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Short Communication

Ex-vivo Thermo-Dynamic Conductivity Model for Osseointegrated Titanium Fixtures.

Modelo de conductividad termodinámica *ex vivo* para accesorios de titanio osteointegrados.

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Tooth loss is associated with oral health-related and/or health-related quality of life (OHRQoL and/or HRQoL). Dental implants are replacement tooth roots that provide a strong foundation for both fixed (permanent) and removable oro-dental prostheses. A predictable treatment modality for the rehabilitation of partially and completely edentulous patients, yet, in spite of having generally high success rates (~90% to 97%),[1,2] it is estimated that at least 3% to 10% of dental implants eventually fail.[3,4] With approximately two million new dental implants placed annually and an increasing number of general practitioners venturing into implantology, implant failure will undeniably continue to rise.

Clinicians already seem to continue to dedicate more and more time and funds to deal with this problem, hence, understanding and the prevention of risk factors involved in dental implant failure is crucial for the future of implant dentistry.

Mechanical stability of dental implants is a pre-requisite for successful rehabilitative and restorative therapy. Osseointegration, often defined as "the direct structural and functional anchorage of living bone on the titanium surface of a loaded implant",[5] is without a doubt the most important factor for dental implant success. The main principles involved in successful osseointegration[6] include (a) implant primary stability and (b) atraumatic surgical technique (Figure 1). It has been suggested that success of osseointegration can be attributed or related to six main criteria: material biocompatibility, implant design, surface morphology, conditions of the implanted tissues, surgical technique, and loading conditions. Hence, excessive surgical trauma, prosthesis over-load, misfit of supra-structures, and/or infection in implanted area are considered the critical modifiable factors. Indeed, over-heating, stirring at the implant-bone interface during the implant placement step (bone-drilling/osteotomy) is constantly mentioned as a risk factor for early dental titanium implant failure. According to the literature, reaching a threshold temperature of 44°C to 47°C for one minute suffices to induce irreversible bone damage; whereas the extent of necrotic or injured area usually correlates exponentially with the magnitude of the drilling force and the temperature achieved.[6,9]

While the immediate consequences of uncontrolled "thermal injury" at the implant site are well-documented (hyperemia, osteoblast apoptosis/necrosis, blood flow disruption, fibrosis and macrophage activation, to mention a few);[9] potential effects of the later exposure to heat –once the implant is fully osseo-integrated and loaded– are still poorly understood or addressed in the literature.

As most metals, titanium and titanium-alloy implants are excellent thermal conductors.[10] Thus, they act as natural bridges linking the oral cavity with the peri-implant bone. Daily food and beverage consumption greatly alter the overall temperature of the oral cavity;[11,12] in fact, under normal drinking conditions, intra-oral temperatures may range from 0.4°C to ~77°C.[13,14]

So, what about the effects of food and beverage consumption, especially hot, on dental implants?

It has been reported that titanium and hydroxyapatite-coated dental implants may reach temperatures as high as ~60°C after just a 30- to 60- second exposure to hot water.[12] Maximum temperatures measured at the abutment level have usually showed a high correlation to those measured at the abutment/implant interface and implant center (>57°C), whereas the mid/apical implant and peri-implant bone regions reached lower temperatures yet still at "threshold temperatures" of around 44°C.[12,15] Interestingly, temperatures measured for 3.5mm-diameter implants were on average 1°C lower than those for 4.5mm-diameter implants; indicating that the heat conduction properties of large-diameter implants may be greater than those of their small-diameter counterparts.[12,15]

Similar studies evaluating the setting of exo-thermic impression plasters over metal abutments,[16] direct abutment or zirconia crown preparations of 2-piece implants reported closely comparable results with studies demonstrating higher peri-implant bone temperatures usually set residually at the marginal/ crestal bone area.[10,15,17]

Figure 1. Factors affecting the Successful Osseointegration of Dental Implants.

