

Rotational Load Fatigue Performance of Titanium Vs Titanium-Zirconium Implant-Abutment Connections

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Introduction

Narrow diameter implants (NDIs) were introduced in a bid to minimise the need for costly and time-consuming surgical augmentation. Although incidence of implant fractures are low, it constitutes a catastrophic failure, and requires surgical removal of the implant. Thus the potential for implant fracture requires further investigation. Titanium-zirconium (Ti-Zr) alloy is known to have superior mechanical properties and comparable biologic response as compared to commercially pure titanium (CPTi). Clinically relevant information is still limited, although short term clinical studies show promising survival results. It is also still not known whether Ti-Zr NDIs are strong enough for application in similar clinical indications as regular diameter implants (RDIs).

Aim

The purpose of this study was to compare the rotational load fatigue performance of 3.3 mm and 4.1 mm diameter dental implants made with commercially pure Grade 4 titanium alloy (CPTi-G4) and Ti-Zr.

Materials and Methods

Two implant diameters (3.3 mm or 4.1 mm) and two implant materials (CPTi-G4 or Ti-Zr) were tested. All implants tested were Straumann Bone Level implants.

Samples were labelled the nomenclature “Diameter-Material-Sample Number” (Fig 1). Test groups had a sample size of 5 (n = 5).

The rotational load fatigue set up used was similar to previous studies and applies fluctuating cyclic stress onto the test specimen. The rotation of the specimen along its long axis allowed the stress to fluctuate from tensile to compressive in a sinusoidal pattern around the specimen. The test specimen was secured at 45° to the horizontal, resulting in bending moment of 35Ncm the implant-abutment interface (Fig 2).

Samples were secured in machined brass specimen holders with PL-2 resin (Vishay Precision Group) which simulated natural trabecular bone (E=1.4x10⁸ N/m²). The implant was positioned simulating 2.0 mm bone loss from the platform level.

