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Proptosis—Correlation and Agreement between Hertel Exophthalmometry and Computed Tomography

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ABSTRACT

Aim: To determine the correlation and agreement between Hertel exophthalmometry and computed tomography (CT) in measuring proptosis.

Materials and Methods: 80 patients (40 normal and 40 with proptosis) were recruited for this study. Exophthalmometry were performed on all of them using the Hertel exophthalmometer and CT. Values and correlations between the modalities were analysed with unpaired t-tests, intraclass correlation coefficients (ICC), and Pearson correlation coefficients (PCC). The Bland–Altman method was used to analyse the agreement between the two modalities.

Results: Hertel exophthalmometer and CT measurements did not differ significantly (p > 0.05), although exophthalmometry measurements of the normal (14.5 ± 2.2 mm) and proptosis groups (20.5 ± 3.9 mm) were higher than those obtained from CT (13.9 ± 2.4 mm and 20.0 ± 3.7 mm, respectively). ICC for both the Hertel exophthalmometer and CT measurements were both 0.99, indicating high intra-observer reliability and reproducibility. PCC between Hertel exophthalmometer and CT measurements in both normal and proptosis groups were strongly correlated (r = 0.96 and 0.93, respectively, p = 0.01). The 95% limits of agreement (LOA) between Hertel exophthalmometer and CT measurements for the normal and proptosis groups were −0.70 to 1.78 mm and −2.36 to 3.33 mm, respectively.

Conclusion: Although Hertel exophthalmometer and CT measurements are similar and strongly correlated, they do not agree well with each other in the presence of proptosis. The measurements should not be used interchangeably as the differences between them may lead to errors in clinical interpretation.

Keywords: Computed tomography, exophthalmometer, Hertel, orbit, proptosis

INTRODUCTION

Proptosis is defined as protrusion of the eyeball anteriorly out of the orbit. Of all the methods that have been proposed to evaluate globe position, the Hertel exophthalmometer is the most widely used tool.1,2 However, previous studies have found limitations in the reproducibility of its measurements, particularly between observers.2–6 The differences in readings that arise with this device may result from asymmetry of the lateral orbital rims, compression of soft tissues, parallax errors and the lack of a uniform measuring technique.7

In contrast, computerised tomography (CT) of the orbits provides more accurate values in exophthalmometry. Kim et al. in their investigation on the range of proptosis values in the Korean population emphasised the use of CT to achieve a more precise evaluation.7 The ever-expanding choice of ocular metrology and imaging equipment requires more
research to be carried out on the validity of their measurements. Consequently, studies on the agreement between two instruments are essential in order to determine if their readings may be used interchangeably.

Although there have been studies on the use of the Hertel exophthalmometer and CT for exophthalmometry purposes, there is no information available in the literature on the agreement between the two modalities for measuring proptosis. Thus, the aim of this study was to determine whether Hertel exophthalmometer and CT measurements agreed sufficiently in order for their readings to be used interchangeably for clinical interpretation and comparison.

**MATERIALS AND METHODS**

Between January 2009 and May 2010, 40 patients (aged 18–80 years) diagnosed with proptosis and 40 normal, healthy patients attending the eye clinic at the University of Malaya Medical Centre were enrolled. Patients were recruited regardless of sex or ethnicity. For each patient, only one (index) eye was enrolled; the abnormal one for unilateral proptosis cases, or the right one for bilateral proptosis and normal cases. Exclusion criteria for both the proptosis and normal groups were any history of intraocular surgery or trauma to the index eye and patients with pseudo-proptosis (e.g. high myopia of more than 6 dioptres, or shallow orbits). The normal group of patients was recruited from those attending the eye clinic, who needed orbital CT for reasons other than investigation of proptosis, e.g. optic disc atrophy or sinus imaging. Informed consent was obtained from all patients who participated. The study was approved by the University of Malaya Medical Centre Ethics Committee and adhered to the tenets of the Declaration of Helsinki.

Globe positions were measured using a Hertel exophthalmometer (Oculus Inc., Wetzlar, Germany) by an independent ophthalmologist. The examination of each patient was performed by the same ophthalmologist using the same exophthalmometer, to exclude inter-observer and inter-instrument variability. Measurements were taken with the patient’s head in the primary position and the examiner’s eyes at the same level as the patient’s eyes. The exophthalmometer supports were placed against the two temporal orbital walls so that the orbital rim and the deepest point of the supports were in contact. The apex of the corneas was viewed from the sides using mirrors with superimposed millimetre rules to assess the degree of proptosis.

