In vitro anchorage measurements and primary stability performance under dynamic loading of two implant designs

A. Irastorza-Landa[1a], M. Geisendorf[1], J. Fabech[2] and P. Heuberger[1]

[1]Nobel Biocare Services AG, 8302 Kloten, Switzerland,
[2]Zürcher Hochschule für Angewandte Wissenschaften (ZHAW), 8401 Winterthur, Switzerland

[a]ainara.irastorzalanda@nobelbiocare.com

Abstract. In immediate or early loading protocols of dental implants achieving a stable anchorage of the implant in the bone is one of the major goals of every surgeon. However, whether the implant anchorage was enough to ensure sufficient primary stability is often only shown by the outcome of the treatment when the system is functionally loaded. Here, we have evaluated the in vitro performance of two implant designs in terms of anchorage and primary stability under dynamic loading, and identified that measuring maximum implant insertion torque, implant stability quotient and periotest value at implant placement do not necessarily predict mechanical stability, i.e. the capability of a system to withstand external loads.

Introduction

Primary mechanical stability of the interface between the implant and the surrounding bone determines the outcome of dental implants' osseointegration, particularly in immediate early loading protocols. The assessment is often carried out by measuring maximum implant insertion torque (IT), implant stability quotient (ISQ) and/or periotest value (PV). However, these values are static anchorage measurements at implant insertion and do not necessarily anticipate the stability progress of the implant-abutment system, i.e. the capability to withstand external loads and maintain its original function, as no physical loading is applied. Here, the in-vitro anchorage and stability performance of two implant designs were compared by static traditional tests and using a biomechanical dynamic test model capable of measuring the micro-movement of the implant-abutment system in bone surrogate.

Material and Methods

Two different dental implants were compared: tapered body with variable-thread design implant with moderately rough anodized surface (NobelActive RP 4.3x11.5 - NA) and parallel body with double-thread design machined implant (Brånemark System Mk III RP 4.0x11.5 - BMK), both manufactured by Nobel Biocare AB, Göteborg, Sweden. All implants (n=10 per design) were inserted into bone-surrogate material to bone level (solid rigid polyurethane foam of 20pcf density, SAWBONES, Pacific Research Laboratories) prepared using clinical drills with the final diameter of: Ø2.8/3.2 mm for NA and Ø2.4/2.8 mm with a widening of marginal cortex with a counterbore for BMK.

Anchorage. The following anchorage parameters were measured: max IT (TesT Model T210), ISQ (Ostell ISQ Device, SmartPeg Type 61 and 01); and PV (Periotest M) after the abutments were placed and tightened to 35Ncm (Snappy Abutment 5.5 CC RP for NA and Snappy Abutment 5.5 Brånemark System RP for BMK).

Primary stability. Primary stability was measured using a dynamic loading test setup [1], which measures the migration and micro-motion of each implant-abutment system in the bone surrogate, adapted from the setup used to measure the micro-motion on carpometacarpal joint endoprosthesis [2]. Briefly, it is an ISO 14801 [3] based test setup (Fig. 1.a.) with two strain gauge sensor units that measure movement in Y-axis (perpendicular to the implant axis with a 30° angle to the force application direction) and in Z-axis (implant axis). Each unit consists of two strain gauge touch probes: one of them at the foam and the other at the edge of the load transmission hemisphere. The migration (Mig) over the whole test duration is calculated comparing the distance of the two touch probes after 500 cycles and at the end of the test (50,000 cycles); and micro-motion (MM) is calculated as the relative motion between the two touch probes (Fig. 1.b.). The distance from load transmission hemisphere centre to bone level, i.e. lever arm, was set to 8.3mm and the test was performed by applying a sinusoidal 14 - 140 N compressive load at 2 Hz at 20 ± 2°C.

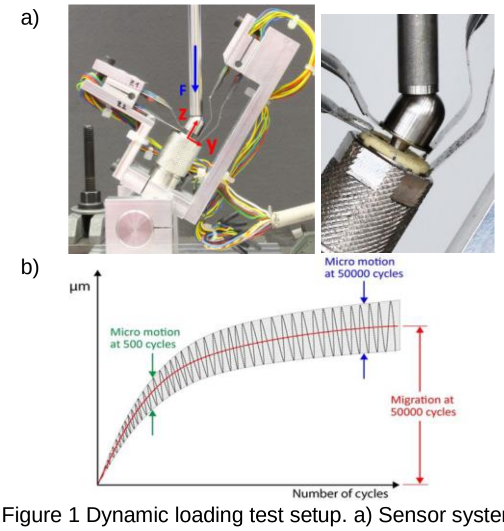

Figure 1 Dynamic loading test setup. a) Sensor system with unit positioning; b) Visualization of Migration (Mig) and micro-motion (MM)

Post-loading test measurements. After dynamic loading test, ISQ and PV values were recorded.
Statistical analysis. Minitab 17 statistical software was used for the statistical analysis. Mann–Whitney U test was used to compare differences and the level of significance was set at α=0.05.

Results

Anchorage measurements. Fig. 2. shows the mean IT, ISQ and PV of NA and BMK after implant insertion into the surrogate bone: NA had higher values of IT and ISQ and lower PV when comparing to BMK. Significant difference between both implant designs in all anchorage parameters was found (p=0.0002), suggesting better anchorage for NA. During the insertion of one BMK sample a torque-drop occurred 0.1 mm before the implant was fully inserted. This corresponded to a spinning BMK implant. Grubbs' outlier test did not detect this sample as outlier.

