BJR https://doi.org/10.1259/bjr.20211408

Received: 23 December 2021 | Accepted: 16 May 2023 | Published online: 19 June 2023

Cite this article as:
Muller-Lisse UG, Garip-Kuebler A, Murer S, Fuchsgruber F, Braeuninger C, Flatz W, et al. Hertel-exophthalmometry-like multi-detector-row-CT-exophthalmometry: inter-disciplinary inter-observer reproducibility of measurements. *Br J Radiol* (2023) 10.1259/bjr.20211408.

FULL PAPER

Hertel-exophthalmometry-like multi-detector-row-CT-exophthalmometry: inter-disciplinary inter-observer reproducibility of measurements

[1]ULLRICH G MULLER-LISSE, [2]AYLIN GARIP-KUEBLER, [3]SOPHIE MURER, [4]FLORIAN FUCHSGRUBER, [1]CHRISTIANE BRAEUNINGER, [1]WILHELM FLATZ, [2]SIEGFRIED PRIGLINGER, [2]CHRISTOPH HINTSCHICH and [2]ANNEMARIE KLINGENSTEIN

[1]Department of Radiology, Klinikum der Ludwig-Maximilians-Universität München, Munich, Bavaria, Germany
[2]Department of Ophthalmology, Klinikum der Ludwig-Maximilians-Universität München, Munich, Bavaria, Germany
[3]Department of Ear, Nose and Throat Surgery, Klinikum der Ludwig-Maximilians-Universität München, Munich, Bavaria, Germany
[4]Department of Anaesthesiology and Critical Care, München Klinik Bogenhausen, Munich, Germany

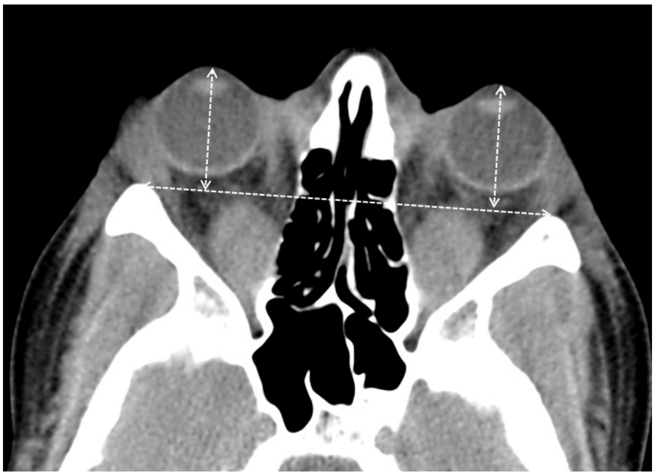
Address correspondence to: Prof. Dr. Ullrich G Muller-Lisse
E-mail: *Ullrich.mueller-lisse@med.uni-muenchen.de*

Objectives: To investigate the interdisciplinary interobserver reproducibility of Hertel-exophthalmometry-like protrusion measurements on multidetector-row-computed-tomography- (MDCT-) images of the orbit to facilitate structured evaluation of the orbit and mid-face.
Methods: Respective reproducibility of base-length along the interfronto-zygomatic line, right and left ocular protrusion, and deriving interocular difference was measured in this retrospective (04/2009-03/2020) single-centre observational study. MDCT-series and slice-positions were selected independently, using picture-archiving-and-communication-system- (PACS-) tools on tilt-corrected axial MDCT-images (slice-thickness 0.6–3.0 mm, window/centre 350/50 HU) in 37 selected adult patients (24 female, age 57 ± 13 years, average±standard-deviation) with clinical indication for Hertel-exophthalmometry, by one radiology-attending, two ophthalmology-attendings, one critical-care-attending, and one ear-nose-throat-surgery resident, respectively. Bland-Altman plots and Wilcoxon-matched-pairs-signed-rank-tests compared interobserver results.
Results: Mean and median interobserver and intraobserver (radiology-attending) deviations were within 1 mm of respective averages of base-length (98 ± 4 mm), right and left ocular protrusion (21 ± 4 mm) and interocular difference (2 ± 1 mm). Relative interobserver deviations were within 2.0% of average (all patients) for base-length, and 5.0% (>80% of patients) for ocular protrusion. Pairwise interobserver comparison showed no significant differences between interocular differences of protrusion.
Conclusions: Respective measurements of base-length, ocular protrusion, and deriving interocular difference show high interdisciplinary interobserver reproducibility in tilt-corrected axial MDCT-images of the orbit or mid-face.
Advances in knowledge: Hertel-exophthalmometry-like protrusion measurements did not depend on the years of experience or the medical subspecialty of the observer. Measurements are objective, well reproducible and important for multiple medical disciplines and should thus be included in pertinent radiology reports.