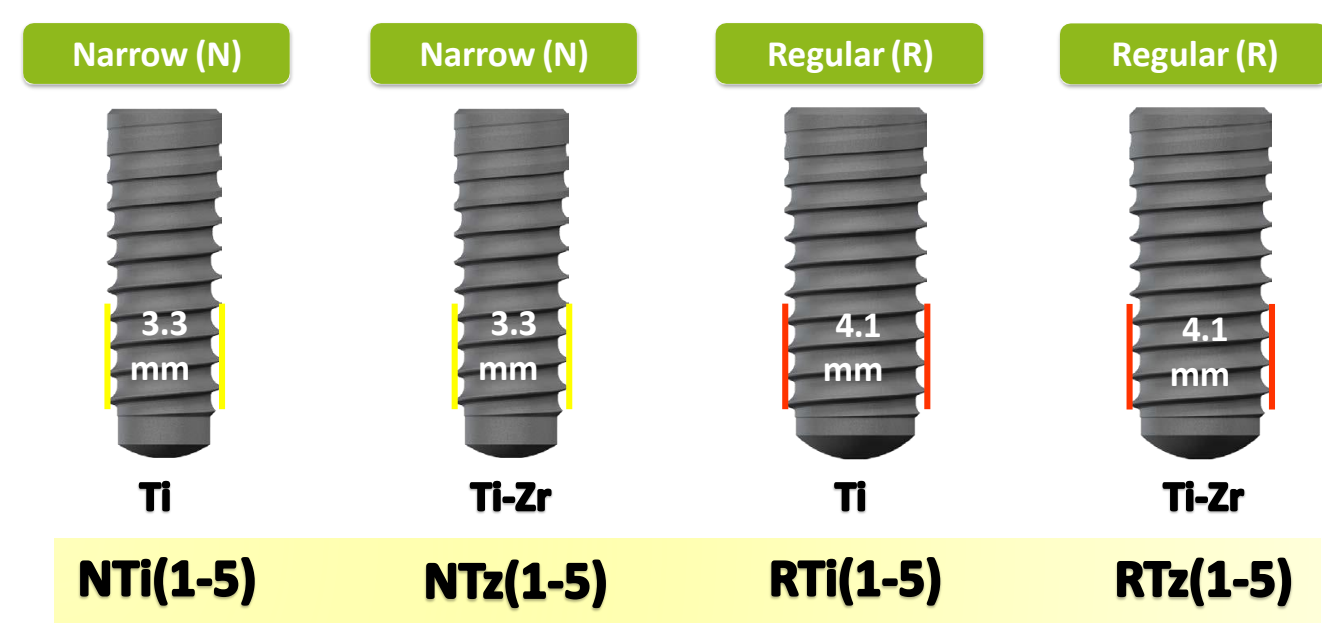


Fig 1 – Visual representation of specimen groups.

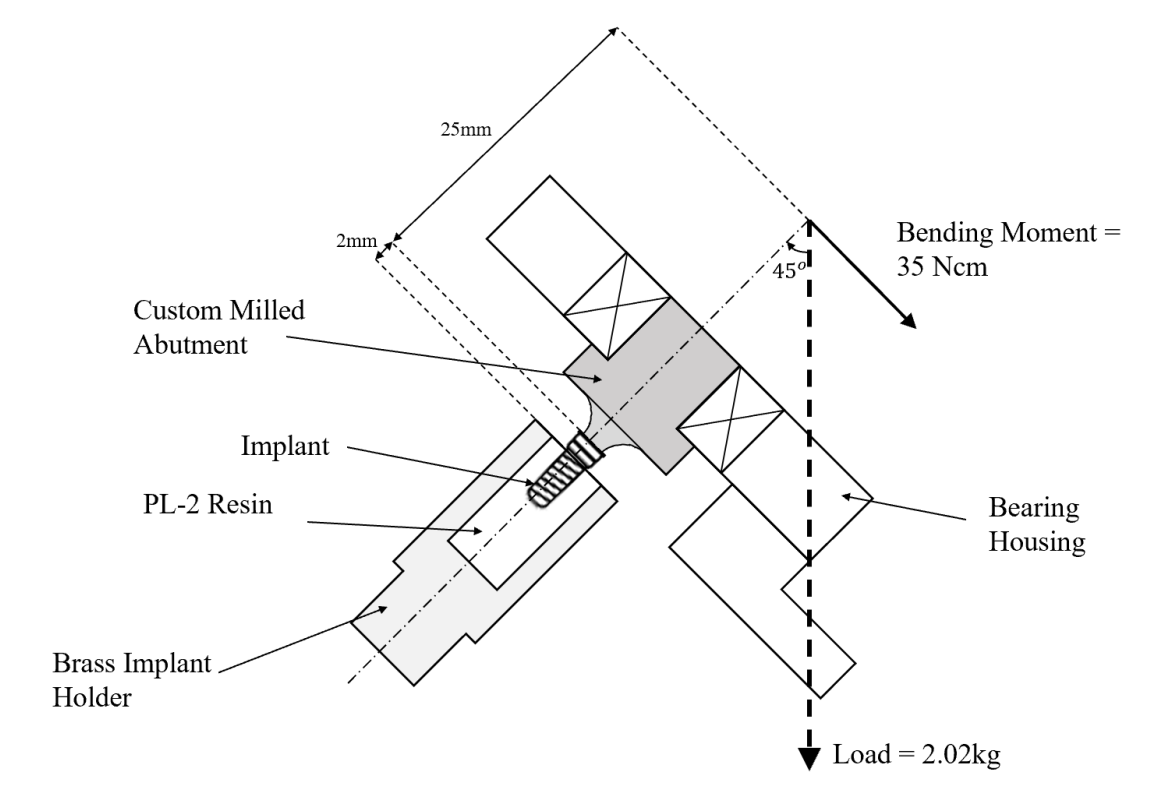


Fig 2 – Schematic drawing showing fatigue load applied, generating a bending moment of 35Ncm on the specimen

Custom-milled Ti abutments (Straumann Pre-milled Abutment Blank CARES (TAN) were milled to appropriate dimensions to ensure secure attachment onto the bearing housing. The test environment was controlled at 20°C and the machine ran at approximately 14 Hz to cut-off count of 5 X 10⁶ cycles. The order of testing specimens was randomized across the four test groups. Two-way Analysis Of Variance (ANOVA) with subsequent One-way ANOVA and Tukey (HSD) post-hoc tests at 95% significance level were conducted.

