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Cusp radius measurement through digital image analysis

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Abstract

Objective. Dental anatomy has been extensively described in numerous textbooks. Nevertheless, there are very few details about the value of the cusp radius of posterior teeth. This *in vitro* study used a laser profilometer to scan the occlusal surfaces of 21 molar teeth. ***Materials and methods.*** The images were analysed with μScan software and the approximate radius of curvature was measured. ***Results.*** The values varied between 0.6–2.5 mm. The radius average value was 1.25 mm bucco-lingually and 1.61 mm mesio-distally. ***Conclusions.*** These findings might serve as a guide for different dental biomechanics studies and the conception, design and manufacturing of dental prosthetics.

Key Words: *dental anatomy, dental informatics, morphometrics, mathematical modeling*

Introduction

The stress state in a body, e.g. tooth, depends partly on the geometric configuration of that body. Dental shape and anatomical features are well-known and have been studied for many decades. However, for a rigorous calculation of the stress state in the dental structure, one must know the details of the surface on which the masticatory force is applied.

One of the requirements for determining the stress that arises during a dental contact involves establishing the shapes and sizes of surfaces in contact. The shape of the occlusal surface is undulating and existing descriptions refer to the most frequently encountered elements of morphology. Each tooth, taken individually, has some surface details which are important for characterizing dental biomechanical behavior, as reported by Frunza et al. [1]. The dimensions of the various elements of the occlusal surface and other morphometry data are either described to a lesser extent or completely overlooked in the literature. Modeling and determining tooth-to-tooth contacts rely on the knowledge of the cusp radius. In a database search, such as PubMed, Google Academics and Scopus, we found no study on the basis of which we could calculate this parameter.

The dental cusp can be geometrically represented as an elliptic paraboloid (Figure 1), which has the following equation: $z = \frac{x^2}{a^2} + \frac{y^2}{b^2}$.

If one carries out two perpendicular sections through this paraboloid, he/she will obtain two curves which can be described by the radii of curvature. These radii are crucial for determining the contact pressure and sub-surface (enamel) stress in different types of dental contact models [2,3]. One of these is the Hertzian model, which is commonly used in the dental literature [4–8].

Currently, with the support of technically advanced devices and software, it is possible to determine with extreme precision features that were once only assumed or estimated. In the present study, we analyzed digital 3D images of the occlusal surfaces of extracted molar teeth. For each cusp, we measured the approximate radius of curvature in sagittal and transverse planes. Analysis of these anatomical data will help improve our understanding of oral functionality, as well as assisting in the

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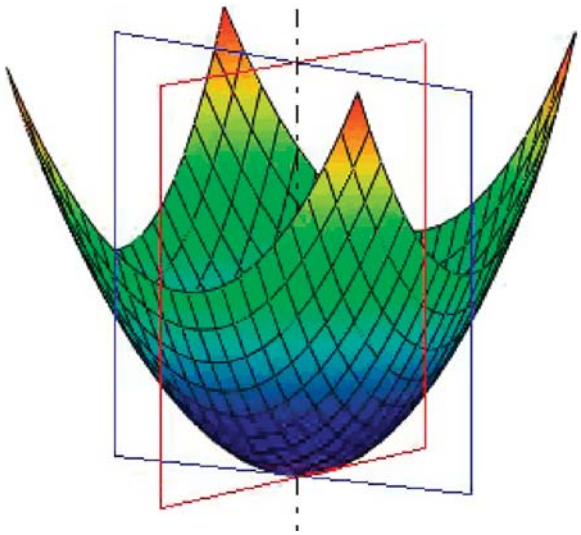

Figure 1. A dental cusp can be modeled as an elliptic paraboloid. The two perpendicular planes (sagittal and frontal) correspond to the bucco-lingual and mesio-distal directions. In each plane, the cusp has two different radii.

prediction of biomechanical risks and the design of prosthetic restorations.