INTRODUCTION

Exophthalmos is a clinical symptom where the globe protrudes from the eye socket, making it appear to bulge. This frequent and important symptom in orbital and oculoplastic surgery consultations may affect one or both eyes. A wide spectrum of conditions may cause exophthalmos, including inflammatory, vascular, posttraumatic, or benign or malignant neoplastic diseases.[1] Measuring the anterior position of the eyeball relative to the orbital rims quantifies exophthalmos.[2,3] Hertel-exophthalmometry is a very common clinical means of measuring exophthalmos.[3,4] Hertel-exophthalmometry establishes the interfronto-zygomatic line (baseline), determines the distance between the crests of the lateral orbital rims along the baseline (base-length) and assesses the respective perpendicular distance from the baseline to the corneal apex of each eye (ocular protrusion). An ocular protrusion of 12–21 mm is within normal limits, with the upper limit of people of African origin being slightly higher (about 23–24 mm).[5] In general, a difference in protrusion between both eyes exceeding

Figure 1. Axial multiplanar reconstruction, of unenhanced 64-row multidetector-row-computed-tomography of the orbits (slice thickness, 3 mm). Tilt-correction was deemed unnecessary. Two-sided arrow along the interfronto-zygomatic line demonstrates measurement of base-length. Perpendicular two-sided arrows show respective measurements of right and left ocular protrusion.



2 mm is considered pathologic.[6] Interobserver reproducibility for Hertel-exophthalmometry is about 60% within ±1 mm[7] and 96% within ±2 mm.[8] Variation between different Hertel-type exophthalmometers is about 0.6–2.4 mm, and repeatability with the same exophthamometer averages at 0.5 mm.[9] Single-mirror exophthalmometers loose accuracy when assessing ocular protrusion less than 12 mm or higher than 23 mm, respectively.[10]

Cross-sectional imaging (computed tomography, CT, or magnetic-resonance imaging, MRI) is frequently indicated in patients presenting with exophthalmos, particularly when the underlying pathology needs to be clarified. Different methods of measuring exophthalmos on CT-images have been described,[11–13] with substantial correlation with Hertel-exophthalmometry in thyroid-associated orbitopathy.[11] CT-data-sets from modern multidetector-row-CT- (MDCT) scanners allow for tilt-corrected multiplanar image-reconstructions (MPR) which display cross-sectional anatomy symmetrically for both orbits.

Measuring exophthalmos on MDCT-images of the orbits or mid-face and including results in pertinent radiology reports may be clinically meaningful if such measurements are reproducible within narrow margins between physicians in different subspecialties, including, *e.g.*, radiology and neuroradiology, ophthalmology, ear-nose-throat-surgery (ENT), maxillo-facial surgery, neurosurgery or critical care.

This retrospective interdisciplinary interobserver study investigated the reproducibility of base-length and ocular protrusion on tilt-corrected axial MDCT-images of the orbits and of deriving interocular difference.

METHODS AND MATERIALS

The manuscript structure followed the STROBE statement.[14]

Study design

The institutional ethics-committee for studies involving human participants decided that this retrospective single-centre observational study in selected patients did not require ethical advice and waived individual patient-consent (vote No. 20–633 KB). However, all patients provided written informed consent for MDCT-work-up.

Setting and participants

The hospital information-system (HIS) was searched in April 2020, for complete records of adult patients presenting with exophthalmos to the orbital/oculoplastic-surgery section of the institutional tertiary-care eye-hospital who subsequently underwent both MDCT of the orbits and Hertel-exophthalmometry within the institution between April 2009, and March 2020. In this study, Hertel-exophthalmometry, performed between eight days and one year of MDCT without interval surgery, solely served as a retrospective inclusion criterion indicating that exophthalmometry had been necessary for clinical patient-care and had been technically successful. The latter suggested that MDCT-based exophthalmometry was possible. However, due to inter-individual time differences between Hertel-exophthalmometry and MDCT, and interval conservative therapy in some patients, respective results were not compared.

