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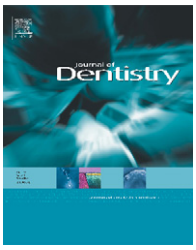

Making three-dimensional Monson's sphere using virtual dental models

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ABSTRACT

Objectives: The Monson's sphere and curve of Wilson can be used as reference for prosthetic reconstructions or orthodontic treatments. This study aimed to generate and measure the three-dimensional (3-D) Monson's sphere and curve of Wilson using virtual dental models and custom software.

Methods: Mandibular dental casts from 79 young adults of Korean descent were scanned and rendered as virtual dental models using a 3-D digitizing scanner. 26 landmarks were digitized on the virtual dental models using a custom made software program. The Monson's sphere was estimated by fitting a sphere to the cusp tips using a least-squares method. Two curves of Wilson were generated by finding the intersecting circle between the Monson's sphere and two vertical planes orthogonal to a virtual occlusal plane. Non-parametric Mann–Whitney and Kruskal–Wallis tests were performed to test for difference between sex and in cusp number within tooth position.

Results: The mean radius of Monson's sphere was 110.89 ± 25.75 mm. There were significant differences between males and females in all measurements taken ($p < 0.01$), within 16.87–17.27 mm. Furthermore, morphological variation derived from variability in cusp number in the second premolar and second molar were not found to influence occlusal curvature ($p > 0.05$).

Conclusions: This study describes a best-fit algorithm for generating 3-D Monson's sphere using occlusal curves quantified from virtual dental models. The radius of Monson's sphere in Korean subjects was greater than the original four-inch value suggested by Monson.

Clinical significance: The Monson's sphere and curve of Wilson can be used as a reference for prosthetic reconstruction and orthodontic treatment. The data found in this study may be applied to improve dental treatment results.

1. Introduction

Two occlusal curvatures and an associated fitted sphere have been proposed to exist in the human occlusal dental arcade. The curve of Spee is an anterioposterior curve that passes through the cusp tips of the mandibular canines and the buccal cusp tips of the premolars and molars.[1] The curve of Wilson is a mediolateral curve that contacts the buccal and

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lingual cusp tips of both sides of the dental arch.[2] Monson described a three-dimensional (3-D) sphere combining the anterioposterior curve and the mediolateral curve, with the mandibular incisal edges and cusp tips touching the sphere.[3]

Occlusal curvatures are clinically important in dental treatment procedures.[4–8] The curve of Spee permits total posterior disclusion on the mandibular protrusion given proper anterior tooth guidance[1] and the curve of Wilson permits lateral mandibular excursion free from posterior interferences.[2] Monson's sphere has been used as a reference for prosthodontic reconstruction of the posterior dentition.[8]

It is essential to recognize the standard values of occlusal curvature for the diagnosis and rehabilitation of occlusal disharmony.[9] For the quantification of these occlusal curvatures, various methods have been developed. Conventional methods rely on measuring the depths or angles of the curvatures directly on dental casts using rulers,[10] analogue callipers,[11,12] digital callipers,[4,13,14] and Broadrick occlusal plane analyzers.[8] Unfortunately, conventional direct measurements from dental casts are limited by not only the accessibility and repeatability in the cognition of reference points but are also restricted to intra-arch measurements.[15] Indirect measurements from 2-D scan images were used to overcome these problems and enabled a variety of analyses using the mathematical calculations or the aid of specialized software.[5,16,17] However, a true curve of Spee and curve of Wilson are not parallel to the sagittal plane or frontal plane unlike the conceptual diagrams which depicts two curves in the frame of 2-D images.[1,2] Such measurements on 2-D Images [5,16,17] were inevitable to address different values from true ones obtained by 3-D environment. Finally, it is impossible to generate Monson's sphere, which requires 3-D information including x, y, z coordinate values,[3] using conventional methods. Therefore, it is necessary to use 3-D tools to comprehend true occlusal curvatures.

Occlusal curvature studies using 3-D tools have usually employed 3-D digitizers.[6,15,18] Ferrario et al.[6] were the first to obtain x, y, z coordinates of cusp tips using a 3-D digitizer and derived a spherical model of the curvature of the occlusal surface. Using a 3-D digitizer, occlusal curvatures can be investigated by geometric-mathematical analyses based on reference points with 3-D coordinates.

Due to recent advances in engineering science and technology, dental research using three-dimensionally reconstructed virtual dental models has been introduced and is widely applied nowadays.[19–27] With the addition of specialized software, several studies have demonstrated that the virtual dental models allow increased recognition accuracy and enable complicated geometric calculations.[22,26]

Until now, most occlusal curvature studies have focused on the curve of Spee,[5,7,16,17,28,29] while the curve of Wilson and Monson's sphere have received little attention.[6,9,18] In addition, curve of Spee has been measured using virtual dental models,[7] meanwhile the generation of a real sphere, not a circle, is hard to achieve owing to the methodological limitation.

Therefore, the aim of this study was to generate the 3-D occlusal curvatures including Monson's sphere and curve of Wilson using virtual dental models and custom designed software. Also, the value of 3-D occlusal curvatures was measured and analyzed.

2. Materials and methods

2.1. Subjects

Mandibular dental casts of 41 Korean males and 27 Korean females (age 23–26 years) were prepared. Subjects were selected based on the following criteria: (1) complete permanent dentition; (2) absence of extensive restorations or cuspal coverage; (3) no previous or current orthodontic treatment; (4) under 3 mm of crowding and/or spacing for the entire mandibular dental arcade. This study was approved by the institutional review board of the College of Dentistry, Seoul National University (S-D20100011).

2.2. Reconstruction of virtual dental models

3-D reconstructions of virtual dental models were performed according to a procedure previously described by Lee at al.[21] In brief, at first, dental casts were scanned using an optoTOP-HE 3-D system (Breuckmann GMBH, Meersburg, Germany), which has a point accuracy of 0.100 ± 0.005 mm and resolution of 0.015–0.500 mm in the X and Y axes and 0.002 mm in the Z axis.[30] Each cast was scanned using ten or more different views that were combined by a registration method (iterative closest point algorithm)[31–35] and merged and rendered as a virtual dental model using Rapidform XO software (INUS Technology, Seoul, South Korea).

2.3. Digitization of reference points

In this study, 26 reference points were generated to measure occlusal curvature beginning with the cusp tip of the canine and following the buccal and lingual cusp tips of the premolar and molar teeth on the right and left sides (Fig. 1). Normal variation in the number of lingual cusps in the second premolars and expression of the distal cusp in the second molars was noted in the study sample. The reference points were generated in all cusp tips of the teeth regardless of the cuspal variation. Additionally, all models were further classified into groups according to the cusp numbers of the second premolar and the second molar to determine differences in occlusal curvatures with the cuspal variation (Table 2). The sample models in this study all had the five-cusp first molars and were not classified into groups. The third molars were excluded from the generation of reference points.

To reduce noise introduced by observer error as much as possible, a custom made software program was applied. The program aided operators by providing a mechanism to specify the direction along which to measure the height of each vertex from a region of interest (Fig. 2A) and then automatically selecting the highest vertex and identifying it as the cusp tip (Fig. 2B). The height was measured parallel to the long axis of the tooth. The long axis was determined using the method described in literatures[36,37] and, although the process of specifying the direction of long axis was subjective, the remaining processes of reference point generation and measurement were not influenced by observer but performed reproducibly using the software. The reproducibility test is described in Section 2.6 in detail.