All patients underwent plain CT scans of the orbit using a Somatom Sensation 16 CT scanner (Siemens AG, Berlin, Germany). Each patient had their head strapped in the supine position during the scan to ensure reliability of the measurements. Their positions were centred by aligning the mid-sagittal line perpendicular to the laser line. The coronal line was centred 1 cm above the external auditory meatus. Spiral acquisitions of the orbits were obtained caudocranially from the upper incisors to the vertex. The scan parameters used were KVP 120, mAs 125, rotation time 1 s, pitch 0.8, slice thickness 3 mm and reconstructed to 0.6-mm high resolution. Field of view was not more than 300 mm.

Measurements from the scans were performed by an independent radiologist who had no knowledge of the Hertel exophthalmometer measurements. An interzygomatic line was first drawn on the axial view image in which the lens was best seen (Figure 1). A perpendicular line was then drawn from the inner corneal surface to the interzygomatic line, bisecting the lens. The length of this perpendicular line was taken as the primary measurement.

To look at intra-observer reliability, both Hertel exophthalmometer and CT measurements were repeated for all patients at a different sitting. The patients’ Hertel exophthalmometer readings were repeated after a few days when the patient returned for review, by the same ophthalmologist without referring to the previous measurements. For the CT measurements, the same radiologist repeated them a few days later, again without reviewing the previous CT measurements.

Statistical analysis was performed using SPSS 13.0 (SPSS Inc., Chicago, IL, USA), including unpaired t-tests to compare between the modalities and intraclass correlation coefficients to look at intra-observer differences. Correlations between the modalities were analysed with Pearson correlation.
coefficients while the Bland-Altman method was used to analyse the agreements between the modalities. Statistical significance was defined as $p < 0.05$.

**RESULTS**

Table 1 shows the demographic characteristics of the patients while Figure 2 shows the causes of proptosis in the 40 affected patients. Table 2 shows the Hertel exophthalmometer and CT measurements for both the normal and proptosis groups. Values are expressed as the mean ± SD (standard deviation). The differences between the normal and proptosis groups in both the Hertel and CT measurements were statistically significant ($p < 0.001$). The values assessed by Hertel exophthalmometry and CT for each group did not show statistically significant differences, although CT recorded a lower measurement compared to the Hertel exophthalmometer in both groups.

For Hertel exophthalmometry, the intraclass correlation coefficient (Cronbach’s alpha) was 0.99. For the CT measurements, the intraclass correlation coefficient (Cronbach’s alpha) was also 0.99. As shown in Figure 3, strong correlations between Hertel exophthalmometer and CT measurements were observed in both the normal and proptosis groups (Pearson’s correlation coefficient $r = 0.96$ and 0.93, respectively, both $p = 0.01$).

The 95% limits of agreement (LOA) between Hertel exophthalmometer and CT measurements were −0.7 to 1.8 mm and −2.4 to 3.3 mm for the normal and proptosis groups respectively (Figure 4). The limits of agreement in the normal group was smaller compared to that in the proptosis group. The mean difference (bias) between Hertel exophthalmometer and CT measurements in the normal and proptosis groups were $0.5 ± 0.6$ mm and $0.5 ± 1.5$ mm, respectively.

A total of 85% of readings in the proptosis group were within the range of 1–2 mm of each measurement method, and this reduced to 60% when a $<1$ mm limit was used.

**DISCUSSION**

We measured patients with and without proptosis to find out whether Hertel exophthalmometer measurements correlate and agree well with CT measurements. There were no significant differences between

| Table 1. Demographic characteristics of proptosis and normal patients. |
|---|---|---|---|---|
| **Sex** | **No.** | **%** | **No.** | **%** | **Total** | **p value** |
| Female | 23 | 56 | 18 | 44 | 41 | 0.263 |
| Male | 17 | 44 | 22 | 56 | 39 | 0.423 |
| Age | 39.33 ± 16.02 | 43.48 ± 15.86 | 0.248 |

| Table 2. Exophthalmometry values for the normal and proptosis groups. |
|---|---|---|---|
| **Normal group** | **Proptosis group** | **p value** |
| Hertel measurement (mm) | $14.5 ± 2.2$ | $20.5 ± 3.9$ | $<0.001$ |
| CT measurement (mm) | $13.9 ± 2.4$ | $20.0 ± 3.7$ | $<0.001$ |
| **p value** | 0.297 | 0.567 |

![Diagram](image.png)

FIGURE 2. Bar graph showing distribution of proptosis patients ($n = 40$) according to diagnosis.
FIGURE 3. Correlations between CT and Hertel exophthalmometer measurements. (A) normal group (Pearson’s correlation coefficient $r=0.96$, $p=0.01$). (B) proptosis group (Pearson’s correlation coefficient $r=0.93$, $p=0.01$).