Results

RTi	Cycles to Failure	Site of Failure	RTz	Cycles to Failure	Site of Failure
RTi1	>5,000,000	NA	RTz1	>5,000,000	NA
RTi2	>5,000,000	NA	RTz2	>5,000,000	NA
RTi3	>5,000,000	NA	RTz3	>5,000,000	NA
RTi4	>5,000,000	NA	RTz4	>5,000,000	NA
RTi5	>5,000,000	NA	RTz5	>5,000,000	NA
Mean	>5,000,000		Mean	>5,000,000	

Table 1 Summary of results, RTi test group

NTi	Cycles to Failure	Site of Failure
NTi1	1,882,708	Abutment & screw fracture
NTi2	1,214,068	Abutment, screw & implant fracture
NTi3	403,530	Abutment & screw fracture, implant damage
NTi4	1,383,151	Abutment, screw & implant fracture
NTi5	774,271	Abutment fracture
Mean (SD)	1,131,547 (586,334)	

Table 3 Summary of results, NTi test group.

All RTi and RTz samples exceeded the 5 x 10⁶ cycles cut-off without failure (Tables 1,2).

For the NTi test group, all samples failed (Table 3) with 2 implant damage, 1 implant fracture, 5 abutment fractures and 4 screw fractures (Figs 3 to 7). Similar to the NTi group, all NTz samples failed (Table 4). All NTz samples consistently failed at the abutment, with no damage seen on the implants. NTz group failures were identical to the fracture mode of sample NTi5 as representatively shown in Fig 7.

Two-way ANOVA found that the combined effect of material and diameter on cycle count was not significant ($P = .197$). The effect of diameter was found to be significant ($P < .000$), while material was not ($P = .197$). Subsequent One-way ANOVA found significant differences between the groups ($P < .000$). Post hoc tests showed significant differences between NTi and RTi ($P < .000$), NTi and RTz ($P < .000$), NTz and RTz ($P < .000$), NTz and RTi ($P < .000$).