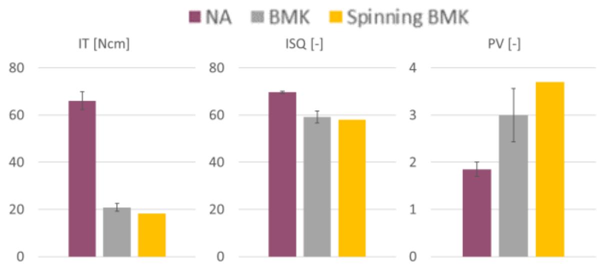

Figure 2 Anchorage measurements (IT, ISQ, PV) at implant insertion (prior to loading). Mean ± standard deviation

Primary stability measurement. Fig. 3.a&b. show the evolution of Migration in Y- and Z- directions of NA, BMK and Spinning BMK. NA had the most stable performance during the whole test, reaching final mean migrations of 42 µm in Mig Y and 17 µm in Mig Z (p=0.003 and p=0.0004 respectively compared to BMK with a mean Mig Y of 123 µm and mean Mig Z of 42 µm). Spinning BMK was the least stable, having ten times larger final mean migration values than NA. Its instability could be detected from the beginning with the steep migration slopes. Fig. 3.c&d show the evolution of MM: NA and BMK show constant MM, NA being significantly lower in Y-direction (p=0.0003) but not in Z (p=0.65). The instability of the spinning BMK led to unstable and higher MM in Z-direction.

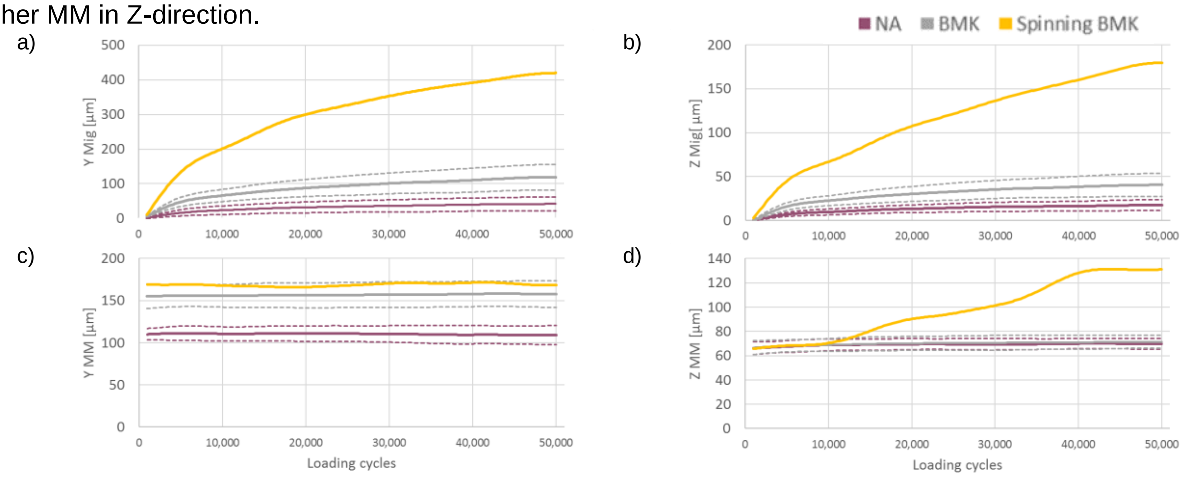

Figure 3 Stability measurements results: a) Mig Y; b) Mig Z; c) MM Y; d) MM Z. Mean (solid line) ± standard deviation (dashed lines)

Post-loading test measurements. Fig. 4. shows the mean ISQ and PV of NA and BMK after dynamic loading test: NA had statistically higher ISQ values and statistically lower PV values when comparing to BMK (both p=0.0003). Compared to initial values, NA's ISQ-dropped by 1% and PV increased by 13%, whereas BMK had higher ISQ-drop (11.4%) and PV increase (135.9%), in agreement with the higher migration values measured for BMK. BMK showed higher standard deviation than NA. The spinning BMK had 75.9% lower ISQ and 983.8% higher PV than prior to dynamic loading.

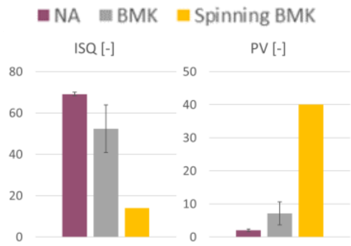

Figure 4 Post-loading test ISQ and PV measurements. Mean ± standard deviation

Conclusion

The in vitro anchorage measurements and primary stability performance under dynamic loading of two implant designs was evaluated. It was observed that the anodized variable-thread tapered implant had better anchorage and stability behaviour than the machined double-thread parallel-wall implant, which parallels the clinical study findings [4,5]. In addition, the anchorage parameters of the spinning BMK failed to predict its instability when loading. Under the described sample preparation and tested loading conditions, the measurement device had the capacity to measure the movement of the dental systems in bone surrogate in the micrometre-range reported to influence osseointegration [6].

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