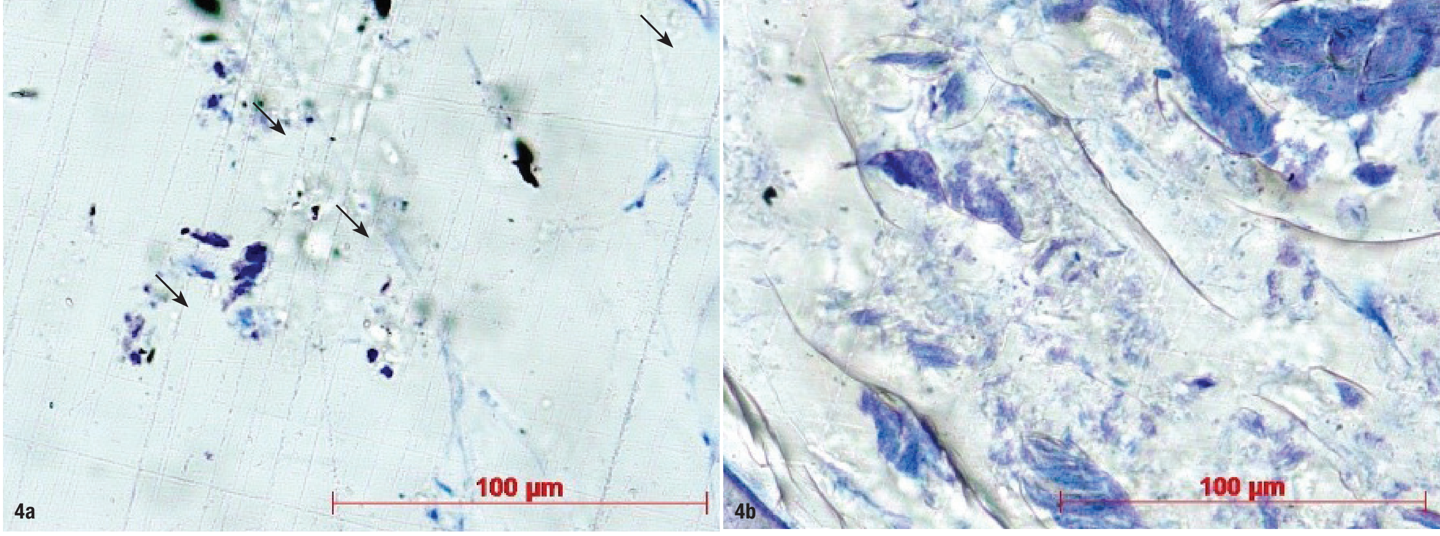
correspondingly harder material. The guide was therefore provided with titanium or zirconia guided sleeves.

Guided sleeves

A M.27.31.D200L5 titanium guided sleeve (Steco) with an inner diameter of 2 mm was glued (BLUE FIX, FLUSSFISCH) into the surgical guide for the ramus. No guided sleeve of zirconia is commercially available, so new guided sleeves were made from yttrium tetragonal zirconia polycrystals according to our specifications:

– collar according to our own design;
– inner diameter of 2 + 0.02 mm or + 0.04 mm;
– length of 8 mm;
– chamfer of 0.5 × 45° on the opposite side of the collar.

To ensure quality control, the outer dimensions of the sleeves were measured with a micrometre screw and the inner diameter was checked with test pins. A 2.02 mm diameter test pin, but not a 2.04 mm diameter test pin, had to be able to pass through the inner drill hole. Furthermore, the manufacturer declared that the



Figs. 4a & b: Histological preparation of the tissue of the drill hole made with the titanium sleeve and steel drill combination. The arrows indicate the metal particles. (© Werner Götz, University of Bonn)

sleeves were compliant with the requirements of Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. The zirconia guided sleeves were glued into the surgical guide.

Drilling

Eleven holes were drilled using the surgical guides. Drilling was carried out without cooling at a low speed of a maximum of 400 rpm. A steel pilot drill (210L16.204.020, Komet Dental) was used for drilling in the ramus of the mandible up to the stop, and a zirconia pilot drill (K210L20.204.020, Komet Dental) was used for drilling ten holes (drilling depth of 8–12 mm) in the body.

