TECHNICAL REPORT

Reliability of computational measurement of the condyles on digital panoramic radiographs

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Objective: The aim of this study was to evaluate the reliability of a computational method for assessing three condylar measurements on digital panoramic radiographs: condylar height, area and perimeter.

Methods: A computer calculation of the area, the perimeter and the height of 34 condyles was determined on digital panoramic radiographs taken from 17 patients. The test–retest precision of measurements calculation was estimated using an intraclass correlation coefficient (ICC) and Dahlberg's formula at 2 week intervals on the same radiograph to assess intraobserver precision and on two radiographs (RX1 and RX2) to assess the radiographic procedure precision. Changes between measurements on RX1 and RX2 were estimated using paired *t*-tests to detect systematic errors.

Results: Precision of all indices was very high when measurements were made on the same radiograph, thus confirming good reliability for the present computational measuring method. The precision was lower when two different radiographs were compared but was still within an acceptable range of tolerance. There were no statistically significant changes in condylar area, perimeter or height values between RX1 and RX2.

Conclusions: This study has demonstrated that (1) the height of the condyle can be rapidly and reliably assessed using a specific computer system directly on digital panoramic radiographs; (2) although less reliable, area and perimeter can also be acceptably evaluated; and (3) this method has the potential for being routinely used to monitor changes in clinical follow-up as well as for research purposes.

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Introduction

Although the cone beam CT (CBCT) scan is progressively becoming the gold standard imaging technique, the panoramic radiograph still represents the most popular radiological exam used routinely in dental and oral and maxillofacial practice.^{1–4} It is a simple, economic and relatively low patient radiation dose imaging modality compared with a CT scan technique, and it allows for a rapid qualitative analysis of both the bony and dental structures.^{1–4} However, the accuracy and reliability of the quantitative measurements have

always been the Achilles' heel of such a technique, mainly owing to problems related to image distortion, magnification, superposition of different anatomical structures and reduced resolution.^{5–7} Despite these methodological limitations, some studies have shown the possibility of performing vertical linear and angular measurements with satisfactory accuracy, provided that the patient is well positioned and the film is correctly exposed.^{8–11} Interestingly, it has also been proposed that errors owing to distortion are mainly influenced by the object's shape, with the distortion being less important for round structures, such as the condylar head.^{5–7} Thus far, efforts have been essentially aimed at developing reliable methods of measuring condylar and ramus height on panoramic radiographs.^{10–14} This may then be used for quantitative assessment of condylar

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Figure 1 Digital panoramic radiograph showing the selection of a tangential line (ramus tangent (RT)) connecting the most posterior part of the condylar head and the mandibular ramus

Figure 2 Digital panoramic radiograph showing the selection of an orthogonal line (OL1) from the RT passing through the most inferior part of the sigmoid incisura

Figure 3 Digital panoramic radiograph showing the selection of a second orthogonal line (OL2) placed arbitrarily 0.25 mm above the first orthogonal line

Figure 4 Digital panoramic radiograph showing the selection of a third orthogonal line (OL3) placed tangentially to the most superior part of the condylar head. C1 and C2: the intersections between the second orthogonal line and the posterior and anterior cortical of the condylar neck, respectively

morphological changes related to pathological entities involving the temporomandibular joint (TMJ), from arthritis or asymmetry for example. All of these studies have been performed by making manual measurements on conventional panoramic radiographs.^{10–16} Now however, improvements in computer technology combined with the constant impetus and versatility of the internet allow for rapid acquisition, access and easy manipulation of different imaging modalities. Moreover, free open-source software such as OsiriX (Pixmeo, Geneva, Switzerland) also offers the possibility of adapting a program by adding new plug-ins for specific tasks.

The purpose of the present study was to evaluate the reliability of a computational method for assessing three measurements characterizing condylar morphology such as condylar height, area and perimeter on digital panoramic radiographs.

Materials and methods

Patients

Digital panoramic radiographs taken as part of diagnostic and follow-up evaluation of 17 patients (10 females, 7 males; mean age 57.7 years) with no history of TMJ disorders were selected for this study at the Hôpitaux Universitaires de Genève in Geneva, Switzerland.