Materials and methods

Third mandibular molars were collected after the donors' informed consent was obtained under protocols approved by the University of Medicine and Pharmacy, Bucharest. These teeth ($n = 21$) belonged to persons of 18–62 years old and were kept in an aqueous solution prior to examination. Most of the teeth were extracted due to an infectious complication, i.e. pericoronitis. Each tooth was examined for caries lesions, fractures or other defects of the occlusal surface. Only the teeth which presented four obvious cusps with intact contours were selected. Every tooth was mounted in an upright position, with roots embedded in an epoxy block.

The specimens were placed on the platform of a non-contact 3D scanning profilometer (µScan, NanoFocus AG, Oberhausen, Germany), equipped with a laser confocal sensor CF 13. This has a maximum resolution of 100 nm and a working distance of 13 mm. The occlusal surfaces were set as horizontally as possible and we used a resolution of 10 µ in the longitudinal axis and 100 µ in the transverse axis. For one single tooth, the scanning time was ~ 15 min.

After scanning all the teeth, we examined the obtained images from an occlusal view with the µScan program, version 6.2. Due to the motley appearance of the occlusal morphology, often the scanned image included only the highest areas, namely the cusps (Figure 2A). Since the grooves, fossae and pits are very abrupt, there were insufficient data for the system to interpret (i.e. show) the actual image, even though the sensor scanned that area. In specific parts of the scanned image, the area is seen at micro-scale and the cusp radius can be calculated. We noticed that each cusp has a tip that may often present a different contour compared with that of the entire cusp and that what we see with the naked eye can be much different from a micro-representation of a surface.

We observed the scanned image from the occlusal perspective (Figure 2B). By selecting the *Profile description* option of the program, we could view the tooth profile on a section in a given segment, manually selected and framed by the arrow. The *Profile values* option can trace the outline of a tooth on a marked area (Figure 3) and thus we calculated the approximate radius of the cusps.

Results

Prior to the actual experiment, we tested the repeatability of the procedure, scanning one specimen 10 times, always in a different position. Nevertheless, the obtained image can be rotated as necessary to facilitate the measuring procedure in the specified

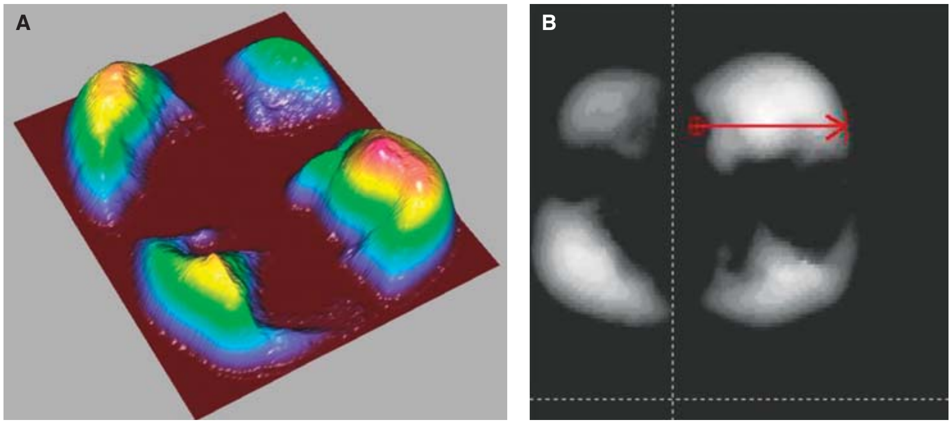

Figure 2. (A) Digitally scanned image of a mandibular third molar. Although the deepest portions of the occlusal surface could not be captured, the cusps are well-represented. (B) Occlusal view of the image from (A). The arrow measures the mesio-lingual cusp in the sagittal direction.

