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An evidence-based guide to occlusion and articulation. *Part 5: New roots: titanium and its influence on occlusion; and to cusp or not to cusp?*

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SUMMARY AND PREAMBLE TO THE SERIES

Although this is essentially a review, it has not been written in the passive, third-person style normally associated with scientific writing, as it is intended to be thought-provoking and, hopefully, educational. It has therefore been written in more of a conversational style, and is aimed at students, dentists and dental technicians who are receptive to a slightly different view of occlusion and articulation, based on evidence.

Occlusion is a topic that has become a kind of archaic minefield of conflicting ideas, propositions, and above all, solutions, most of which are based on a complete lack of understanding of the evolution and development of teeth, and by extension, of clinically objective evidence.

That in itself is a statement of conflict (and perhaps even heretical), but it is by way of warning that this guide is not going to be much like anything you will find in standard text-books of dentistry or dental technology. It is, rather, an attempt to help you navigate through what you will read elsewhere, in the hope that eventually you will find an understanding that you can live with. It will appear as a sequential series in 7 Parts.

New roots: titanium and its influence on occlusion

Arguably the greatest advance in Prosthodontics was brought about by the successful integration of titanium implants into bone by Brånemark and co-workers.[1] Since then, and its use in dental treatment from the 1980s, thousands of implants have been placed, and thousands of papers published. At some stage, and possibly still in the minds of some clinicians, titanium was thought to be superior to teeth, but of late some sense has prevailed and several papers have now questioned what has been referred to as "implantomania" [2] and are suggesting that preserving teeth for as long as possible may be a better strategy. [3-5] A 2007 consensus report [6] stated that "teeth should be given priority whenever possible", and "oral implants represent the last resort, they are not replacing teeth; they should replace missing teeth".

But this is not intended to be a treatise on implant dentistry, but rather its relationship to occlusion. Whilst implant dentistry seems to be more common now in the partially edentulous jaw, implants were originally prescribed for the completely edentulous, and this falls into the "re-organised" approach as do complete dentures themselves. The options are a fixed prosthesis supported entirely by implants, or a removable overdenture prosthesis mostly supported by implants. The problem is not necessarily the implants themselves, but what we are putting on top of them, and if we do that as if the implants are teeth, we may have a problem.

Let's go back to the chewing cycle or rather the chewing envelope, under the influence of the central pattern generator, with its closing, contact and opening phases (see Parts 2 and 3). As the jaw closes, it is receiving afferent impulses from the muscles and joints, producing a rapid acceleration to tooth contact, which then initiates impulses from the tooth and periodontal ligament. This contact phase will provide feedback until the teeth have moved over each other (with a bolus of food in between) and as the jaw then moves from the chewing side to the non chewing side, this feedback reduces quickly, as do the afferents from the closing muscles and now the opening muscles are activated to move into the (slower) opening phase.

The feedback from the teeth and periodontal ligaments is rapid, which of course is a preventive mechanism should you encounter something too hard too quickly; if it's not fast enough, and the jaw doesn't open quickly enough, then damage to the tooth is likely. Chipped teeth, cracked teeth and even split teeth all can be the result.

If you are not sufficiently aware of all this, and have been brought up with a mechanistic view of how teeth come together, it is likely that you may not have subscribed to all the principles we have derived for conventional fixed prostheses (see Part 4), and your occlusal scheme may well be 'canine protected', based on the need to protect the other teeth in the arch. Even if it is a form of group function (as it should be) you would still be desperately trying to avoid balancing side contacts. And then if you

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want to get the best aesthetic result, you are likely to have used ceramics. My contention is that you are then most likely to see much chipping and cracking and breaking if this is the scheme you use on an implant supported prosthesis. Sadly, some recent reviews bear this out. A review of prosthetic complications from implant prostheses over a 16 year period[7] concluded "porcelain veneer fracture/ chipping was the most common complication identified in the studies of implant fixed partial dentures". In the same year (2018) a systematic review and meta-analysis of full-arch implant-supported fixed prostheses [8] came to a similar conclusion, which the authors described as clinically unacceptable: "chipping of the veneering ceramic was frequent, resulting in estimated 5-year complication rates of 22.8% for partial fixed prostheses and 34.8% for full-arch prostheses". In the following year two other studies, one of a 5-year follow up of ceramo-metal restorations [9] and one of a 1-12 year follow of ceramic and metal-resin restorations [10] came to similar conclusions: "the most frequent major complication was fracture of porcelain" and "the most frequent major complication was fracture of the prosthetic material".