FIGURE 4. Bland-Altman plots comparing the Hertel exophthalmometer and CT measurements. (A) normal group. (B) proptosis group. The limits of agreement for the proptosis group was larger than for the normal group.
the Hertel exophthalmometer and CT measurements in both normal and proptosis groups. However, the values measured by CT for both the normal and proptosis group were lower than the readings from Hertel exophthalmometry, by about 0.5 mm. Although not significant, this discrepancy could be due to the fact that clinical measurements with the Hertel exophthalmometer are referenced to the anterior corneal surface, whereas the CT measurements are referenced to the posterior corneal surface, as suggested by Segni et al.\textsuperscript{9} Since corneal thickness is approximately 0.5 mm, the lower values measured on the CT scan can be attributed to this difference in reference points. Additionally, the small difference could also be due to the natural postural proptosis in the seating or standing positions,\textsuperscript{10} or the human tendency to round up the readings on Hertel exophthalmometry due to its subjective method of measurement.

Intra-observer reliability indicates how readings obtained from the same observer at different time points may vary, and affect the reproducibility of proptosis measurements. From the intraclass correlation coefficients of 0.99 with both Hertel exophthalmometer and CT measurements, both methods were shown to be highly reliable and excellent reproducibility could be attained with same-observer measurements. This is in keeping with other reported studies.\textsuperscript{2,4,9}

CT measurements were strongly correlated with Hertel exophthalmometry in both the normal and proptosis groups, as showed by Pearson correlation coefficients of 0.96 and 0.93 respectively. This is similar to the results reported by Segni et al. and Hallin et al. from their work measuring proptosis with Krahn exophthalmometers and CT scans, where they obtained correlation coefficients of 0.91 and 0.73 respectively.\textsuperscript{9,11} Nkenke et al. also found non-significant differences in their study which involved comparison between Hertel exophthalmometers and CT scans.\textsuperscript{1}

Pearson’s correlation coefficient is a measure of the strength of linear association between two variables, but is not a measure of their agreement.\textsuperscript{8} In contrast, limits of agreements provide direct information on clinical agreement between two tested methods, by indicating how far apart their measurements are for most patients or individuals. For example, in our analysis, 95% LOA values of −0.7 to 1.8 mm means that CT measurements were between 0.7 mm less and 1.8 mm more than Hertel exophthalmometer measurements in 95% of our patients. We found the limits of agreements to be smaller in the normal group compared to the proptosis group. This indicates that in the proptosis group, the differences in measurements between modalities were larger. We postulate that this may be due to the exaggeration of postural proptosis in disease states as the two modalities are tested in different positions, which are supine for CT and sitting for exophthalmometry. Additionally, the divergence in correlation could also be due to the level of the CT slice which may not correspond to the area of maximal proptosis, unlike in Hertel exophthalmometry where the maximum protrusion is easier seen. Additional studies are indicated to determine the exact cause of this finding.

In the clinical setting where only up to 2 mm differences in exophthalmometry readings are considered acceptable, the wider limits of agreement in the proptosis group should be considered carefully.\textsuperscript{2,4,6,12} Although Hertel exophthalmometer and CT measurements in the normal and proptosis groups correlate well with each other, their readings are not interchangeable as they are not equivalent, especially in the presence of proptosis.

One limitation of this study was that we did not look at inter-observer variability with the two modalities. Knowledge of this variability could add to that of Hertel exophthalmometer and CT proptosis-measurement studies and potentially strengthen the results of our study. However, as mentioned previously, the higher variability of measurements between different observers have been widely reported.\textsuperscript{2,3,5,6} Additionally, due to the relatively small sample size, we did not stratify the patients by ethnic origin. It would have been interesting to see if there were any differences between the major ethnic groups in our population, i.e. Malay, Chinese and Indian.

**CONCLUSION**

Hertel exophthalmometer and CT measurements of globe position are similar and strongly correlated. However, the 95% limits of agreement between measurements from both modalities are comparatively large when there is proptosis. This weaker agreement suggests that the two results should not be used interchangeably; the difference between them may lead to errors in clinical interpretation.

**DECLARATION OF INTEREST**

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper. This study was supported by a grant from the University of Malaya, Kuala Lumpur, Malaysia (Research Grant RG485/12HTM).

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