

LECTURE II

1

Studies and developments

Welcome back. In this second session I intend to review what is being done and what remains to be done to realise the potential of titanium's biocompatibility for dental prosthetics.

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Let us review our list of desirable improvements. They can be divided into two: alloy improvement and improved milling techniques.

By designing an alloy with greater strength, we could design bridges with larger spans and use thinner copings.

With lower elastic modulus, nearer that of gold alloys, retention would be less of a challenge for cements and there would be less stress concentration in the bond between the porcelain veneer and the titanium framework.

If the alloy remains stable at the temperatures of porcelain firing, today's titanium porcelains would suffice

Milling techniques and strategies need quite drastic modification from those employed for stronger metals and ceramics. The principles are known, but they need to be broadcast to a wider audience. The keywords in this context are support, coolant and tooling.

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Let us examine the alloy design parameters. If we consider grade 2 CP titanium as today's norm, we are looking at an increase in yield strength of 150-250 MPa.

Similarly for elastic modulus we ideally would achieve an reduction in modulus of 30 GPa.

If we are to use the same porcelains, the α -to- β phase transition temperature should not be lowered significantly.

As we shall see, these two criteria are generally in conflict and a compromise must generally be sought.

Finally we either develop an alloy that is sufficiently hard at 700°C so that it can be milled

or we must use milling techniques that avoid creating such high temperatures.

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Orthopaedic prostheses have been made from titanium for several decades and a number of alloy alternatives have been trialled. The major concern has been wear – something that isn't an issue for dentistry, as long as there is no loosening of the bridgework. However like dental implants, orthopaedic implants are not custom-made in the sense that dental bridge-and-crown or partial prostheses are. This means that parts can be fabricated to create optimal alloy properties and not be subject to firing that might degrade them.

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There are 7 titanium alloys with international standards approved for surgical implants. In addition to the four grades of unalloyed titanium, there are three alloys much stronger alloys. Note however that these all contain aluminium. In some circles aluminium in the mouth is considered detrimental – I am not a clinician, but I am not convinced by the evidence either way.

Nonetheless there has been more than ten years of research into possible alloys without aluminium that will satisfy our design criteria.

How does this work? Let us look at β -alloys first

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From observations of trial alloys, we know that the E-modulus is lowest for alloys that are fully β -phase. Alloys that are a mixture are above this value. Our own trial alloy was less successful in that it measured at 102 GPa.

So it seems that an alloy that is fully or at least dominantly β -phase is to be preferred.

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Our next aim is to increase strength. This is achieved by alloying. Again, we have enough research data to know how much strength a given alloying element can add for each percentage point we add. At the same time we know that some elements promote the β -phase. While the detailed percentages need not be memorised, please do notice that between 10 and 25 percent is needed. This is substantial, because these alloying elements are not as readily available as titanium is. They are quite expensive.

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Here are some of the candidates that have received attention. Note just how heavily alloyed they have to be to be fully β -phase, especially TNTZ with only 52% titanium. This shouldn't be too surprising. Stainless steel, for example has less than 70% iron.

But will it really be necessary to alloy so heavily, can we make do with a good balance between α and β . One of the most promising alloys is a Japanese design, based on zirconium, niobium and tantalum. It has been undergoing pre-clinical tests for 10 years and is showing very useful properties. No clinical trials have been reported. NIOM's experimental alloy *Tiqq* has passed the basic preclinical requirements and been the subject of a two quadrant double blind trial of single crowns, with results no problems being reported in a study group of twenty patients. We make no commercial claims. our purpose was to be better acquainted with the alloys, but when they passed all the pre-clinical tests, Einar Berg in Bergen took up the challenge. Note however that this was

alloy was cast and prostheses produced by traditional lost-wax techniques.

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The 15Zr-4Nb-4Ta alloy that the Japanese are developing attains its best properties after hot rolling and annealing. Milling is therefore the obvious alternative for preparing a framework. This observation applies to all the advanced alloys; their peak properties would be lost if they were melted and recast.

For none of the candidate alloys have milling properties been a factor in their optimisation. They are somewhat harder than pure titanium, and our experience with *Ti66* is that a 25 % increase in hardness leads to perceptibly easier milling. The anecdotal evidence is that our very experienced instrument-maker complained less about turning test specimens.

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Still we must adapt milling techniques. Primarily, everything must be done more slowly, but also special tooling and new coolants are needed. And for the most intricate tasks, electric discharge erosion.

10 Tools

The use of carbon-boronitride has been tried with success, but the essential strategy is to use a rapidly rotating, bur-like tool to grind not cut and to remove small amounts on each pass.

11 Lubricants

For titanium where cooling is the primary need, chilled water with a dilute mixture of esters to whet the workpiece. The source of esters poses a dilemma. If we use mineral oil esters, which are saturated, we have to dispose of an environmental pollutant. If we source the ester from unsaturated vegetable or animal fats, they breakdown and turn rancid not an environmental pollutant, but it leaves its aroma throughout the dental laboratory.

12 Strategy

The workpiece needs to be supported throughout the milling operation. Start with a much larger blank. Retain supporting braces until the last stage of milling.

Use of CAD/CAM is virtually obligatory. The inner surface of pontics and copings should be shaped first and full compensation for the low elastic modulus needs to be available when shaping thin walls and especially margins. Indeed one should consider using spark erosion to remove the final braces.

13 EDM can be a useful tool to cut the finished work from its block.

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let us then compare milling with casting

15

and now milled titanium with zirconia

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NIOM is a neutral part in evaluating dental materials. We do draw conclusions when they are warranted. Titanium can be improved. Milling titanium has the potential to realise the improvements. If those improvements mean using new alloys, studies to ensure the right surface preparation and porcelains will be needed.

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My debt is to colleagues at NIOM whose combined practical experience with titanium is enormous. From colleagues within the International Standards Organisation's technical committee on dentistry I have learned a vast amount. And finally to my mentor, Professor emeritus Ian Polmear, who has contributed to my transformation from a physicist to a metallurgist in many ways.