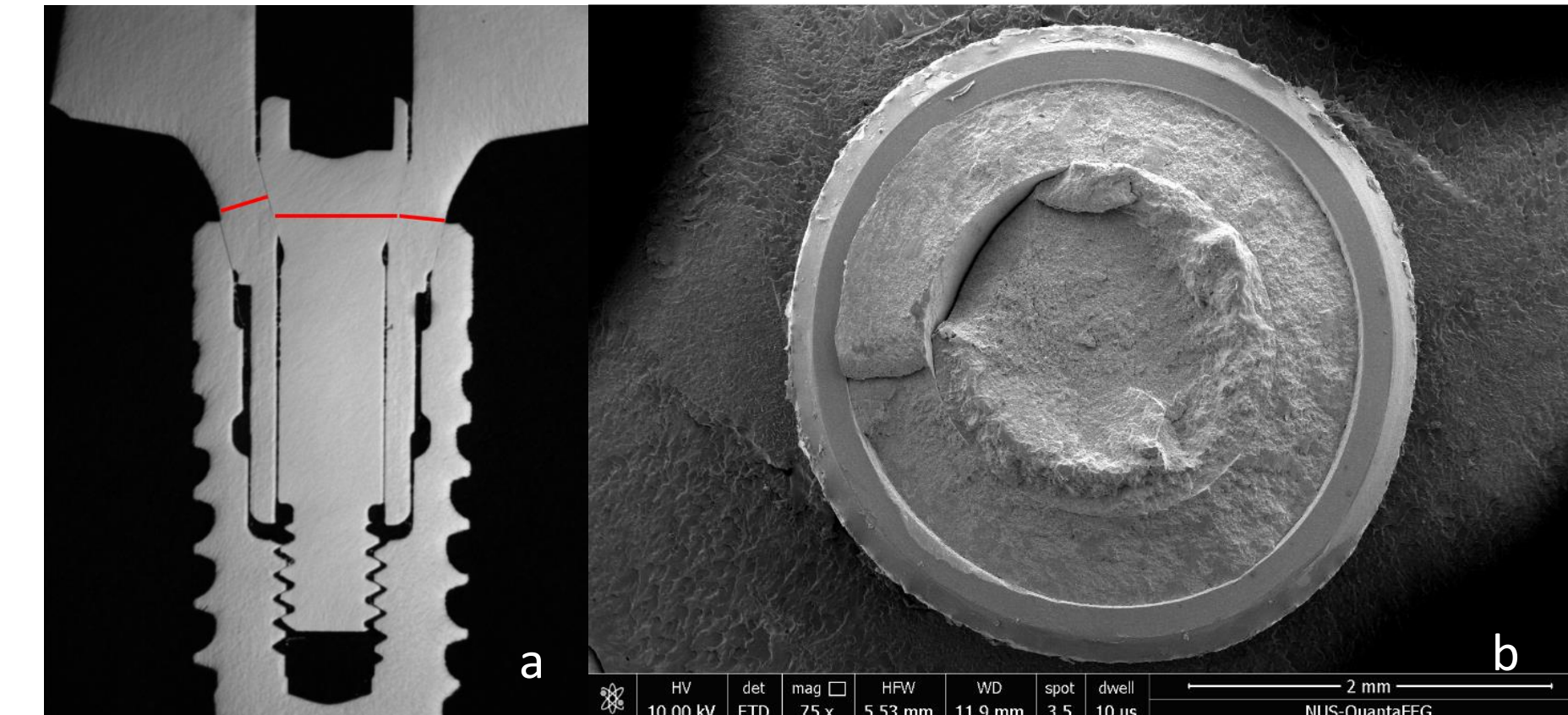


Fig 3 – Fracture mode of Specimen NTi1. (a) Vertical section of NTi1. Red lines= sites of fracture. (b) SEM of failed NTi1