Feedback from implants is very poor, because it depends only on osseoperception, which takes some time to develop after acceptance of the foreign body that is the implant, and the appearance of neural endings near the implant-bone interface, [11] so greater force will be required before the afferents to the opening muscles are triggered, thus somewhat overriding the central pattern generator rhythmicity. If this is correct, and if the occlusal scheme used does not take this into account, this would entirely explain the reporting of the most frequent complications of implant supported prostheses, namely chipping and fracture of the prosthetic material.

This has in fact been recognised, in a paper published in 2005, in one of the most prestigious implant journals, but which seems to have been largely ignored. The concern was that higher occlusal forces would lead to "implant overload" and peri-implant bone loss, as well as failure of the implants and prosthesis. [12] The authors did admit that "currently, there is no evidence-based, implant-specific concept of occlusion" but nevertheless made a series of recommendations for different clinical situations from single implants to full arch prostheses. But once again, if you have been following the arguments so far, it should be fairly obvious that if you think of an occlusal scheme that distributes the forces of mastication (and of parafunction, which may just be more important), as widely as possible, just as happens in a natural dentition that wears naturally, then you will protect the materials being used, be they ceramics or acrylics or anything in between (such as composites) and you will automatically protect the implants, if you think that is also necessary. But frankly, it is not the implants that need protecting, but the materials.

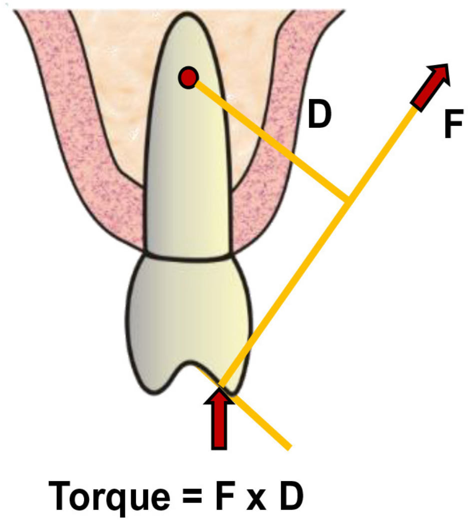
Which brings us to my next contention, which is why you do not need the beautiful occlusal surfaces that expert ceramicists create, and that exist in libraries of digital designs.

To cusp or not to cusp?

Whatever occlusal scheme you end up adopting, here is some of the evidence for keeping cusp angles low and grooves non-existent.

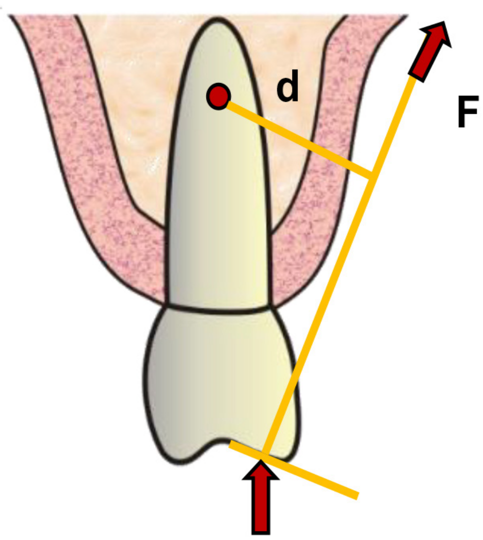
One of the first papers to be concerned with occlusal design (mainly because of its effects on implants) was a review from 1993. [13] The author expanded on this in a later paper [14] and pointed out that cuspal inclines influence the torque exerted on a tooth because an axially directed force against an incline produces a resultant force vector at right angles to the incline (Fig. 1). As the point of rotation of the tooth is approximately one third from the apex, the distance from the force vector to that point will determine the torqueing effect of the force because torque = the force multiplied by that distance.