Histological preparation for the examination

For the histological examination, the fixated mandible was cut into narrow bone slices (approximately 5 mm thick) with a large diamond separating disc (333C450, HORICO), and numbered. These were further processed using a sawing-grinding technique. The sections were first dehydrated in an ascending alcohol series (70%, 90%, 96% and 100%), followed by infiltration in two steps.[15] The specimens were infiltrated with a one-to-one mixture of 2-hydroxyethylmethacrylate and Technovit 7200 VLC (Kulzer) for seven days and then infiltrated with Technovit 7200 VLC for another seven days. Both steps were carried out under vacuum (500 kPA) and light exclusion. For polymerisation, the infiltrated preparations were left in a light polymerisation unit (EXAKT) under yellow light for 4 hours and under blue light for 4 hours.

Subsequently, the resulting discs were trimmed and attached to a plastic carrier with a three-component resin (Technovit 4000). Grinding using a micro-grinder (EXAKT 400 CS) was carried out until the holes were reached. Another plastic carrier was fixed to the ground surface, which was the surface to be examined. With a diamond bandsaw (EXAKT 300 CP), a 100–150 µm thick section of the block was removed and ground down to a thickness of 10–15 µm with the micro-grinder. In this way, between one and three preparations could be obtained per bone block. A total of ten segments were prepared. The ground sections were then stained with toluidine blue.

Histological evaluation

The sections were examined under a light microscope (ZEISS Axioscope 2) at different objective magnification (50×, 100×, 200×, 400× and 500×). The images were digitised via a connected digital video camera (ZEISS AxioCam MRc). All histological preparations were examined for artifacts, possible heat damage and other foreign bodies (e.g. caused by abrasion).

Energy-dispersive X-ray spectroscopy

Owing to unclear structures in the histological preparations of Segment 3, they were additionally subjected to

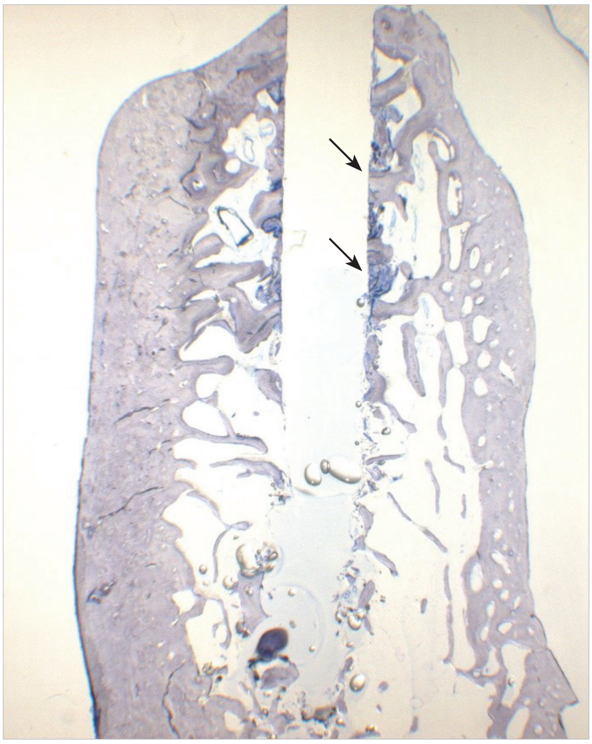


Fig. 5: Histological preparation of segment 3. Compacted debris (marked with arrows). Small granular fragments at the bottom; 500× magnification. (© Werner Götz, University of Bonn)

"The aim of this research was to investigate to what extent abrasion can be found in zirconia or titanium guided sleeves after drilling."

EDS to detect any zirconia. EDS is used to determine element concentrations in solids.[16, 17] It uses "the characteristic X-rays emitted by a solid as a result of electron bombardment to qualitatively and quantitatively determine the elements contained therein".[18]

Results

Observations during drilling

The rather jerky guidance of the steel drill was conspicuous. In contrast to the titanium–steel pairing, the very good gliding ability of the zirconia drill in the zirconia sleeve was noticeable. The drill could be guided very well in the pre-planned sleeves in depth and axis. Macroscopically, no abrasion was detected during drilling. The surfaces of the preparations cut with the steel drill were clean and smooth, as were the surfaces of the preparations cut with the zirconia drills.