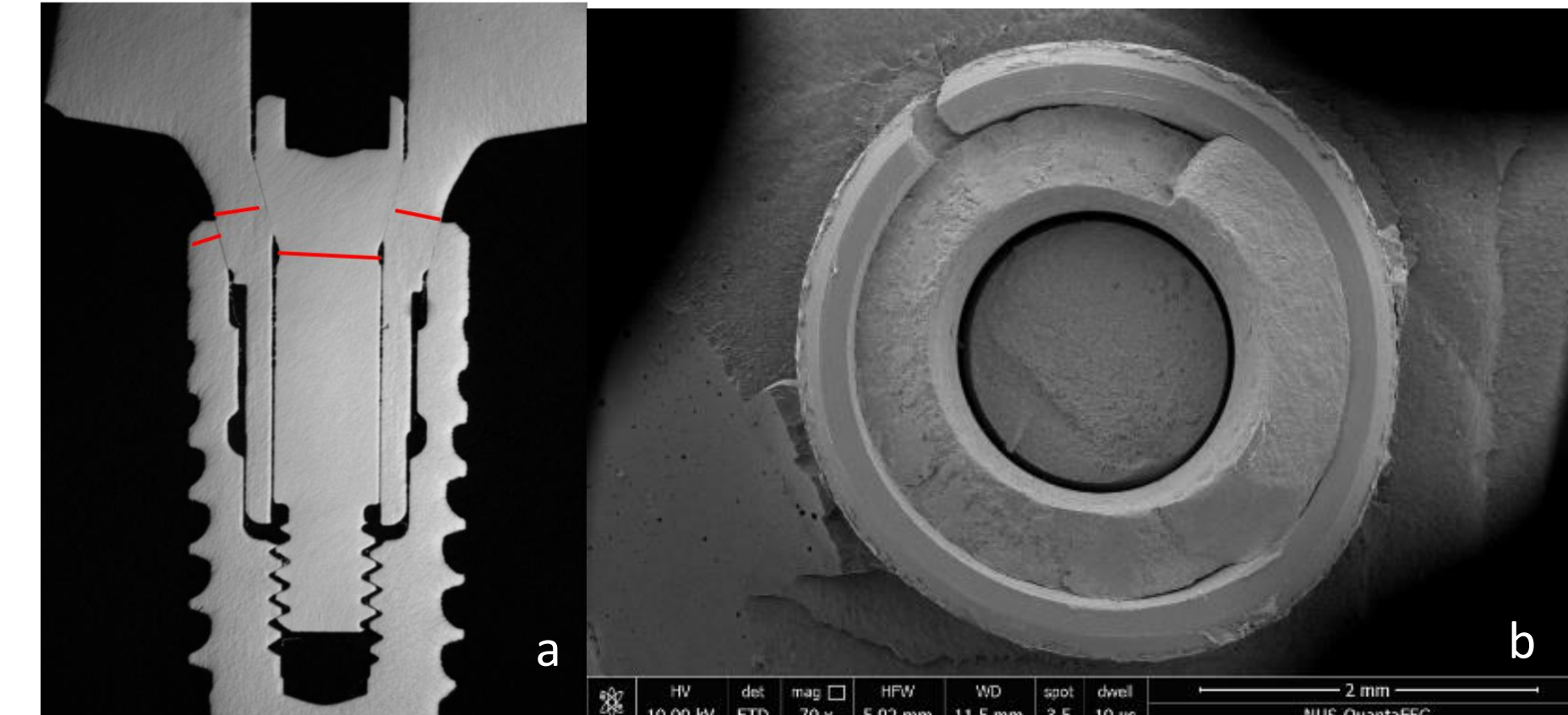


Fig 4 – Fracture mode of Specimen NTi2. (a) Vertical section of NTi2. Red lines= sites of fracture. (b) SEM of failed NTi2. Crack of implant is seen.

