Effect of Occlusal Morphology on the Accuracy of Bite Force Measurements Using Thin Film Transducers

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Purpose: Occlusal transducer foils using piezoelectricity or pressure-dependent electric resistance are potential candidates for a measurement system for both absolute levels and changes in bite force. This preliminary in vitro study evaluated the possible usefulness of such transducer foils in the assessment of occlusal forces in centric occlusion. ***Materials and Methods:*** Piezoelectric force transducer foils 33 μm thick were placed between pairs of teeth with the dentition in centric occlusion. Occlusal forces were recorded in five patients, who were instructed to bite as hard as possible for about 1 second. Acrylic resin casts of each pair of antagonistic teeth were aligned with the help of interocclusal records. The casts were mounted in a jig, where a defined load could be applied. The ratio of applied force and measured sensor signal permitted a set of calibration factors. ***Results:*** A correction factor for each pair of teeth helped determine the ratio by which measured occlusal force exceeded actual tooth load. Differences in occlusal morphology gave rise to a wide span of correction factors (1.01 to 2.80). Steep cusp angles resulted in a wedge action that gave rise to a strong increase in occlusal forces, which were about twice as high as actual tooth load, with wide variation. ***Conclusion:*** This method of bite force measurement eliminated the influence of occlusal morphology by individual correction for each pair of opposing teeth. To measure the absolute load of antagonistic teeth with thin film transducer foils, one must take into account individual occlusal morphology. Forces measured with the films are a function of both actual tooth load and occlusal morphology. *Int J Prosthodont 2004;17:518–523.*

Measurement of maximum forces on teeth has long been of interest. Such measurements have been carried out using a variety of methods, with great variation in results, depending on the exact measurement conditions.[1–5] The determination of the maximum load on individual teeth with the dentition in centric occlusion is of particular interest, and efforts have been made to measure such loads and/or bending moments on teeth[6–10] as well as osseointegrated oral implants. Thin film-type sensors are commonly used for teeth with intact crowns.[11–14] These sensors are based on different physical mechanisms of transducing forces (eg, into electric signals using the piezoelectric effect or changes in the electric resistance under mechanical load). These transducers find a wide range of application in research as well as in the clinical field.[15–19]

The advantage of using thin, flexible films is that they adapt to the occlusal morphology of any tooth, and, in the absence of any discernible malocclusions (interocclusal locking or opening), the forces generated by the masticatory muscles are probably evenly distributed over the entire dentition, while the individual tooth's load can be determined.

This study sought to determine the accuracy of thin film transducers for different cuspal inclinations by measuring the effect of the occlusal morphology on the output signal of thin film transducers. Load levels studied presumably corresponded to forces generated by each patient during 1 second of maximal clenching.

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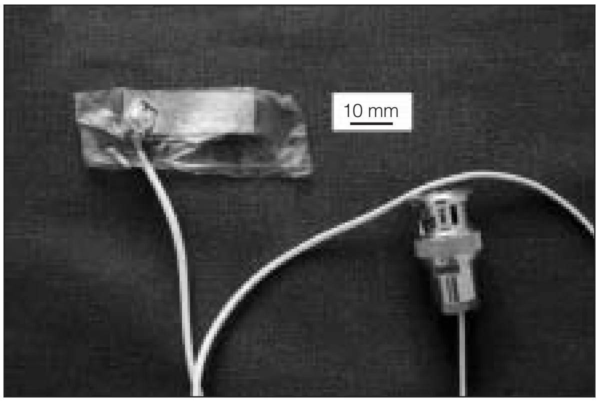
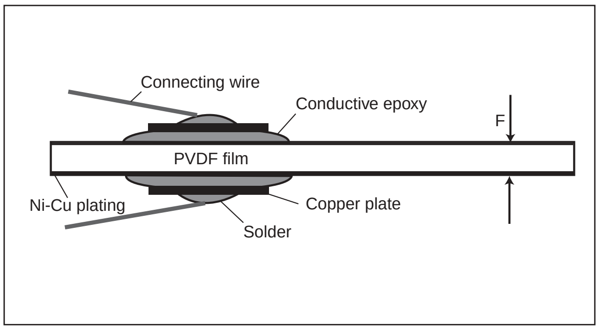
Fig 1 *(right)* Transducers: PVDF foil with upper and lower insulation film and thin, low-capacitance coaxial line with barrel nut connector.