Image acquisition

All of the panoramic radiographs were taken with a digital panoramic radiographic system (Gendex Orthalex 9200, IL; power supply 115–250 VAC $\pm$ 10%, frequency 50/60 Hz $\pm$ 2 Hz, maximum line power rating 10 A at 250 V or 20 A at 115 V, anode voltage 70–78 kV in 2 kV steps, anode current 3–15 mA in 1 mA steps, exposure time 12 s for standard pan, total cycle 24 s, focal spot 0.5 mm, distance spot-sensor 505 mm, pixel size 48 μ m, resolution 10.4 lp mm⁻¹, image size 1536 $\times$ 2725 pixels, active area sensor 146 $\times$ 6 mm, 1.25 $\times$ magnification, delivered dose 0.325 mGy s⁻¹ at 70 kV and 10 mA).

Computer image analysis

The DICOM (digital imaging and communications in medicine) data were processed using OsiriX imaging software (version 3.8.1, Pixmeo, Geneva, Switzerland, www.osirix-viewer.com) running on a MacOS 10.5 (Apple Inc., Cupertino, CA). Radiological landmarks used in the present study were based on those described in previous studies concerning condylar measurements on panoramic radiographs. These landmarks were validated by taking panoramic radiographs of dry skulls placed in different positions.¹⁰

They were determined as follows: first, a tangential line (ramus tangent (RT)) connecting the most posterior part of the condylar head and the mandibular ramus

Figure 5 Digital panoramic radiograph showing the selection of the condylar head height (white line), the condylar perimeter (red outline) and the condylar area (green surface)

Table 1 Precision of the measurements

<i>Measures</i>	<i>Same RX</i>		<i>RX1–RX2</i>	
	<i>ICC (95% CI)</i>	<i>Dahlberg</i>	<i>ICC (95% CI)</i>	<i>Dahlberg</i>
Area	0.97 (0.95–0.99)	0.01 cm ²	0.72 (0.44–0.86)	0.16 cm ²
Perimeter	0.97 (0.95–0.99)	0.02 cm	0.73 (0.47–0.87)	0.34 cm
Height	0.97 (0.93–0.98)	0.004 cm	0.82 (0.64–0.91)	0.04 cm

RX, radiograph; ICC, intraclass correlation coefficient; CI, confidence interval

was defined (Figure 1). An orthogonal line (OL1) from the RT passing through the most inferior part of the sigmoid incisure was automatically generated by using a plug-in designed specifically for this purpose (Figure 2). A second orthogonal line (OL2) was arbitrarily placed 0.25 mm above OL1 (Figure 3). A third orthogonal line (OL3) was placed tangentially to the most superior part of the condylar head (Figure 4). The intersections between the OL2 and the posterior and anterior cortical of the condylar neck were named CN1 and CN2, respectively. The condylar head height (distance OL2–OL3), the condylar perimeter (distance CN1–CN2) and the condylar area of the 34 condyles were then measured (Figure 5).

Statistical analysis

Data were analysed using the statistical software R 2.10.1 (R Foundation for Statistical Computing, Vienna, Austria). The test–retest precision of measurements of height, perimeter and area calculation was first estimated using an intraclass correlation coefficient (ICC). Precision calculation with an alpha of 5%, an expected test–retest ICC of 0.90 and a precision of an estimated 10% around the ICC indicated that a sample size of a minimum of 34 condyles was necessary. The error variance of the measurements was also calculated using Dahlberg's formula: mean square error (SE^2) = $d^2/2n$ (where d is the difference between repeated measurements and n is the number of radiographs recorded). The measurements were made by the same investigator (AM) at 2 week intervals on the same panoramic radiograph to evaluate the reliability of the method for identifying the radiological landmarks. Measurements were also made on two different panoramic radiographs (RX1 and RX2) from the same patients to evaluate the influence of the radiographic procedure. Since patients did not undergo any TMJ surgery nor develop any TMJ pathological entities during the interval between RX1 and RX2, we expected no significant changes to occur. Changes between measurements on RX1 and RX2 were estimated using paired t -tests to detect systematic errors and were illustrated using Bland and Altman graphs of the difference between measures as a function of the mean of these differences.¹⁷