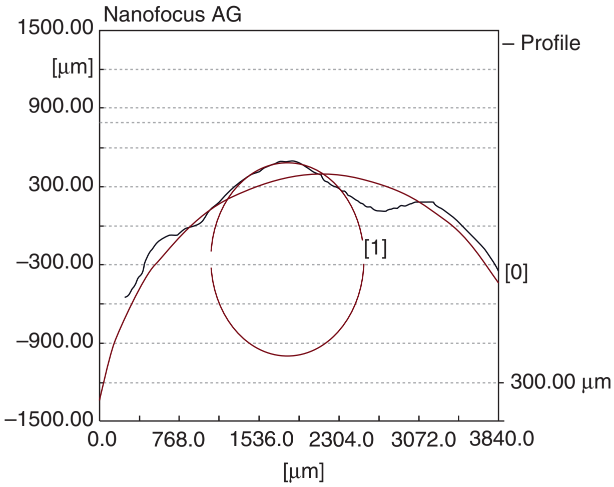

Figure 3. Mesio-lingual cusp profile. Circle [1] measures the radius of the cusp's tip, while circle [2], of which only a part can be observed, measures the cusp as a whole.

directions. For the mesio-lingual cusp, in the bucco-lingual direction, the values ranged from 1006.32–1048.72 µ, with a SD of 15.016 µ.

In Table I we present all the data, indicating the measured cusps, the direction of measurement and the cusp radius values.

Between the minimum and maximum values, we observed that the radius of curvature of the mandibular third molar cusps varied between 658.16–2157.03 µ in the bucco-lingual (BL) direction and between 786.87–2548.39 µ in the mesio-distal (MD) direction. The limits of these ranges are very close, which allows us to conclude that the cusp radius generally varies between 0.6–2.5 mm (see Table II).

The cusps are wider in the MD direction than in the BL direction. The mean radius of all cusps in the BL direction is 1.25 mm and 1.61 mm in the MD direction. From all directions, the mesio-lingual cusp has the highest radius. Also, the mesial cusps are wider than the distal cusps. In both directions, ranging from largest to smallest, the cusps are ML, MB, DB and DL. However, in the MD direction, we cannot differentiate between the distal cusps, since the values are very similar.

Discussion

There are few references in the literature on this topic. Thus, many of the trials [4,9,10] which focus on dental contacts quote Wheeler [11], who, in his textbook on dental anatomy, mentions cusp radii between 2–4 mm.

Table I. Radii cusp values for all specimens (mm).

	Bucco-lingual direction				Mesio-distal direction			
Nr. Crt.	MB Cusp	DB Cusp	ML Cusp	DL Cusp	MB Cusp	DB Cusp	ML Cusp	DL Cusp
1	1429.49	1590.43	1613.12	1193.33	1690.44	1889.53	2078.1	1354.96
2	1355	803.46	1472.07	1072.16	1380.83	1237.37	2171.42	1648.62
3	699.55	948.18	1006.32	924.55	1817.8	1302.92	1764.61	1597.73
4	1965.64	1264.15	1573.56	1121.92	2364.82	2133.9	1646.67	1653.26
5	953.68	762.68	1344.97	651.23	1043.35	1235.77	1717.1	1489.19
6	1894.57	658.16	1197.7	1143.81	1837.65	1333.7	1633.39	1732.17
7	693	937.68	1320	1221.88	786.87	1299.21	1645.11	1531.53
8	749.43	1128.4	993.43	1039.03	933.64	1236.47	833.84	1662.43
9	724.96	674.92	1289.42	909.72	1602.56	1383.81	1638.52	1326.38
10	926.87	890.43	1590.41	1226.48	1885.23	1930.8	1544.37	1642.71
11	1494.62	1353.74	1749.52	1337.42	2012.3	849.56	2142.85	982.97
12	1737.05	1239.95	1890.63	1230.4	1636.74	1480.3	2298.32	1873.4
13	980.62	1257.85	1,238	1085.54	1210.49	1302.43	1625.3	933.26
14	1468.09	1089.74	1352.42	902.57	1502.09	1375.3	1934.63	1730.43
15	789.07	948.94	1,249	1031.37	2091.62	1627.52	2015.46	1573.58
16	1339.6	1089.65	1458.77	922.54	936.53	938.42	1847.33	1477.52
17	1638.95	1348.28	2011.8	1173.42	1837.48	1929.61	2065.38	1391.28
18	1302.38	1283.59	1678.85	1200.14	1574.41	1483.09	2364.49	1842.75
19	1542.78	1291.21	1677.63	1232.4	1730.32	1972.44	1942.96	1642.48
20	1802.7	1735.45	2157.03	1340.31	1648.37	2392.5	2548.39	1383.22
21	1490.32	1273.64	1,712	930.74	1702.82	1537.47	1445.74	1293.29

MB, mesio-buccal; DB, disto-buccal; ML, mesio-lingual; DL, disto-lingual.