Fig 2 *(below)* Cross-section of transducer foils (insulation not shown). The Ni-Cu–plated PVDF film is 25 µm thick. Wiring is soldered to copper plates (3 mm^2) glued on one end of the PVDF foils using conductive silver-filled epoxy. Finally, assembly is covered by insulating film. Total thickness is 33 µm. *F* = force.

Fig 3 *(below right)* Transducer is placed between the right first premolars.





Materials and Methods

Piezoelectric Transducers and Measurement Equipment

The authors used 33-µm-thick piezoelectric sensor foils made from 25-µm-thick polyvinyliden fluoride (PVDF; EIC Consulting) insulated with 4-µm-thick Hostalen foils (type GM 5255F, Elenac) (Figs 1 and 2). Further details on the properties of PVDF are described by Kawai.[20] The piezoelectric charge generated by the sensors was measured with an HBM amplifier (type MGC 01/AP 08, Hottinger Baldwin Messtechnik) and recorded using an RS 232 connection to a laptop computer. The force (in N) was calculated from the piezoelectric charge produced by the transducer, using the piezoelectric constants given by the supplier of the material and verified with a Mecmesin Versa-Test stand and AFG 2500 force gauge (Mecmesin). The sensors showed a linear increase in output and were tested up to 2 kN. The output signal for a given force was found to be independent of the number of spots at which the force was compressing the transducer (ie, a fixed load applied to a single spot on the film produced the same signal as when spread out over several spots). The measurement resolution was 10 ms and 0.2 N in time and force, respectively.

Because the measurement involved large tilt angles at the contact areas between antagonistic teeth, shear stress in addition to the compression of the transducers was to be expected. Tests with measurement geometries that resulted in both compression and shear forces showed that the calibration of the transducers did not depend on the tilt angle.

In Vivo Measurements

Occlusal forces were initially measured between the molars and premolars of five individuals. The transducers were placed between the individual teeth and allowed to adapt to the oral temperature for about 2 minutes to eliminate any influence of pyroelectricity on the force measurement. After this time, no visible drift in the output signal of the unloaded sensor was present, and the measurement was started. The patients were instructed to bite as hard as possible for about 1 second (Fig 3). This was repeated three times for each pair of teeth.

Before and after measuring each patient, the calibration of the transducers was tested with five different loads in a test jig. Because of drift in the signal, the baseline had to be subtracted to obtain absolute force figures. A typical measured force curve is shown in Fig 4.

Master casts were made from each patient's teeth, and interocclusal records were made with heavy-body

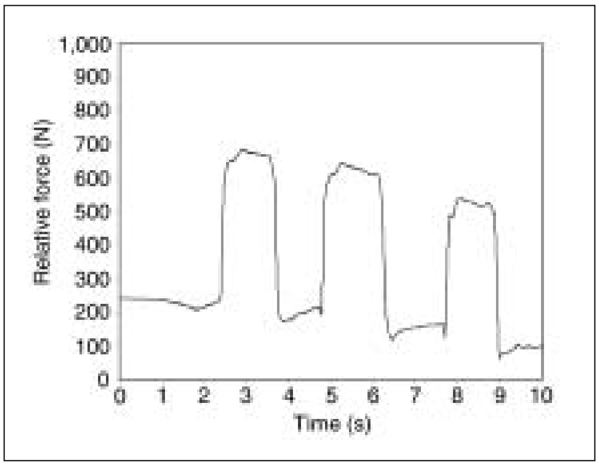


Fig 4 Measurement signal. Patient is instructed to bite as hard as possible and hold the force for about 1 second. In this case, transducer foil was placed between left first molars. The baseline drift is typical for piezoelectric transducers. To obtain absolute forces, baseline for each peak was subtracted.