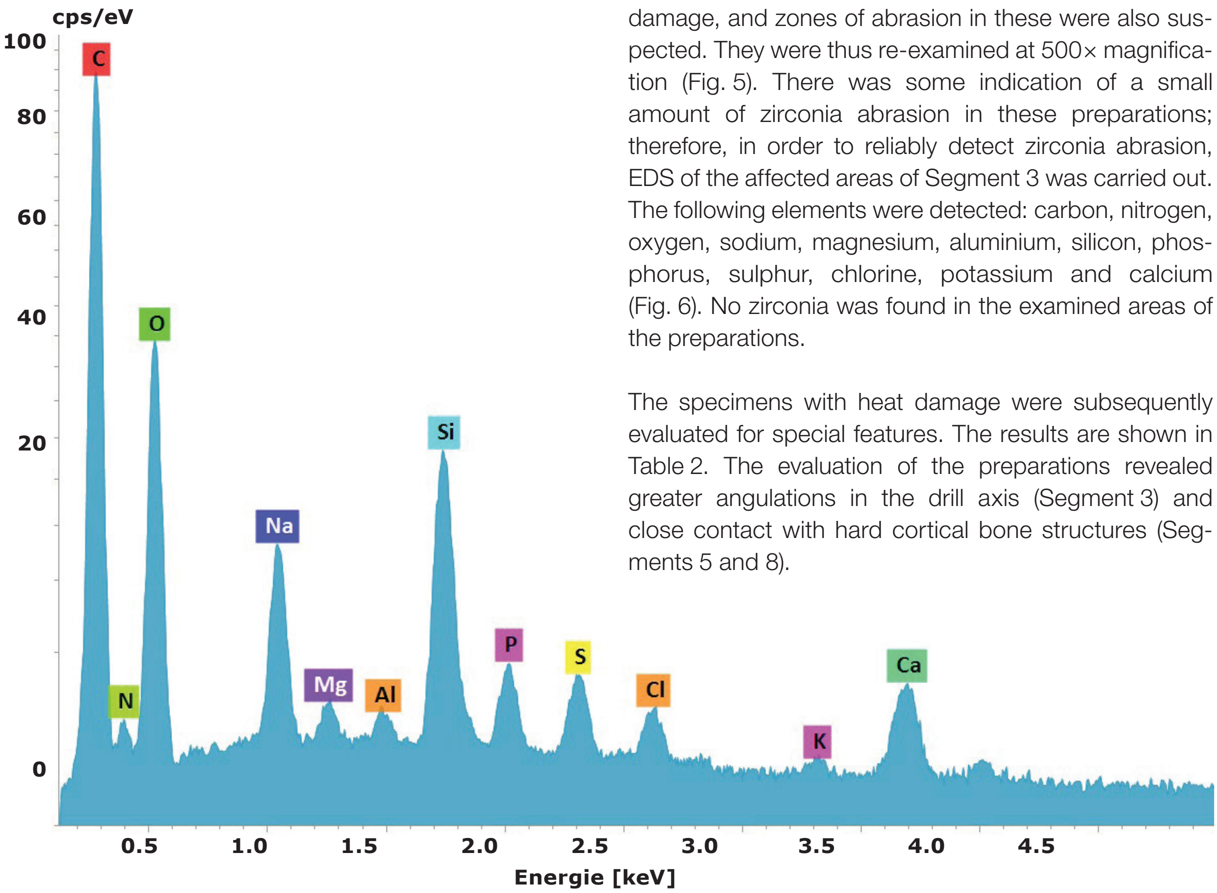


Fig. 6: Spectra of the energy-dispersive X-ray spectroscopy. C = carbon; N = nitrogen; O = oxygen; Na = sodium; Mg = magnesium; Al = aluminium; Si = silicon; P = phosphorus, S = sulphur; Cl = chlorine; K = potassium; Ca = calcium. (© nanoAnalytics GmbH)

Histological results

In the histological preparations of Segments 1–3, 5, 6, 7 and 9, as well as of the tissue of the drill hole made with the titanium sleeve and steel drill combination, frequently occurring artifacts due to the infiltration (e.g. bubble formation, Figs. 4 and 5) were visible. Histologically, no foreign bodies were detected in any of the sections. Granular fragments, smaller bone debris and granular debris were found in all the sections.