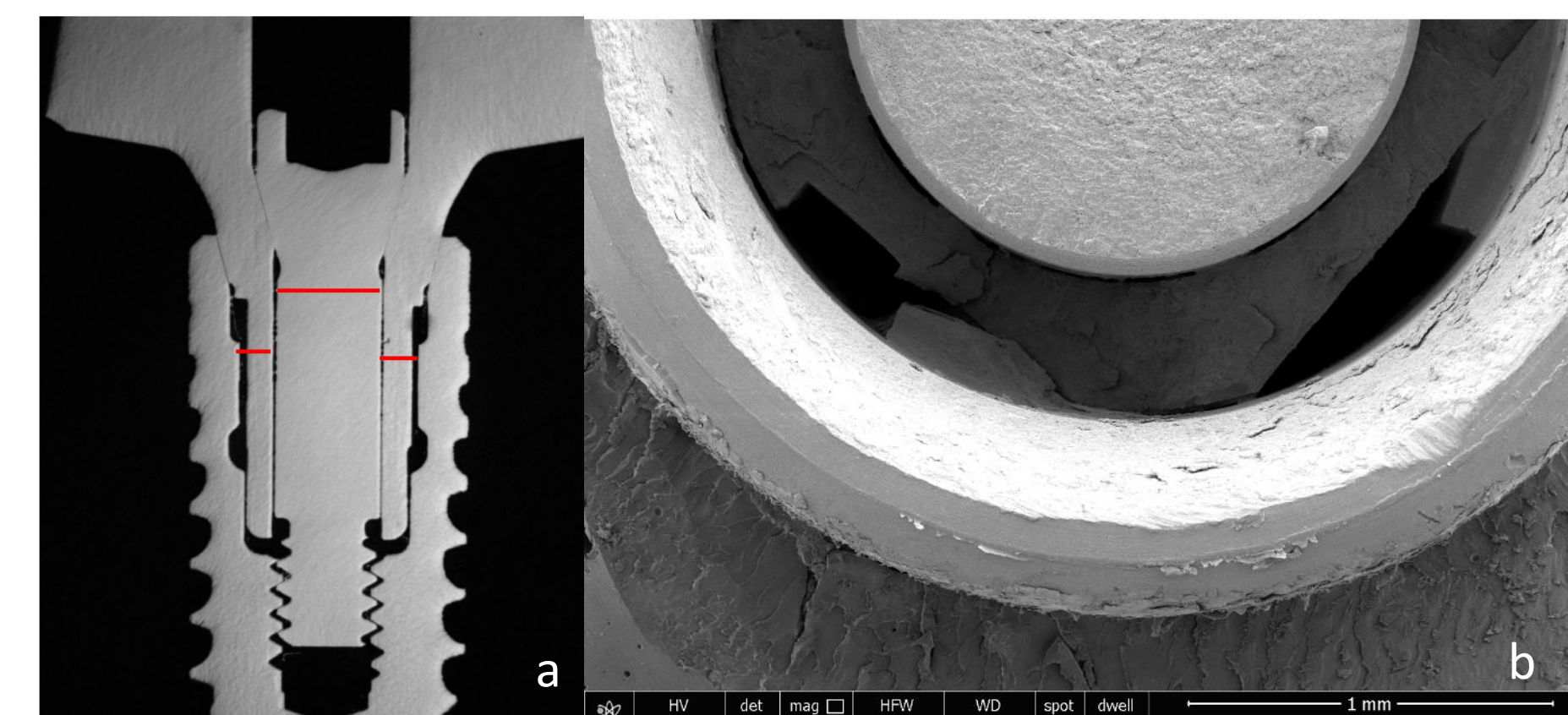


Fig 5 – Fracture mode of Specimen NTi3. (a) Vertical section of NTi. Red lines= sites of fracture. (b) SEM of failed NTi3. Damage to anti-rotational feature