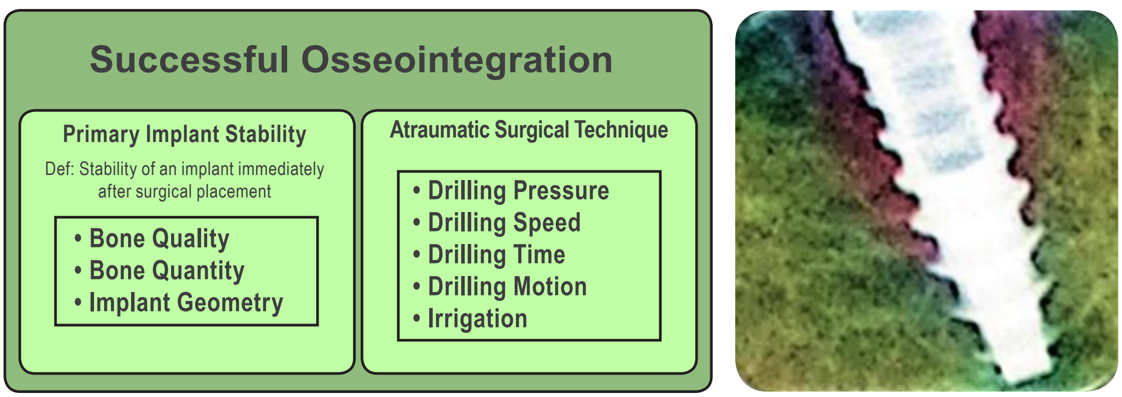


Figure 2. BioMAT'X *ex-vivo* X'PLANT 3Ss model – thermal change monitoring/recording (imaging and quantification, in real-time) performed using a CorDEX TP3R ToughPix DigiTherm Digital Thermal Camera.

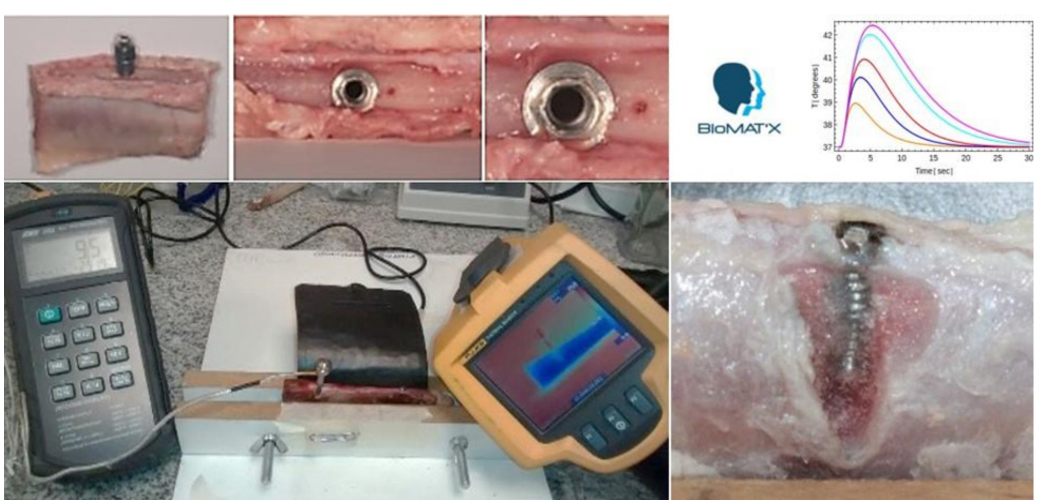
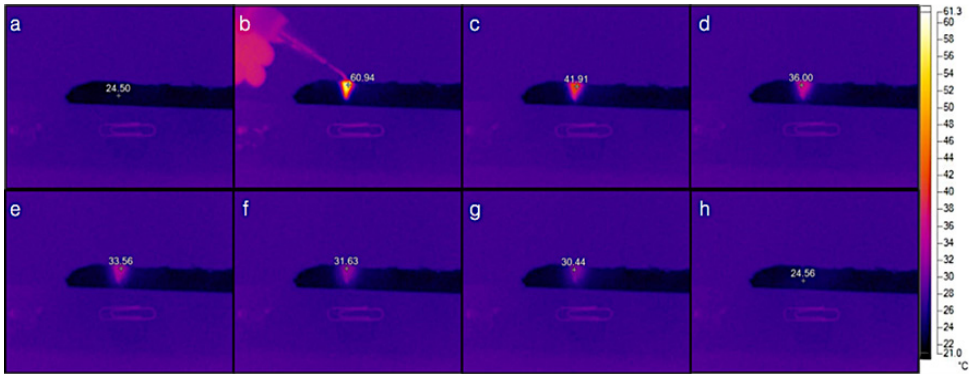


Figure 3. ***Ex-vivo*** **Thermo-Dynamics - Monitoring temperature variation recording before, during and after exposing a titanium dental implant placed into a porcine rib.**



a: Basal temperature. b: post-15 sec scaling. c-g: 10 sec cooling down - continuous. h: 100 sec cooling down (initial temperature).

Ex-vivo Thermo-Dynamic Model for Ti Implants

Heat is a kinetic process whereby energy flows from between two systems; hot-to-cold objects. In oro-dental implantology, conductive heat transfer (or thermal stress) is a complex physical phenomenon to analyze and consider in treatment planning. Hence, ample research has attempted to measure heat-production to avoid overheating during bone-cutting and -drilling for titanium (Ti) implant-site preparation and insertion, thereby preventing or minimizing both early and delayed implant-related complications and failure.