Variables

Base-length, respective right and left ocular protrusion on axial MDCT-images, and deriving interocular difference of protrusion were dependent variables whose outcomes were continuous positive rational numbers with “mm” as unit of measurement. Individual independent observers represented the independent variable. Independent selection of CT-series and axial CT-image-level by each observer were effect-modifiers.

Data sources and measurements

The orbital MDCT-examination closest in time to HIS-documented Hertel-exophthalmometry was retrieved for each patient from the institutional picture-archiving-and-communication system (PACS, Syngo, Siemens Healthineers). Diagnostic 16-row- or 64-row-MDCT-scans (Optima 660 or Discovery 750, GE Healthcare, or Mx8000 IDT or Brilliance 64, Philips Medical Systems, or Somatom Scope, Siemens Healthineers) had been performed supine, head on a cranial-CT head-rest, and eyes looking straight-forward into the gantry if possible, collimation 0.625 mm, 120KVp, and dose-modulation as appropriate. Intravenous contrast media were administered in body-weight-adapted standard-doses, followed by 60 ml of normal saline solution, for imaging in the venous phase, approximately 60 s after commencing contrast-media injection. Unenhanced MDCT was performed instead for suspected dysthyroid optic neuropathy in six patients, and in two patients who reported previous severe reaction to intravenous contrast media. MPR in the axial, coronal, and sagittal planes were based on primary reconstructions with a slice-thickness of 0.625 mm, and tilt-corrected when necessary to the interfronto-zygomatic line connecting the rostral fronto-zygomatic sutures, with fields-of-view adapted to the respective morphological dimensions of

Table 1. Respective patient-population average-values and mean, median, minimum, and maximum absolute interobserver deviations of base-length, right and left ocular protrusion, and interocular difference of protrusion on axial CT-images of the orbit (n = 37 patients; m = 5 independent observers)

Population values (all patients, all observers)	Base-length (mm)	Right ocular protrusion (mm)	Left ocular protrusion (mm)	Interocular difference of protrusion (absolute, mm)
Population average	98	21	21	2
Standard deviation	4	4	4	1
Deviation from mean				
Mean deviation of observers	1	1	1	1
Standard-deviation of mean deviation of observers	1	1	1	1
95% limits of agreement [a]	±1.8	±1.7	±1.8	±2.0
Median deviation from mean of observers	1	1	1	0
Minimum deviation from mean of observers	0	0	0	0
Maximum deviation from mean of observers	5	4	3	4

Values are rounded to the next full millimetre except for 95% limits of agreement.
[a] 95% limits of agreement were calculated as ±1.96*standard-deviation of mean deviation of observers.

the orbits and mid-face, and reconstruction slice thicknesses of 0.6–3.0 mm, respectively.

Independent observers included one radiology-attending specializing in head-and-neck imaging with 18 years of post-fellowship work-experience, two ophthalmology-attendings specializing in orbital/oculoplastic surgery with five and six years of post-fellowship work-experience, one critical-care-attending with six years of post-fellowship work-experience, and one second-year ENT-resident, respectively. The radiology attending repeated measurements after three weeks. Observers individually selected the axial MDCT-series that displayed the orbits most symmetrically, and the individual MDCT-image in that series which best bisected both ocular lenses and came closest to the equators of both eyeballs. The selected MDCT-image was displayed in soft-tissue window (W350/C50 HU) on a 21-inch 5K-monitor licensed for medical image interpretation. Applying measurement-tools provided by PACS, base-length was measured along the baseline, between the crests of the right and left bony lateral orbital rims, and respective protrusion of each eye was determined as the distance from the baseline to the corneal apex along a perpendicular line (Figure 1), per Figure 1 (A) in.[11] Submillimetre results were rounded mathematically to the next full millimetre.

Bias

Separation of HIS-searches and extraction of clinical data from blinded review of and measurements on MDCT-images precluded bias of MDCT-results. Each observer independently reviewed the orbital MDCT-scans of all selected patients in individualized order, per ascending random numbers as generated individually by MS-Excel (Microsoft Corporation), to avoid potential bias from learning-effects.

Study size

The study population included thirty-seven patients. Among forty-seven patients appearing eligible, ten were subsequently excluded because they were underage (two), had out-of-range time-intervals between MDCT and Hertel-exophthalmometry (one), did not have dedicated MDCT of the orbits (six), or had incomplete data sets, because Hertel-exophthalmometry had failed (one).