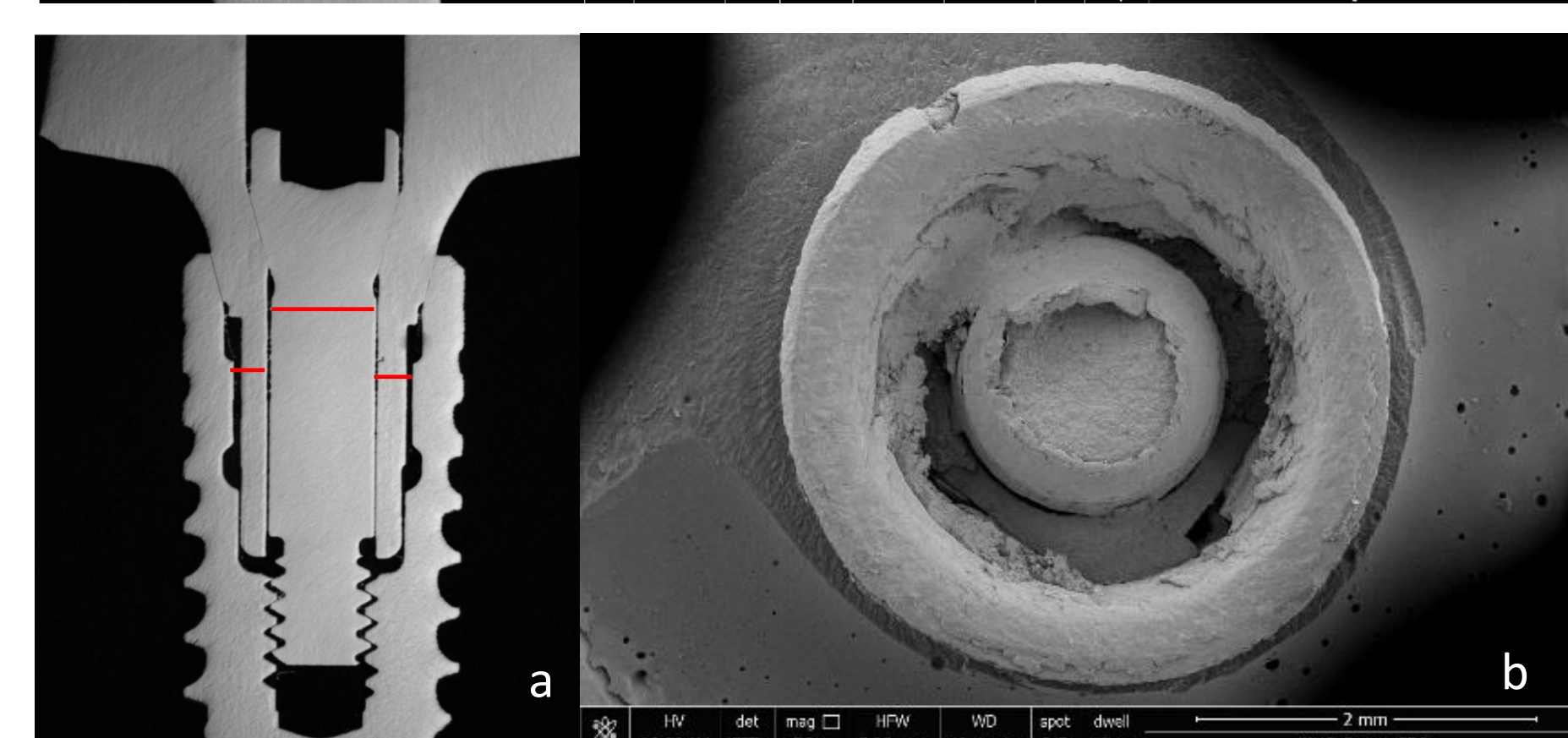


Fig 6 – Fracture mode of Specimen NTi4. (a) Vertical section of NTi4. (b) SEM of failed NTi4.