Given the low bone-thermal conductivity whereby heat generated by osteotomies is not effectively dissipated and tends to remain within the surrounding tissue (peri-implant), increasing the possibility of thermal-injury, we employed an in-house set-up using titanium dental implants placed into porcine ribs, without coolant, alongside thermal monitoring and imaging performed using a CorDEX TP3R ToughPix DigiTherm Digital Thermal Camera, designed as an ex vivo heat distribution model (Figure 2), ultrasonic scaling of dental implants for merely 15 seconds sufficed to produce temperatures as high as 60.94°C (Figure 3).

While higher temperatures concentrated at the marginal/crestal bone area; mid and apical implant and peri-implant bone areas still reached temperatures above 44°C, which is alarming. Indeed, considering that bone necrosis provides an ideal environment for bacterial invasion and infection, higher temperatures at the crestal bone area may increase the risk of peri-implantitis onset and subsequent complications up to dental implant failure.

An even more interesting discovery, was the fact that repetitive exposures gradually increased the implant and peri-implant bone temperature, and subsequently clinically damaging peri-implant, despite our deliberate establishment of in-between application of resting/cooling periods. This suggests that the imposed thermal damage may also result from repetitive, cumulative or amassed stimuli (*i.e.* consecutive scaling or hot beverage drinking, for example) and not solely from single high-temperature exposures.

As mentioned earlier, heat generation during rotary cutting is one of the important factors influencing the development of osseointegration (intra-/para-bony heat generation). Minimizing surgical trauma to bone tissue during the osteotomy is a controllable factor and may contribute to the osseointegration success. Bone trauma control, and consequently its effects on bone healing have been receiving increasing interest recently, marked by ample investigations of different drills, designs and osteotomy protocols. The relationship between thermal changes, heat generation and implant drilling osteotomy is multifactorial in nature and its complexity has not yet been fully studied.

Lack of scientific knowledge regarding this issue still exists. Further studies should be conducted to determine the various factors which generate less heat during osteotomy, such as ideal ratio of force and speed in vivo, exact time to replace a drill, ideal drill design, irrigation system, and drill-bone contact area. Post-op prognosis and stages (life-span) should not be left out either. Indeed, although our *ex-vivo* evidence cannot be directly equated with *in-vivo* behaviour of titanium-based dental implants, current evidence indicates that the innate thermal conductivity of titanium and titanium-alloys may be a risk factor for implant failure of long-term osseointegrated/functional implants due the direct conduction of heat from the oral cavity to the osseointegration, the bone-implant interface.

Repetitive, cumulative or accumulating (sudden or gradual) exposures to different heat sources, ranging from hot foods or beverages to exo-thermic dental materials and procedures, may increase implant and peri-implant bone temperatures above the threshold levels - especially at the marginal/crestal bone area – thereby increasing the risk for peri-implantitis onset and future implant failure, as mentioned earlier. Undeniably, peri-implantitis, with a reported prevalence of 12–47% of dental implants, if left untreated can promote irreversible tissue damage, that will cause bone loss and even loss of the implant, similar to what occurs with similar to periodontal disease and teeth.[18-20]

Thermal stress convoys an unaccounted risk for bone necrosis and peri-implantitis, thereby not to be ignored when evaluating the potential performance, prognosis and survival of dental implants

Based on these preliminary observations, clinicians should perhaps strongly avoid any form of single or repeated cumulative heat generation near osseo-integrated dental implants (*i.e.* ultrasonic scaling without sufficient coolant, direct implant abutment preparation, crown cementation with exo-thermic cements, electrocautery use, etc), as well as take into consideration for treatment planning that the habitual consumption of extremely hot foods and beverages may affect the overall implant treatment modality. Intra-oral temperatures, developed during the consumption of very hot substances, may be capable of damaging peri-implant tissues. Hence, our patients should be cautioned to avoid or minimize the intake of hot food and beverages at least until soft-tissue healing and wound closure is complete.

Once implants are exposed to the oral media, plastic or ceramic abutments should be used in the provisional stages of rehabilitation to provide temporal insulation from the environment until the definitive ceramic crown is delivered. Nonetheless, more effort and evidence are still needed in order to arithmetically (mathematically) quantify/equate and analytically confirm these recommendations and to obtain an exact analytical solution of/to the heat equation under exponential thermal-stress (*i.e.* modeling transient heat transfer and temperature changes in Ti implants —length *versus* width— upon hot-liquid intake/heat expsoure); a current topic of vigorous enquiry and investigation at our BioMAT'X R&D&I Chile.

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