Fig. 1. A force vector F is produced as a response to an axial force against a cusp incline, at a distance D from the point of rotation of the tooth (redrawn after Weinberg 2001 [14]).



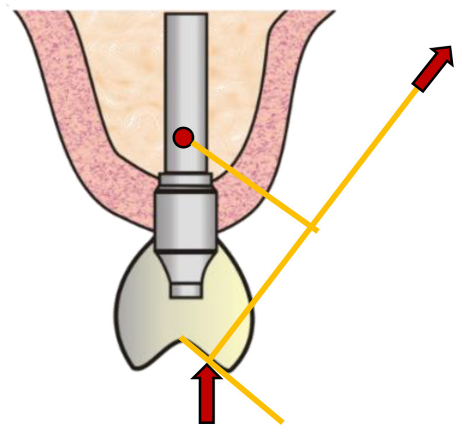
If the cusp incline is now reduced (Fig. 2), the force remains the same, but the distance from the force vector line to the pint of rotation is reduced, thus reducing the torque: a 10 x reduction in cusp incline can result in a 30% reduction in torque.

Fig. 2. A reduced cusp angle brings the force vector F closer to the point of rotation of the tooth, thus reducing the torque (after Weinberg 2001 [14]).



The same principle applies to an implant-supported crown, only this time the point of rotation is considered to be at approximately the third thread (Fig. 3).

Fig. 3. The same principle applies to an implant but the point of rotation is considered to be at approximately the third thread; it is possible this may affect marginal bone loss over time (redrawn after Weinberg 2001 [14]).



There have been a number of other papers since then that have looked at the effect of not only cusp angles but also enamel groove configuration on such aspects as the resistance of crowns to fracture and even the effect on the cervical area in terms of observed crown fractures and tooth abfraction. A seminal paper in 2011 used an analytic model to determine the influence of occlusal geometry on ceramic crown fracture by examining the role of cuspal inclines and fissure radius. [15] They regarded a fissure as effectively a notch in terms of its geometry as a notch concentrates stress around the notch tip, or in this case, the depth of the fissure. They used data from fracture load tests of a ceramic veneered premolar and the fractographic analysis of the fractured fragments (fractography is used to determine the origin and propagation of cracks, from the patterns generated). The load was applied vertically using a 4 mm diameter cylindrical bar, and found that the fracture was initiated from the occlusal fissure. Using fracture mechanics models, they were able to establish correlations with cusp angles, fissure radius and angle and the combined effects of these. Correlations were found between the fracture load and cusp angle as well as the fissure radius and angle. Fig. 4 for example shows the correlation between cusp angle and fracture load.

From this model they recommended that cusp angles should be no greater than 25° and grooves and fissures should be wide and shallow, as the fracture resistance will be affected by the combined effect of cusp angle and fissure radius which may predict the fracture resistance of all-ceramic crowns.

Similar findings were found in a finite element analysis (FEA) study using tooth enamel data [16] and again combining the effect of cusp angles and different geometries of the occlusal fissure. In this case, it again confirmed the susceptibility of natural teeth which retain their cusps, and that as teeth wear, they become more resistant to fracture, as the cusp angles lessen and the fissures widen and eventually disappear.