Titanium–steel pairing

At the higher magnifications, the titanium–steel segment showed abrasion typical of metal cutting in the form of irregularly shaped blackish particles of up to 20 µm (Fig. 4). Heat damage could not be detected.

Zirconia–zirconia pairing

In the zirconia–zirconia segments, no evidence of zirconia particle abrasion could be found in seven segments when magnified up to 20×. Heat damage could also not be detected in these seven specimens. Only three (3, 5 and 8) of the examined segments showed minor heat damage, and zones of abrasion in these were also suspected. They were thus re-examined at 500× magnification (Fig. 5). There was some indication of a small amount of zirconia abrasion in these preparations; therefore, in order to reliably detect zirconia abrasion, EDS of the affected areas of Segment 3 was carried out. The following elements were detected: carbon, nitrogen, oxygen, sodium, magnesium, aluminium, silicon, phosphorus, sulphur, chlorine, potassium and calcium (Fig. 6). No zirconia was found in the examined areas of the preparations.

The specimens with heat damage were subsequently evaluated for special features. The results are shown in Table 2. The evaluation of the preparations revealed greater angulations in the drill axis (Segment 3) and close contact with hard cortical bone structures (Segments 5 and 8).

Segment	Drill hole depth	Diameter	Angulation	Close contact with cortical structures	Heat damage
1	6.0 mm	2 mm	2°	Yes	No
2	8.0 mm	2 mm	0°	Yes	No
3	13.0 mm	2 mm	21°	No	Yes
4	13.0 mm	2 mm	0°	No	No
5	13.0 mm	2 mm	0°	Yes	Yes
6	13.0 mm	2 mm	0°	No	No
7	11.5 mm	2 mm	10°	No	No
8	11.5 mm	2 mm	11°	Yes	Yes
9	13.0 mm	2 mm	15°	Yes	No
10	13.0 mm	2 mm	25°	Yes	No
Titanium	15.0 mm	2 mm	0°	No	No

Table 2: Overview of the deviations of the drill holes from each other in terms of drill hole depth, angulation, contact with cortical structures and heat damage. (© Leonard Vollmer)

Discussion

The aim of this research was to investigate to what extent abrasion can be found in zirconia or titanium guided sleeves after drilling. Abrasion could be found in titanium guided sleeves but not in zirconia sleeves, neither by histological analysis nor by EDS. In the present test set-up, drilling was always carried out at the same low speed of a maximum of 400 rpm. Whether abrasion occurs in a zirconia–zirconia pairing at higher speeds remains to be investigated.

Titanium particles can lead to intolerance and to inflammatory reactions.[19] Furthermore, the prevalence of titanium particles in the vicinity of diseased peri-implant tissue is higher than that in the vicinity of healthy peri-implant tissue.[20,21] These particles can originate from metal instruments during implant bed preparation, from the implant surface itself and from the insertion of the abutment.[22] However, "while titanium is subject to tribocorrosion in the biological system and subsequently triggers immunological reactions, [...] zirconia is characterised by excellent corrosion resistance and has a high biological compatibility due to this."[23] The zirconia sleeves examined in the present study could thus possibly represent a further advancement on titanium guided sleeves.

Regarding the deviations from the other drillings found for specimens with heat damage, this may be cited as a point of criticism but are the result of the anatomical mandibular preparation. This made a very realistic examination possible on the one hand, but on the other meant that the drill holes were not all equally reproducible.

This work has laid the foundation for the use of zirconia guided sleeves. In order to make a definitive statement relevant to the practice of dental implantology and to clarify the question of whether zirconia sleeves are clinically preferable to titanium sleeves, a larger number of drill holes should first be tested in another *ex vivo* bone model and then with an *in vivo* approach.

Conclusion

Based on the known problems with titanium particles from hip arthroplasty, the titanium incompatibilities described by Jacobi-Gresser and the effects of titanium particles on peri-implantitis, it can probably be assumed that the use of zirconia guided sleeves in combination with zirconia drills offers advantages over titanium guided sleeves with steel drills.[19,21]

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