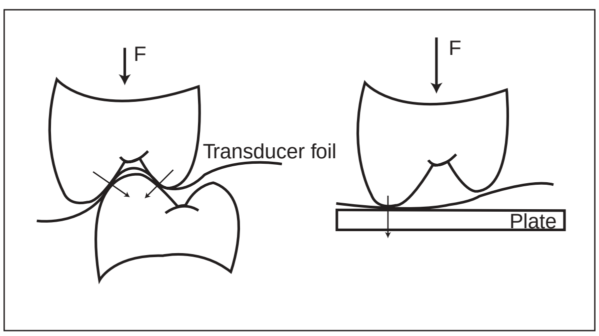


Fig 5 Two setups for in vitro measurements: teeth are mounted in jig and loaded according to the schematics. *Left:* Mounting of resin models in accordance to in vivo situation. Transducer signal corresponds to the sum of the levels of force and is greater than loading force *(F). Right:* Mandibular tooth is replaced with a plate, and measured force equals loading force.

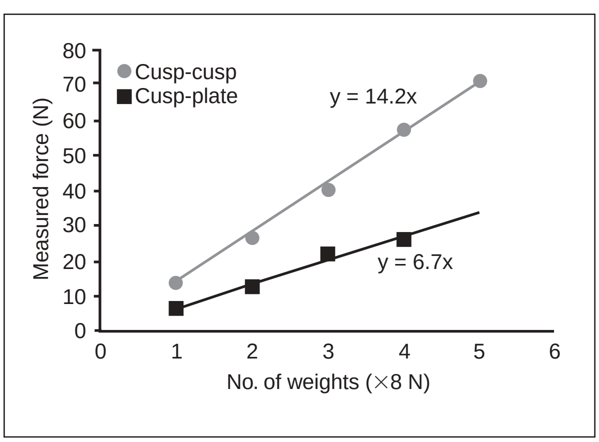


Fig 6 To determine the correction factor for each pair of teeth, the two sets of data are fitted to a straight line, with the ratio of the slopes yielding the correction factor. For this patient, the forces measured with the transducer foil in vivo need to be multiplied by 6.7/14.2 to obtain the true periodontal load.

silicone to allow reproduction of the occlusal relation between the jaws in the master casts.

In Vitro Measurements

Individual resin casts were made from each measured tooth. The corresponding pair of resin teeth was aligned using the interocclusal records bite and mounted in a jig that allowed loading with a defined force. The axial inclination of each pair of teeth was visually aligned to resemble the conditions in the respective patient's mouth as closely as possible. Articulating paper was used to mark the contact points to ensure that they reproduced the in vivo contact situation. The transducer foil was placed between the teeth, and the output signal was recorded while forces in multiples of 8 N were applied to the jig. Subsequently, the resin model of the mandibular tooth was replaced with a metal plate so that the highest cusp of the maxillary tooth touched the plate, forming a single contact area normal to the direction of the loading force. A second series of measurements was carried out with the transducer foil between the tooth and the plate (Fig 5).

Results

The in vitro measurements produced two sets of data for each pair of teeth, one set taking into account the full occlusal morphology, and one set with a single contact area perpendicular to the load vector. A linear regression was fitted to each set of data (Fig 6). The ratio of the slopes served as a correction factor for each tooth, by which the measured occlusal force needed to be multiplied to obtain the actual load force, which was assumed to be identical to the load on the periodontium (Fig 7).

The degree of overestimation can be defined as:

$$(F_{occlusal}/F_{load} - 1) \times 100\%$$

Accordingly, overestimation of 100% means that the occlusal force is twice the real loading force. The differences in occlusal morphology gave rise to a wide span in correction factors, with the overestimation ranging from 1% to 180% (Fig 8). A large variation was apparent for individual teeth, and the correction factors for the teeth in each patient varied considerably. This excluded the use of general correction factors.