Quantitative variables and statistical methods

Each observer entered respective MDCT-series and MDCT-image-level, and measurements of base-length and right and left ocular protrusion for each patient into a standardized MS-Excel-worksheet, with patient-names and dates-of-birth replaced by identifying numbers, ages, and genders for study purposes. The radiology attending performed measurements twice, with an interval of 21 days, for analysis of intraobserver repeatability. Raw data were collated in another MS-Excel-worksheet for analysis. Respective interobserver average-values and mean, median, minimum, and maximum absolute and relative (percent) deviations of base-length, right and left ocular protrusion, interocular difference of protrusion, and CT-image-level were calculated and displayed in tables and Bland-Altman plots. Pairwise comparison between and within observers of deriving differences of

Table 2. Mean relative interobserver deviation from individual patient average-measurements of base-length and right and left ocular protrusion on axial CT-Images of the orbit (n = 37 patients; m = 5 independent observers)

Mean relative interobserver deviation from individual patient average-measurement	Base-length (No. of patients)	Right ocular protrusion (No. of patients)	Left ocular protrusion (No. of patients)
<1.0%	31	0	1
1.0–1.9%	6	10	10
2.0–2.9%	0	12	7
3.0–5.0%	0	9	12
>5.0%	0	6	7

protrusion in two-tailed Wilcoxon-matched-pairs-signed-rank-tests, and of rates and proportions in chi-square-tests yielded significant differences for $p < 0.05$.[15]

RESULTS

Participants

Twenty-four patients were females and thirteen males. Age was 57 ± 13 years (average±standard deviation, median, 57, range, 25–84). Median time between MDCT and Hertel-exophthalmometry was 23 days (range, 8–281). Final clinical diagnosis was benign neoplasia in six, malignancy in thirteen, inflammatory disease in fourteen and other in four (excluding facial trauma).

Main results

Table 1 displays respective patient-population average-values and interobserver deviations between measurements. Mean and median deviations were within 1 mm of each, and 95%-limits of agreement were about 2 mm for each, interobserver average-measurements of base-length, right and left ocular protrusion and interocular difference of protrusion. Relative deviation was within 2.0% of average-measurements for base-length in all patients, and within 5.0% in more than 80% of patients for ocular protrusion, without statistically significant differences between right and left eyes (chi-square = 0), respectively (Tables 1 and 2, Figure 2; see Supplementary Tables 1-4 for respective raw data). Pairwise comparison between observers yielded no significant differences between respective calculated interocular differences of protrusion (Table 3).

Intra-observer repeatability of measurements after three weeks by the radiology attending yielded the same MDCT-series in 31/37 patients (84%) and slice selection within one level in all. Intra-observer differences between measurements were 1 mm or

Figure 2. Respective Bland-Altman plots show interdisciplinary interobserver agreement with upper and lower limits of agreement (dark grey horizontal lines) among five independent observers (O1, diamonds; O2, squares; O3, triangles; O4, cross-marks; O5, circles). Measurements include base-length (a, upper left panel), interocular difference of protrusion (b, upper right panel), right ocular protrusion (c, lower left panel) and left ocular protrusion (d, lower right panel) in 37 patients. Unit of measurement is 1 mm in each panel.