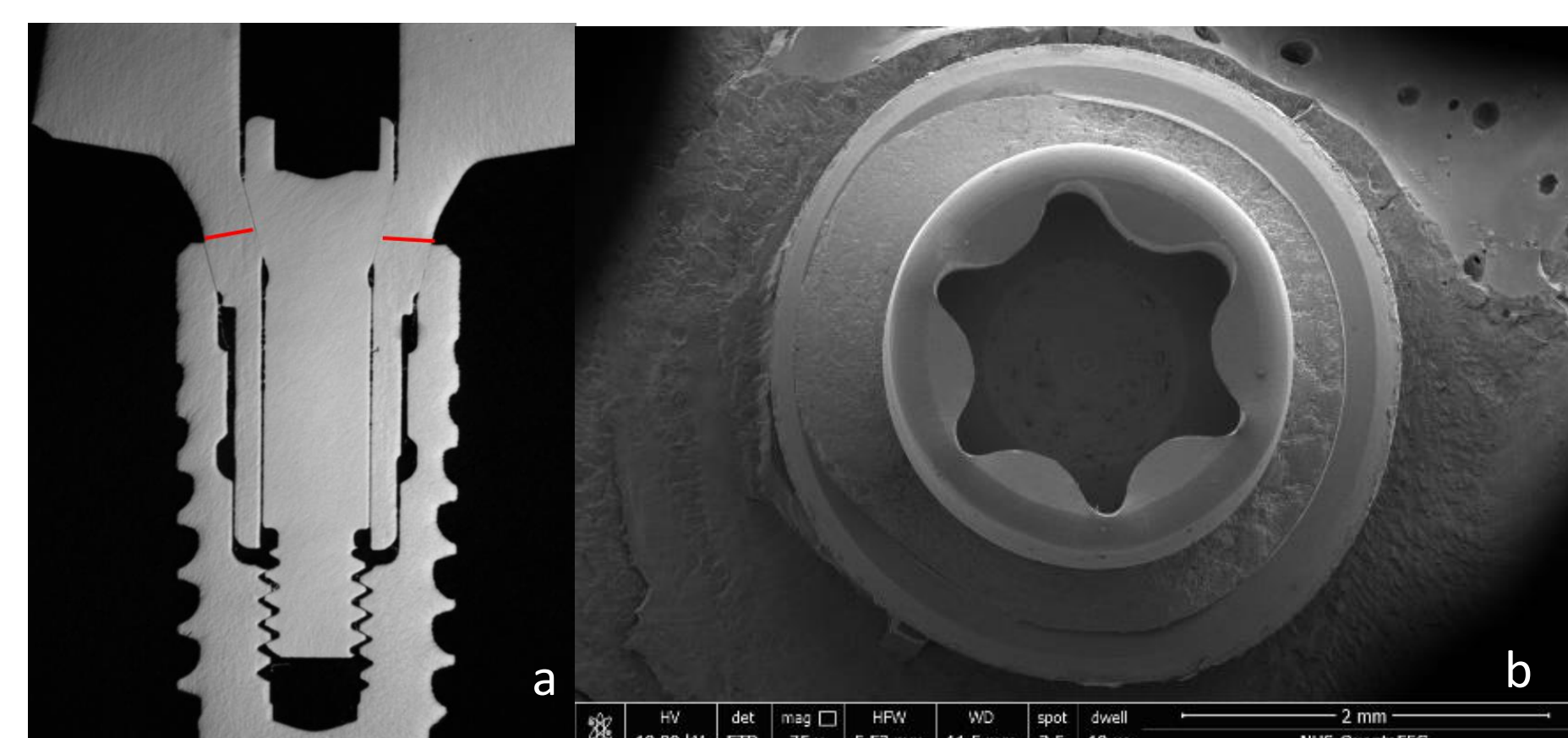


Fig 7 – Fracture mode of Specimen NTi5. (a) Vertical section of NTi5. Red line= site of fracture. (b) SEM of failed NTi5. This fracture mode is also representative of all NTz specimens.

Discussion

Implant diameter

Regular diameter implants exhibited significantly greater resistance to fatigue failure as compared to narrow diameter implants. This can be attributed to the increased thickness of the implant-abutment complex, which has a direct impact on mechanical properties.

Material

NTi group exhibited implant fractures while NTz group had none. In addition, NTz group exhibited higher mean cycle to failure count and more consistent fracture pattern always limited to the abutments as compared to NTi group. This may be the result of the superior mechanical properties of Ti-Zr as compared with CPTi.

Study Limitations

This study was conducted in a dry environment that does not simulate the oral environment. Application is also only valid for the Straumann Bone Level system and cannot be extrapolated to other implant systems even if the same material is used.

Clinical Implications

NDIs are significantly less fatigue resistant compared to regular diameter implants. Regardless of the material, NDIs are at a significantly higher risk of mechanical failure. Even though short-term clinical data showed high survival rate, their indication should still be limited to anterior teeth, where forces are relatively lower. Occlusion of prosthesis supported by NDIs should be controlled to limit the forces exerted onto the implant-abutment complex to ensure long-term survival. Abutments connected to Ti-Zr implants showed slight superiority compared to CPTi implants. They failed at a higher cycle count. Importantly, Ti-Zr specimens fractured consistently at the abutment, with no damage to the implant. This allows for relatively easier retrieval and subsequent replacement of the prosthesis without further surgical intervention. As the NTz group had a consistently less unfavorable failure pattern of abutment fracture only compared to the NTi group, it would seem that when NDIs are indicated, Ti-Zr implants can be recommended over CPTi implants.

Conclusions

- RDIs performed significantly better than NDIs, regardless of material. All narrow diameter implant-abutment samples failed, while no failure was observed in the regular diameter implant-abutment groups.
- No significant differences to the cyclic load to failure were found between groups of different alloys. However, for the NDI test groups it could be observed that NTz showed a higher mean cycle count as compared to NTi.
- Implant fracture and damage was recorded only for the NTi group (3 out of 5 specimens).
- The NTz group failed exclusively at the abutment only, without damage to the implant. This failure pattern can potentially be clinically advantageous in terms of retrieval and subsequent replacement of a failed prosthesis.