Discussion

Geometric Considerations

Because of the cusp-fissure relation of the crown and the cusp angles showing a wide range of variation, bite forces acting on the sensor foils placed between antagonistic teeth do not necessarily resemble the presumed load the periodontium has to carry. For the T-Scan system (transducer foil, based on resistance changes of a sensor foil under load), accuracy and repeatability of sensor foils was investigated, with mixed results reported.[15,21] Tekscan, the manufacturer of T-Scan, concedes that the current system precludes obtaining absolute occlusal forces in engineering units.[22] We are unaware of any research that assesses the effect of occlusal morphology on the output signal of thin film transducers.

The forces acting on the contact areas are shown schematically in Fig 9. The foils cannot determine the direction of the forces, but they do integrate the absolute values of the forces of all contact points. Coronal occlusal morphology includes contact points on marginal crests that can be nearly perpendicular to the tooth axis. Contacts between steeply sloped cusps can also occur, however, and the contact area can be tilted considerably against the tooth axis, acting like a wedge and thus increasing the forces with which the sensor foils are compressed.

Two different situations are shown in Fig 10. The same force vector can give rise to different results, depending on the steepness of the cusps. The force measured by the foil corresponds to the sum of the forces acting through the contacts but does not take into account the different vector directions. The likely specific periodontal load is given by the vector sum of these forces, which are not accessible with the foils.

In terms of a presumed periodontal load, the force components perpendicular to the load vector F_{sum} cancel out each other. The difference ΔF corresponds to these force components. From such geometric considerations, ΔF can be expected to become a considerable fraction of the measured occlusal force.

Measurement Error

The use of a silicone check bite to align the tooth pairs with respect to each other facilitated a realistic reproduction of the contact situation that could be verified with articulating paper. However, alignment of the tooth pair with respect to the maxillomandibular geometry could only be carried out visually. Geometric consideration showed that the systematic error of misalignment up to 10 degrees could be calculated to remain well below 10% of the measurement value for most realistic crown morphologies.

The thin insulation layer of the transducer foils could be mechanically damaged during the in vivo measurement, causing saliva to partially short the signal. When major damage was clearly visible in the signal, the measurement was repeated with a new sensor. However, minor leaks could go undetected while still slightly altering the calibration of the transducers. Therefore, a check of the calibration process before and after each series of measurements was done. When differences exceeded 10%, the measurement series was repeated to reduce any error introduced by leakage.

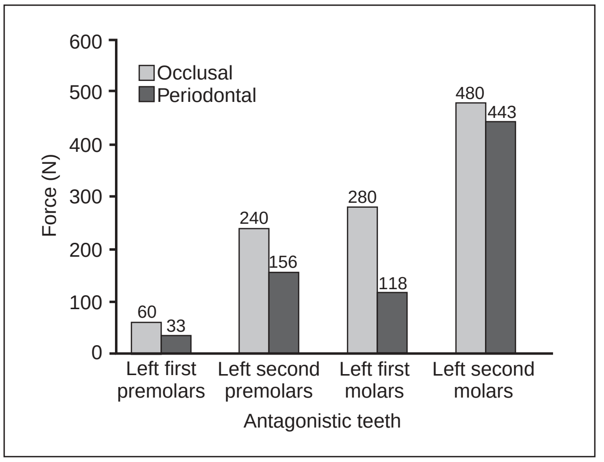


Fig 7 Occlusal forces as measured with the transducer foils and corresponding periodontal loads of the left teeth for one patient. Periodontal load is smaller than in vivo–measured occlusal forces.