There is an argument that when replacing only one or two crowns in an unworn dentition that the occlusal morphology of that dentition should be retained, but that argument is based more on a perceived aesthetic need to make everything look the same; but from a functional point of view it is really not desirable, and hardly ever necessary. However, if it is considered necessary to have cusp angels of greater than 20 or 25°, then you should be using a material that will hopefully be strong enough or thick enough to resist fracture. In fact this has been tested, again using an FEA model and a simple

Fig. 4. Relationship between cusp angle and fracture load (redrawn and simplified from Sornuswan and Swain 2011 [15])

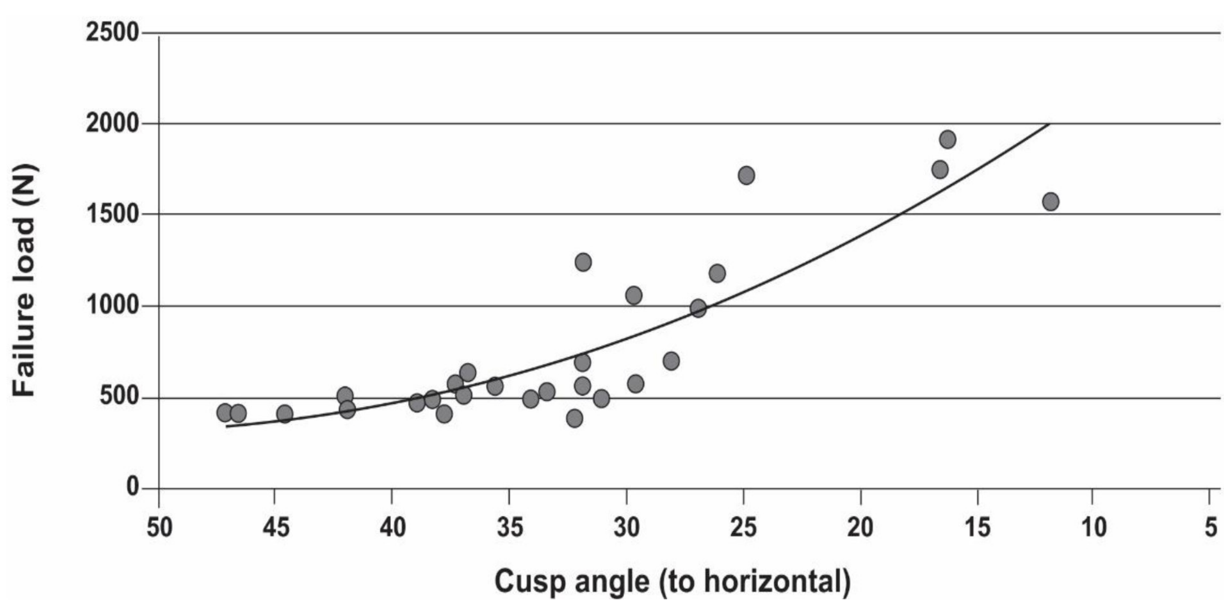
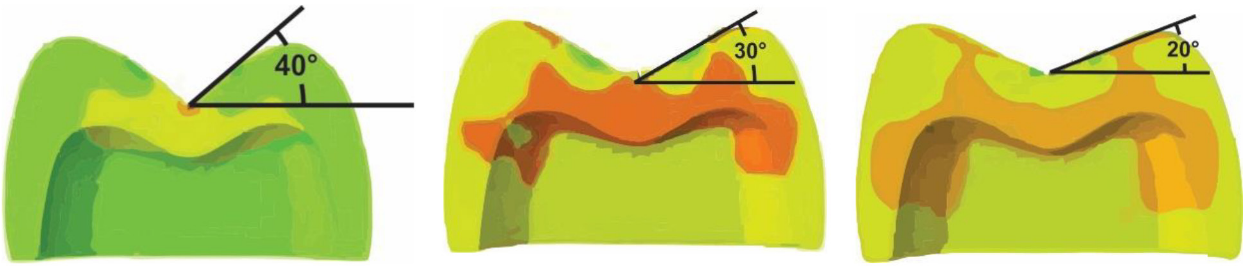


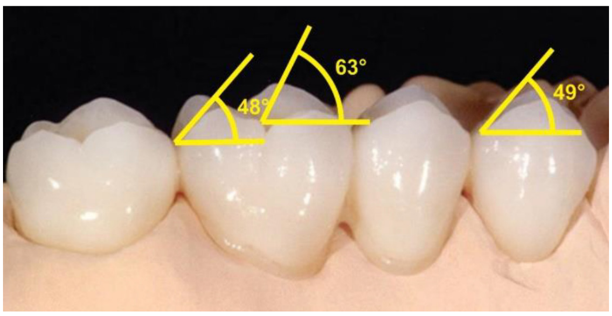
Fig. 5. Decreasing cusp angles took the stress away from the central fissure and distributed it more widely (redrawn from Shahmoradi *et al* 2020 [17]).