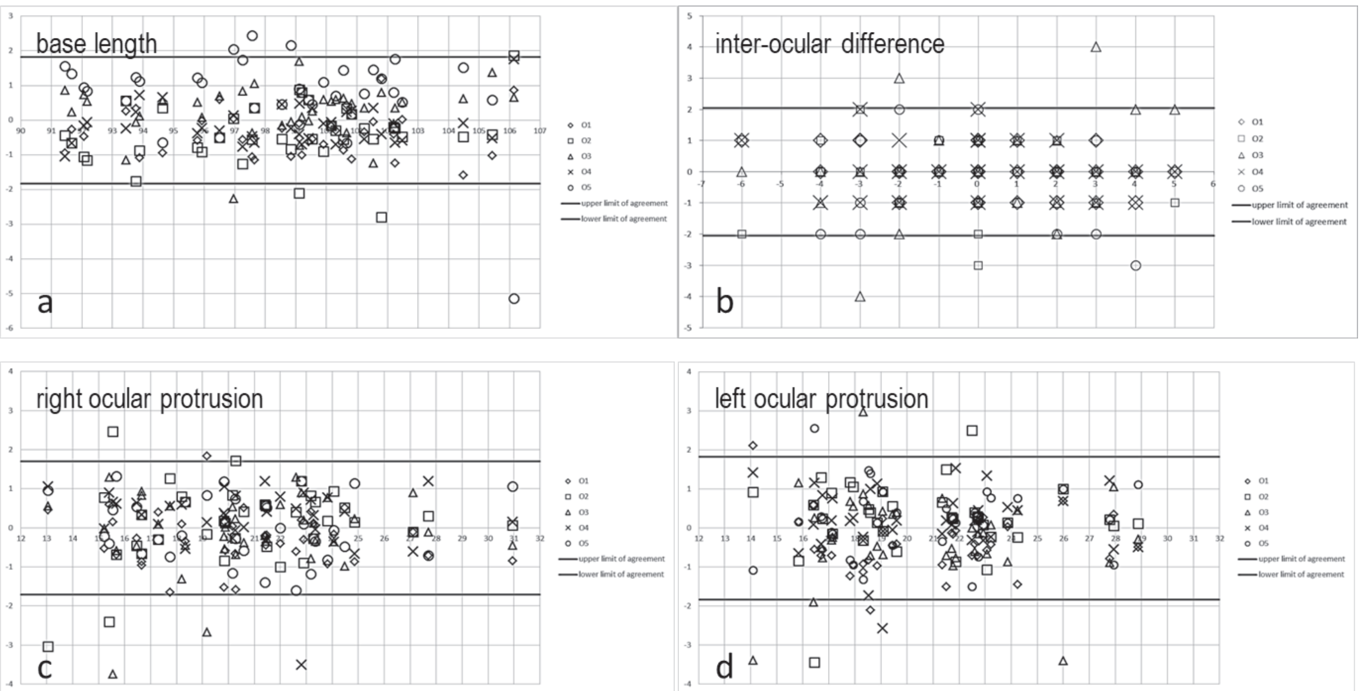
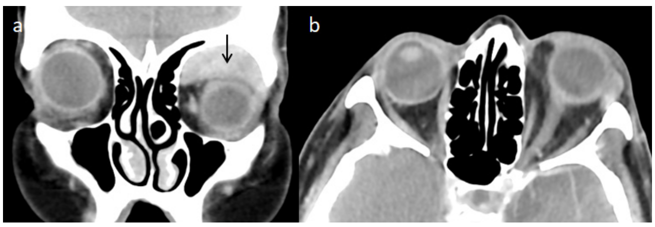


Table 3. Pairwise comparison between five independent observers (O1 to O5) of respective calculated interocular differences of protrusion on axial MDCT-images of the orbit (n = 37 patients). Two-tailed Wilcoxon-matched-pairs-signed-ranks-test with critical values for alpha-error <5%.

Test	No. of ties	No. of ranks	Rank sum	Negative ranks (sum)	Positive ranks (sum)	Critical value	Statistically significant differences
O1 versus O2	17	20	210	89	121	52	no
O1 versus O3	12	25	325	172.5	152.5	89	no
O1 versus O4	16	21	231	104	127	58	no
O1 versus O5	14	23	276	86.5	189.5	73	no
O2 versus O3	16	21	231	138.5	92.5	58	no
O2 versus O4	14	23	176	148	128	73	no
O2 versus O5	9	28	406	173	233	116	no
O3 versus O4	8	29	435	200.5	234.5	126	no
O3 versus O5	8	29	435	148	287	126	no
O4 versus O5	13	24	300	109	191	81	no

Figure 3. Tilt-corrected multiplanar reconstructions of contrast-enhanced 64-row multidetector-row-computed-tomography of the orbits are orientated along the interfronto-zygomatic reference line as displayed by PACS (arrows in a, coronal reconstruction, and b, axial reconstruction; slice thickness, 2 mm).