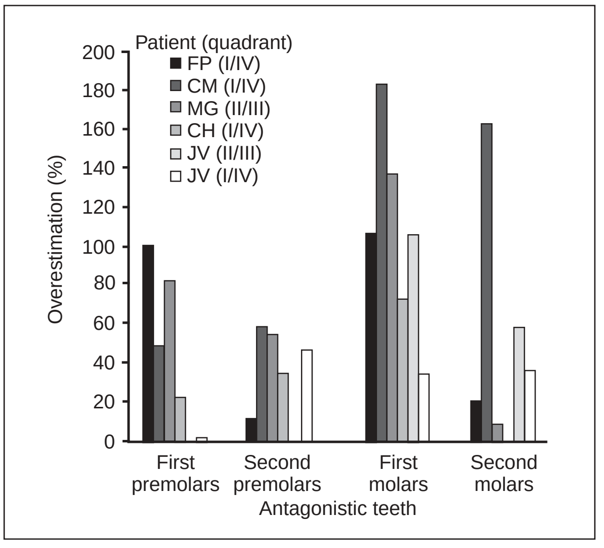


Fig 8 Calculated overestimation of forces caused by occlusal morphology for all tested patients, grouped by tooth. The covered range is large, with typical overestimation on the order of 50%.

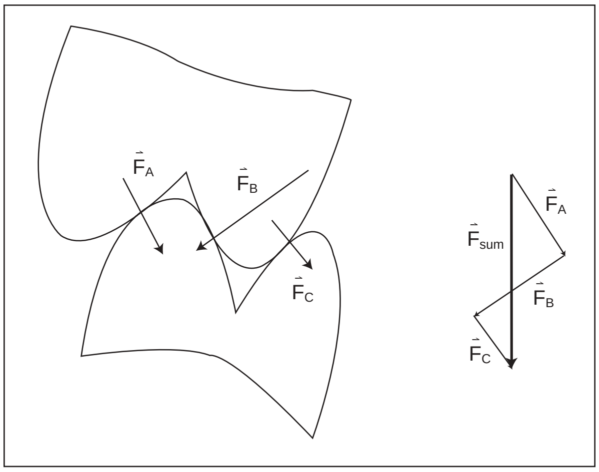


Fig 9 Effect of occlusal morphology on direction of force vectors acting through contact points. The resulting force F_{sum} for the periodontium is given by the vector sum of the individual contact forces F_A, F_B, and F_C.

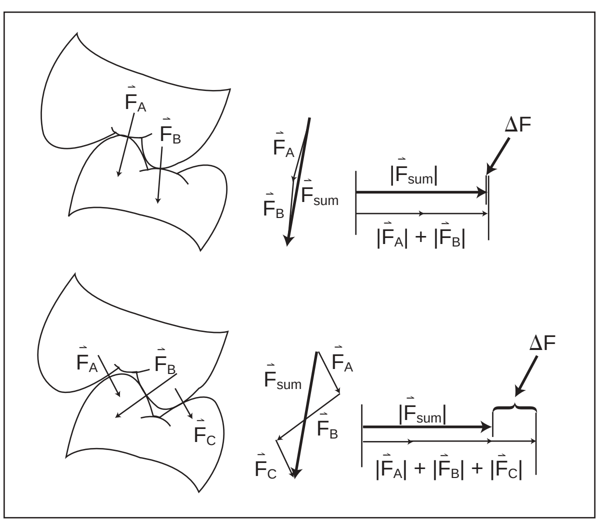


Fig 10 Influence of occlusal surface of a crown on size and direction of oblique occlusal forces. For the same loading force F_{sum}, small differences in occlusal morphology cause large effects on both direction and absolute level of forces. Thin film transducers measure the sum of individual forces $F_{meas} = \Sigma|\vec{F}|$ in each contact area, whereas the periodontium is only loaded with the vector sum $F_{sum} = |\Sigma\vec{F}|$. The difference ΔF between these two levels varies greatly with the details of occlusal morphology, as shown on the right. *Top:* Contact on marginal ridges produces forces almost parallel to each other; ΔF remains small. *Bottom:* Contacts between cusps increase wedge effect dramatically; ΔF becomes large.