occlusal morphology of either a V-shape or U-shaped fissure, and varying the occlusal thickness and ceramic material. [17] The model also allowed for calculation of the stress within the material and how it changed with the changing parameters of cusp angle, fissure shape, and material. The changing cusp angles illustrated the distribution of stress very clearly as shown in Fig. 5. The steeper angles concentrated the stress in the fissure area and the flatter cusps eliminated that and distributed the stress more widely. The conclusions were again similar: for the ceramic monolithic materials, a design with a rounded occlusal notch, 20° cusp angle and medium thickness (1.5 mm occlusal) was considered optimal in terms of tooth conservation and fracture resistance.

Fig. 6. Beautiful ceramic work but will it function beautifully?

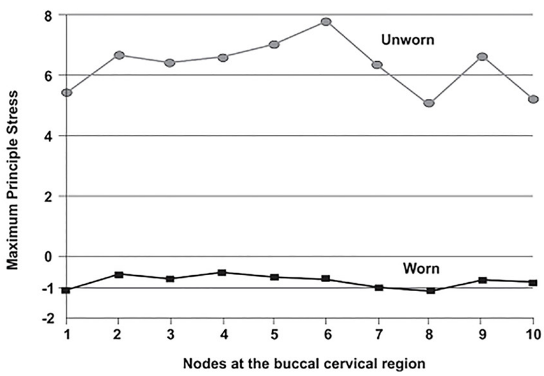
Fig. 7. The cusp angles of ceramic crowns



study of abfraction, or non-carious cervical lesions (NCCL). One study used a combination of FEA and strain gauges on artificial teeth, and found that oblique loads to the cusps resulted in tensile stresses in the cervical lesion and concluded that the pattern of stress coincided with the clinical appearance of an NCCL.[18] Similar findings were reported using photoelastic stress analysis. [19]

A more recent study from the world of Physical Anthropology looked at the stress distribution of unworn and worn teeth using three dimensional FEA. [20] In keeping with earlier papers of this series, the authors noted that NCCLs were seldom observed in non-industrialised societies and found that this was related to wear. Stress values calculated at the cervical region, depended on occlusal wear and the cusp inclination. In addition, they noted that with steep cusp inclines the stress distribution was not limited to the cervical area but extended to the root, and speculated that this may in part account for tooth fracture. Fig. 8 shows the tensile stress values at nodes along the buccal cervical region for the same tooth with unworn cusps and with a worn occlusal surface.

Fig. 8. Stress values at nodes along the buccal cervical area for the same tooth under occlusal load showing values for the unworn and then worn occlusal surface (redrawn from Benazzi et al 2013 [20]).



So when you see beautiful ceramic work such as in Fig. 6 and then measure the cusp angles as in Fig. 7, and look at the intricate occlusal fissuring, think about how this is going to function in the mouth. May look pretty, but it could be pretty liable to chipping and fracture under function.Finally, if you are not convinced, or even if you are, some additional evidence comes from the

So finally (again) I hope you are now convinced that cusps, although friendly to aesthetics, are the enemy of occlusal freedom, so there needs to be an understanding of how to retain looks with freedom. To return to the title of this section, and with tongue firmly in cheek, I leave you with an alternative to the first few lines of Shakespeare's famous soliloquy:

SHAKESPEARE	ME
To be, or not to be: that is the question:	*To cusp or not to cusp: that should not be the question!*
Whether 'tis nobler in the mind to suffer	*Whether 'tis nobler in practice to suffer*
The slings and arrows of outrageous fortune,	*The chips and cracks of outrageous slopes,*
Or to take arms against a sea of troubles,	*Or to take burs against the cusps of troubles,*
And by opposing end them	*And by grinding, end them*

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