Results

The precision of all indices was very high when the same radiograph was used, thus confirming good

reliability for the computational measuring method. The imprecision for area was 0.3% of the mean value (Dahlberg/mean (area-RX1) = 0.01/3.02), 0.3% for perimeter and 0.2% for height. The precision between two different radiographs was lower, showing that the radiographic system used contributed to a certain amount of variation in the measurements, although it was still acceptable (Table 1). The imprecision for area was 5.3% of the mean value between RX1 and RX2, 4.5% for perimeter and 1.7% for height. Thus, all indices were similarly reliable when computed on the same radiograph, whereas condylar height was found to be a more reliable measurement compared with perimeter and area measurements, which were a little less precise.

There were no statistically significant changes in the condylar area, perimeter or height values between RX1 and RX2 (Table 2). Thus, while the estimation of all indices is less precise, there does not seem to be a systematic bias toward a higher or lower evaluation of condylar height, perimeter or area. As expected, most differences in measurements fall within the confidence interval (Figures 6a–c).

Discussion

Panoramic radiography has proven to be a simple and useful first-line technique for detailing morphological condylar abnormalities such as erosions, sclerosis, osteophyte formation and resorption.^{1–4} Methods for assessing mandibular dimension on panoramic radiographs have been reported as far back as the early 1980s. Larheim *et al*⁸ showed an acceptable reproducibility of vertical and angular measurements, whereas the horizontal measurements were found to be unreliable, with variations depending largely on the head positioner. Kjelberg *et al* reported on a reliable method of evaluation of the condylar height provided that the same radiographical machine was used. Moreover, they showed that head position did not influence the variation in the vertical measurements.¹⁰ Recent studies on the reliability of the panoramic radiograph continue

Table 2 Values of area, perimeter and height on RX1 and RX2

<i>Measures</i>	<i>RX 1</i>	<i>RX 2</i>	<i>P</i>
Area	3.02	2.99	0.81
Perimeter	7.60	7.60	0.99
Height	2.39	2.40	0.98

RX, radiograph

Figure 6 Bland and Altman figures of difference in (a) height, (b) perimeter and (c) area as a function of mean height, perimeter and area across the radiograph (RX). The full horizontal line represents the mean of the difference between measures and the dotted line represents the 95% confidence interval of the difference

to be persuasive and indicate that it remains a method of choice.^{14,18} Our results seem encouraging concerning the reliability of computational measurements of the two-dimensional (2D) morphological parameters of the area, perimeter and height of the condyle. The main criticism that can be raised about the described method is that the analyses were based on 2D radiographs, which in the era of three-dimensional images might appear outdated. This could be considered a deficiency of our study but, as previously outlined, our main objective was to confirm the precision and reliability of a particular computational method of measurement on

the most accessible and used radiological examination method currently used.

In our opinion, the present method results in four useful advantages. The first is the possibility of operating a fully digital workflow from the radiographic acquisition to the computer workstation, which strongly improves the ease and rapidity of access to images. Secondly, it allows practitioners to work on a single panoramic radiograph without having to resort to highly sophisticated CT and computer graphics hardware and image processing software. Thirdly, only very basic computer knowledge is needed to be able to

use the software rapidly and autonomously. Finally, it is cost (free open-source software) and time effective.

Our method has two unique properties which, as far as we know, have never been previously reported: (1) the evaluation of perimeter and area, which together with the measurement of height allow for a more detailed 2D morphological condylar analysis, and (2) the computational measurements were made directly on digital radiographs. To the best of our knowledge, Bulut *et al*¹⁸ have been the only authors to report on a computational method of measuring surface area on panoramic radiographs. In contrast to our technique, the authors performed measurements on scanned conventional radiographs.

In conclusion, this methodological study has demonstrated that measurements such as area, perimeter and

height of the condyle can be rapidly and reliably assessed using a specific computer system directly on digital panoramic radiographs. These encouraging results indicate that this method has the potential of being routinely used to monitor changes for clinical follow-up of congenital or acquired condylar deformities. This technique could also serve future research purposes to detect morphological changes, *i.e.* following orthognathic procedures.

Disclosure statement

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