Conclusion

The study demonstrated that actual tooth load was considerably smaller than the recorded in vivo occlusal forces, and that the correction factor depended on individual occlusal morphology. Pairs of teeth that showed contacts on steeply sloped cusps typically gave rise to a much larger overestimation than teeth where the contacts were located in flat parts of the contacting occlusal areas. This suggests that unless occlusal morphology is taken into account, the accuracy of bite force measurements with thin film force transducers may be unreliable. Consequently, the considerable effort required to correct each measurement for the occlusal effects reduces the range of application for such measurements, particularly in the clinical fields. On the other hand, the absence of occlusal interference, ease of use (high adaptability to each individual tooth, no need for precise alignment in the mouth), and inexpensive fabrication of thin film force transducers make them useful tools in determining changes in periodontal loading of specific pairs of teeth before and after different types of treatment (eg, orthognathic surgery). It also seems pertinent to suggest that scrupulous use of other clinical adjustments, such as articulating paper and shimstock, continues to offer valuable clinical information.

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Literature Abstracts

Influence of dietary simulating solvents on the hardness of provisional restorative materials

Provisional restorations are expected to maintain proper mechanical properties in the intraoral environment until they are replaced by permanent restorations. This article evaluated the influence on surface hardness of provisional restorative materials for crowns and fixed partial dentures by dietary simulating solvents. Samples were fabricated (3 mm × 4 mm × 2 mm) with Temporary Bridge Resin, Protempt Garant, Luxatemp Automix, Unifast LC, Luxatemp Solar Plus, and Provipoint DC. After polymerization, the samples were stored at 37ºC in a dietary simulating solvent for 1 week. Heptane and ethanol solutions of various concentrations (100%, 75%, 50%, and 25%) were used as solvents. A digital microhardness tester (FM 7, FutureTech, load = 100 gf; dwell time = 15 s) converted the measurement to the Knoop Hardness number (KHN; n = 6). The data was analyzed with analysis of variance and Scheffe's test. The Environmental Index was calculated to indicate the durability of each material. Results showed that the solvents decreased KHN values significantly in all concentrations of ethanol solution compared to controls (air and water). Dimethacrylate-based materials were more resistant to the effects of heptane compared to methylmethacrylate and urethane dimethacrylate–based materials. Rankings of the Environmental Index of the tested materials were presented.

Yap AUJ, et al. *Dent Mater* 2004;20:370–376. **References:** 21. **Reprints:** Dr Adrian U. J. Yap, Department of Restorative Dentistry, Faculty of Dentistry, National University of Singapore, Lower Kent Ridge Road, Singapore, Singapore 119074. e-mail: rsdyapuj@nus.edu.sg—*Eunghwan Kim, Lincoln, NE*

Radiographic follow-up of peri-implant bone loss around machine-surfaced and rough-surfaced interforaminal implants in the mandible functionally loaded for 3 to 7 years

Thirty-six of 51 patients (70.6%) were included in this retrospective study, each with four interforaminal screw-type endosseous implants. Nineteen patients received four Brånemark System Mk II implants with machined surfaces (length 13 or 15 mm), and 17 patients received four Frios sandblasted/acid-etched implants (length 12 or 14 mm). Both groups were restored with similar bar-supported overdentures with 12 resin teeth and cantilevers of less than 1.6 times the implant A/P spread. The minimum follow-up was 36 months (range 37.8 to 86.4 months). Significantly less bone loss resulted in the sandblasted/acid-etched implant group (1.65 mm vs. 2.36 mm) when measured on panoramic radiographs. There was no significant difference between groups with regard to bone loss and patient age, nicotine use, implant life, or patient gender. No implant failed during the study. The authors concluded that the marginal peri-implant bone loss around sandblasted/acid-etched implants was significantly less after 3 to 7 years of functional loading. No reference was made to opposing prostheses or teeth present with respect to loading and marginal bone loss.

Zechner W, et al. *Int J Oral Maxillofac Implants* 2004;19:216–221. **References:** 47. **Reprints:** Dr Werner Zechner, Department of Oral Surgery, Dental School of the University of Vienna, Waehringerstrasse 25a, A-1090, Vienna, Austria. e-mail: werner.zechner@univie.ac.at—*Donald A. Somerville, Toronto, Canada*