Table II. Minimum, maximum and average values (mm).

	Bucco-lingual direction				Mesio-distal direction			
Value	MB Cusp	DB Cusp	ML Cusp	DL Cusp	MB Cusp	DB Cusp	ML Cusp	DL Cusp
Minimum	693	658.16	993.43	651.23	786.87	849.56	833.84	933.26
Maximum	1965.64	1735.45	2157.03	1340.31	2364.82	2392.5	2548.39	1873.4
Average	1284.6843	1122.4062	1503.6138	1090.0457	1582.2076	1517.72	1852.5705	1512.5314
				1250.1875				1616.2574

Since the protocol followed by Wheeler could not be studied, we cannot make an accurate comparison between our study and Wheeler's. In some indentation studies, the cusp was approximated by a sphere with a radius of 3.18 mm [4] or 3.2 mm [10]. By scanning the teeth, Krejci et al. [12] found a formula for the surface geometry of the third molar palatal cusp, $y = 0.001 \cdot x^2$, likening it to a symmetrical dome. At a distance of 500 microns from the y-axis, analyzing the obtained parabola, they found that it best fit a sphere with a radius of 0.6 mm.

Although the mandibular third molar anatomy varies to a great extent, it resembles the second molar when it has four cusps, as stated by Scheid [13]. In general, our results match those in the classic textbooks [14], which specify the order of the cusp size, with the ML cusp being the largest. Nevertheless, these are described vaguely by adjectives like 'largest, longer, widest, highest' and this demonstrates their relative descriptive character.

Scanning the occlusal surfaces of the teeth, we observed that the cusps did not always have a uniform contour and they can have a tip which is geometrically separated from the cusp design (Figure 4). In these instances, we measured the tip and not the whole cusp, considering that it is the part which actually provides the inter-tooth contact.

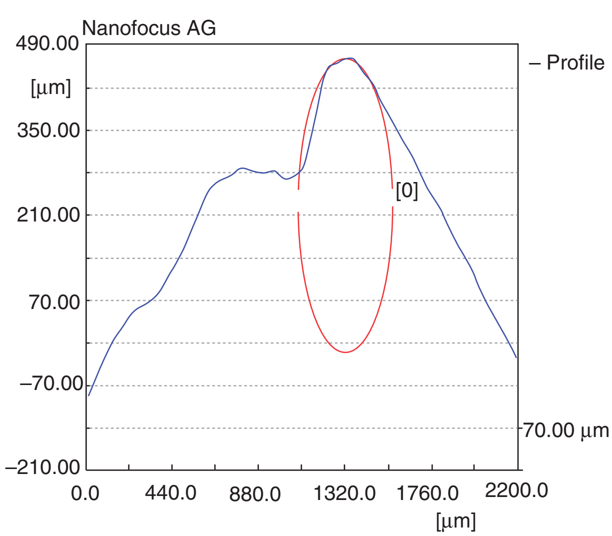

Figure 4. Bucco-lingual profile of a MV cusp. The tip has a very different morphology, defined by a circle [0], rather than the entire cusp.

While the scanning procedure could not capture the entire occlusal surface of the tooth, the cusps were well-represented. Even in the cases when only parts of the cusps were scanned, it did not affect the measurements, since we needed only the higher portion. Another type of bias related to this procedure is the manual selection of the area to be measured (arrow length) and of the circle that follows the contour.

Laser scanning and image analysis can be used in various situations and purposes, as reported by Ungar and colleagues [15–17] and Dennis et al. [18]. Knowing the cusp radius value is important in all dental contact studies as well as, for example, for assessment of material properties and in fractography research. In practical terms, cusp radius value could be used in CAD-CAM systems, if one could set this parameter.

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Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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