Figure 4. Tilt-corrected multiplanar reconstructions of contrast-enhanced 64-row multidetector-row-computed-tomography of the orbits are orientated along the interfronto-zygomatic reference line (slice thickness, 2.5 mm). A contrast-enhancing orbital mass displaces the left eyeball (arrow in a, coronal reconstruction), impeding exact measurement of left ocular protrusion on the axial reconstruction (b). This patient was excluded from the study because of incomplete data sets, *i.e.,* Hertel-exophthalmometry had been attempted but failed.



less in 36/37 patients for base-length (97%; 1 tie; test statistic, 295; critical value, 182; not statistically significant, ns). Repeat measurements of ocular protrusion were statistically shorter for both eyes. Differences were 1 mm or less in 35/37 right eyes (95%; 0 ties; 210.5; 221; p<0.05), and in 33/37 left eyes (89%; 4 ties; 147; 170; p<0.05). All other differences were 2 mm. Resulting inter-ocular difference of protrusion was 1 mm or less in 36/37 patients (97%; 1 tie; 303.5; 182; ns), the one greater difference being 3 mm.

Other analyses

The five independent observers decided on the same axial MDCT-series in 14/37 patients (38%), on two different MDCT-series in 19 (51%), and on more than two in 4 (11%). Among 185 individual series selections, 164 (89%) matched for at least two observers, with 157/164 individual slice-selections (96%) being within one slice-level (average slice thickness, 2.2 ± 0.8 mm) of one another.

Tilt-corrected axial MDCT-images were generated in 16 patients (43%) and had been deemed unnecessary in 21 (57%) (Figure 3). Among 185 individual observations, the five independent observers reported technically symmetrical display of both orbits in the selected axial MDCT-series in 172 (93%), and called asymmetry in 13 (7%), including calls by one observer in nine patients and by two observers in two. Displacement of one eyeball was noted in eight patients (two cranial, six caudal). These patients were included in the analysis, because Hertel-exophthalmometry had been technically successful. However, Figure 4 shows displacement of one eyeball deemed too severe for meaningful exophthalmometry; this patient was excluded from the study because Hertel-exophthalmometry had failed.

DISCUSSION

Key results

Interdisciplinary interobserver reproducibility and intraobserver repeatability of measurements of exophthalmos, including base-length, right and left ocular protrusion, and calculated interocular difference of protrusion, on tilt-corrected axial MDCT-images of the orbits and mid-face were high in this study. Hertel-exophthalmometry-like protrusion measurements on tilt-corrected axial MDCT-images did not depend on the medical subspecialty or the years of work-experience of the assessing physician.

Limitations

The retrospective, single-centre design, the criteria of patient-selection, and the small number of patients may limit generalisability. However, there is no conceivable advantage of a prospective study assessing the interobserver reproducibility of quantitative measurements on MDCT-images. Various potential effect-modifiers were considered. Institutional MDCT-examinations represented five different MDCT-scanners of two different scanner-generations and three different manufacturers. Each observer individually selected respective axial MDCT-series and MDCT-images to perform requested measurements. Individual MDCT-series had different slice-thicknesses and were individually tilt-corrected. The five independent observers represented four different clinical subspecialties involved with the evaluation of cerebral and orbital cross-sectional imaging in routine practice, and a vast spectrum of work-experience, respectively. Retrospective selection of patients who had institutional Hertel-exophthalmometry generated a study-population uniformly characterized by the clinically conceived need for exophthalmometry and proved that exophthalmometry was technically successful. Among the neoplastic orbital lesions in this study, two-thirds were malignant and one-third benign, a proportion previously encountered in a review of orbital tumours.[1]

Interpretation

Within their limitations, study results suggest that Hertel-exophthalmometry-like measurements of exophthalmos on tilt-corrected MDCT-images of the orbits and mid-face are highly precise and reproducible between independent observers representing different medical subspecialties and years of clinical expertise, and highly repeatable for an experienced radiologist. In a previous study of Hertel-exophthalmometry in 70 Chinese adults, Lam and co-workers[16] demonstrated high intraobserver and acceptable interobserver agreement, the latter showing wider 95% limits of agreement than our study results. While different studies[11,17,18] report substantial-to-high correlation between Hertel-exophthalmometry and different methods of CT-exophthalmometry, Nkenke and co-workers[13] report differences in patients with zygomatic fractures, finding CT more clinically reliable. Reliability of Hertel-exophthalmometry can be challenged for both patient-related reasons, such as, *e.g., facial fractures, severe upper eyelid swelling, eyelid ptosis, vertical deviation of the globe, and poor compliance, and observer-related reasons, such as, e.g., inter- and intraobserver variability of measurements, and dependency on clinical experience.*[4,7–11,13] Different researchers agree that CT should not be applied interchangeably with Hertel-exophthalmometry.[11,13,17]

