Innovative Biomaterials Research under the Northern Lights

In most developed countries today, dentists focus not so much anymore on restoring individual teeth following tooth decay, but rather attempt to improve patients' dentition and smile esthetics. The impact on dental health services of a generation of elders who today are dentate instead of wearing dentures is formidable. Many elders nowadays choose to re-establish to its youthful state a dentition that has been repeatedly restored and worn down over a lifetime. They are joined by an increasing number of adults who, for a variety of reasons, decide to proceed with a total or local makeover of some body part, including their teeth.

To meet the needs and demands of these emerging patients dentists require the use of innovative and novel dental biomaterials to replace oral hard and soft tissues. Moreover, such materials need in many cases to be combined, e.g., in multiple layers, and intermixing materials with different physical and mechanical properties poses challenges. Current novel materials in use in dentistry fall within the categories of composite resins, glasses and ceramics placed in or on teeth or on tooth analogues, termed dental implants. The dental implants are placed in the jaw bones, and they are made from a metal, a metal alloy or a ceramic and even combinations exists as well as multiple ingenious surface treatments. Connecting the dental implant surgically placed in the jaw bone with the intra-oral restoration is accomplished by using a trans-mucosal element termed "implant abutment". While abutments were mostly prefabricated in the past, today's trend is to use individualized, also known as customized, implant abutments manufactured in the dental technician laboratory.

Within each of the biomaterials groups described above there is an abundance of commercial products, indicating that none so far has been identified as superior. Over the last decade there has been a sudden increase of new products within all the groups. E.g., the number of implant manufacturers has grown from approximately 90 to close to 300 today, manufacturing some 2000 different implant brands. Likewise, within ceramics, dentists can now choose amongst a wide range of traditional feldspathic ceramics with or without aluminium-oxide crystals, feldspathic glasses, ceramics

containing leucite crystals, tetra-silico-mica glasses, lithium-disilicate glasses, pre-sintered aluminium-oxide glass-infiltrate, high pressure sintered aluminium-oxide and zirconium-oxide, alternatively named zirconia, combinations. Just within the group of zirconium oxide, which is now used widely in dentistry and orthopedic medicine, minor chemical differences between products are reflected by great variations with regard to hardness, fracture resistance, grain size, tension strength, elasticity module, opacity and sintering (powder fusion) time. The net effects on long-term clinical performance are hitherto largely unknown. Examples of current combinations of zirconium-oxides are TZP (tetragonal zirconia polycrystals) consisting of ZrO_2 / Y_2O_3 (95/5%), TZP-A (ZrO_2 / Y_2O_3 / Al_2O_3, ~95 / ~5 / 0.25%), FSZ (ZrO_2 / Y_2O_3, 90 / 10%), PSZ (ZrO_2 / MgO, 96.5 / 3.5%) and ATZ (ZrO_2 / Al_2O_3 / Y_2O_3, 76 / 20 / 4%). Even the temperatures used for sintering different types of zirconium oxides used in dentistry and orthopedic medicine vary between ~1350°C to -1530°C. Finally, some of the above named ceramics have inferior optical properties, which mean that they need to be veneered with a layer of a second type of ceramic, which introduces challenges manufacturing wise, but also uncertainty with regard to unknown potential future thermal or chemical incompatibility problems. The net message for all is that there appear to be exciting avenues for developing and testing innovative biomaterials that may meet the requirements for clinical performance of an emerging large group of patients. The biomaterials research environment at the Department of Clinical Dentistry in Tromsø is eager and capable of contributing in such endeavors. We anticipate also that our biomaterials research attract our faculty colleagues within the Department of Clinical Medicine that focus on orthopedic medicine investigations.

Moreover, new additive and subtractive fabrication processes are being implemented to produce 3-dimensional customized objects, being implants, abutments or restorations. One example is the machining of zirconium oxides to fabricate customized abutments or restorations, which is done in multiple ways. *E.g*. one method is by machining the porous or green state prefabricated blanks, a second method encompass using the pre-sintered state blanks, while a third approach is to use sintered or sintered and HIP-ed blanks. In some environments the machining is done in the dental office using a milling unit running at 8K rpm, while in many so-called dental milling across Europe high-output,

high-volume 5-axis milling machines operating at 45K rpm with excessive cooling churn out restorations at very high rates. Little is known how the actual ceramic surface or immediate subsurface is altered with these manufacturing processing parameters. Confounding the complexity is the need to veneer the ceramic with more translucent ceramics, introducing issues of compatibility between different types of ceramics. All the developments described above occur in spite of lack of persuasive published medium- or long-term clinical data. No regulatory bodies check, for example the ceramic veneering compatibility, the optimal core-veneer layering thicknesses, or the properties of the ceramic blanks *vs*. intended usage in dentistry or orthopedic surgery.

Unwanted clinical performance of materials and restorations in dentistry are, e.g., bulk or margin discoloration, surface wear, margin leakage or structural degradation. A problem is to identify the optimal combination of the material physical and mechanical properties as well as how the handling, casting process or machining influenced these properties.

Consequently, a critical activity in the developments of novel materials and fabrication procedures is to develop in-vitro tests that predict clinical performance, thus avoiding expensive and time consuming clinical testing. The development of such tests is undertaken in experts working within the framework of TC106 of the International Organization for Standardization (ISO). The Department of Clinical Dentistry in Tromsø, Norway can boast with faculty that represents and have represented for many years the ISOTC106 delegations from respectively Norway, Sweden and Canada (Professors Arne Hensten, Ulf Örtengren and Asbjørn Jokstad). Hence, the accumulated experience that is available here is quite unique.

With our recently purchased mechanical testing equipment for biomaterials research (UTM DO 711903, Zwick GmbH & co., Germany) we will be able to conduct measurements of materials or products subjected to static stresses (compressive (crushing) strength, tensile strength, transverse strength, flexure/bending/modulus of rupture, modulus of elasticity (Young's Modulus), shear modulus). Alternative tests are dynamic (compressive modulus, tensile modulus, bending modulus, resilience, fatigue, fracture toughness). Of relevance are also tests for flow (creep) tests, dimensional change upon polymerization (setting contraction/expansion), Vickers hardness tests,

thermal expansion coefficient, water solubility or water sorption, abrasion resistance (wear), adhesion, color stability or surface roughness tests.

We have recently negotiated with the Department of Physics and Technology, Faculty of Science and Technology and entered an agreement whereby they host a new industrial 5-axis milling machine maintained by their engineers that is owned by the Department of clinical dentistry. Our ultimate objective is to study how the processing of prefabricated blanks made from various new biomaterials can be influenced by the rotating tools and other machining parameters. The milling machine will be able to machine base, gold, non-precious and titanium alloys, commercially pure titanium, composite resins, cast resins, wax, polymethyl-metacrylate (PMMA), porous or sintered aluminium oxides, feldspathic ceramics, lithium-disilicate ceramics and zirconium oxides in the porous or green state, pre-sintered state, and sintered as well as sintered and HIP-ed state.

Ceramics cannot be placed directly on teeth, but needs to be “glued” onto tooth structures using quite advanced organic chemistry products. Tooth substance is first etched to create microretention before being primed with a low-viscous water-soluble resin. The surface of the ceramic can be sandblasted, etched using hydrofluoric acid and silanized to create an active surface. Finally an intermediate adhesive, which is most commonly some form of polymer resin based material, bond the ceramic to the tooth surface. As for the other dental biomaterial groups, there is a wide range of commercial products available, highlighting the lack of any superior product.

For partnering enterprises that desire to venture into the advancement of new dental biomaterials applicable to current trends in dentistry and orthopedic medicine the present research conditions at the Department of Clinical Dentistry, Faculty of Health Sciences at the University of Tromsø appear to us to be very favorable. The biomaterials research environment here is eager and capable of contributing in such endeavors.

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