Exophthalmos can be measured in different ways on CT-images.[11] Technically, the method applied here comes close to Hertel-exophthalmometry, because it first establishes a baseline touching the lateral orbital rims tangentially, which is superimposed on the selected axial CT-image, and then measures ocular protrusion along a line perpendicular to the baseline, which crosses the ocular lens at its centre and extends to the corneal apex of the eyeball. Tilt-corrected MPR could be the reason why the five independent observers found most axial MDCT-series selected depicting the orbits and mid-face with technical symmetry. Recent research suggests that MDCT-measurements are significantly more consistent with Hertel-exophthalmometry when based on three-dimensional MPR applying anatomical landmarks, i.e. applying tilt-correction, than when conventional two-dimensional MDCT-reconstructions are used.[19]

Generalisability

This retrospective single-centre observational cohort-study showed high interdisciplinary interobserver reproducibility and intraobserver repeatability of Hertel-exophthalmometry-like measurements of base-length and ocular protrusion on tilt-corrected axial MPR-MDCT-images of the orbit and midface. It derives that the multiplanar reconstruction of MDCT-images covering the orbits should consider anatomical landmarks to allow for precise and reproducible measurements in and comparison between individual eyes, and that radiology reports on MDCT-examinations of the orbit or midface should include respective measurements of base-length and protrusion of each eye.

Integrity of research and reporting

Ethical standards:

The institutional ethics-committee for studies involving human participants decided that this retrospective single-centre observational study did not require ethical advice and waived individual patient-consent (vote No. 20–633 KB). The study has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

AUTHORS' CONTRIBUTIONS

All authors made substantial contributions to the conception and design, or the acquisition, analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work.

AVAILABILITY OF DATA AND MATERIAL (DATA TRANSPARENCY)

Supplementary tables with raw data of individual measurements are submitted. Additional information is available from the corresponding author upon reasonable request.

FUNDING

Open Access funding enabled and organized by Projekt DEAL.

ETHICS APPROVAL

The ethics-committee for studies involving human participants of Ludwig-Maximilians-Universität, Munich, Germany waived individual patient-consent for this study (vote No. 20-633-KB).

REFERENCES

1. Hassler W, Unsöld R, Schick U. Orbital tumors. *Diagnosis and Surgical Treatment Dtsch Ärztebl* 2007; **1004**: 496–501.
2. Ameri H, Fenton S. Comparison of unilateral and simultaneous bilateral measurement of the globe position, using the Hertel Exophthalmometer. *Ophthalmic Plast Reconstr Surg* 2004; **20**: 448–51. https://doi.org/10.1097/01.iop.0000143712.42344.8c
3. Segni M, Bartley GB, Garrity JA, Bergstralh EJ, Gorman CA. Comparability of Proptosis measurements by different techniques. *Am J Ophthalmol* 2002; **133**: 813–18. https://doi.org/10.1016/s0002-9394(02)01429-0
4. Lam AKC, Lam C, Leung W, Hung P. Intra-observer and Interobserver variation of Hertel Exophthalmometry. *Ophthalmic Physiol Opt* 2009; **29**: 472–76. https://doi.org/10.1111/j.1475-1313.2008.00617.x
5. de Juan E, Hurley DP, Sapira JD. Racial differences in normal values of Proptosis. *Arch Intern Med* 1980; **140**: 1230–31. https://doi.org/10.1001/archinte.140.9.1230
6. Klingenstein A, Hintschich C. Diagnostic Management of Exophthalmos. Klin Monatsbl Augenheilk 2017;234:53-8.
7. Kashkouli MB, Beigi B, Noorani MM, Nojoomi M. Hertel Exophthalmometry: Reliability and Interobserver variation. *Orbit* 2003; **22**: 239–45. https://doi.org/10.1076/orbi.22.4.239.17245
8. Mourits MP, Lombardo SHC, van der Sluijs FA, Fenton S. Reliability of Exophthalmos measurement and the Exophthalmometry value distribution in a healthy Dutch population and in Graves patients. *Orbit* 2004; **23**: 161–68. https://doi.org/10.1080/01676830490504089
9. Sleep TJ, Manners RM. Interinstrument variability in Hertel-type Exophthalmometers. *Ophthalmic Plast Reconstr Surg* 2002; **18**: 254–57. https://doi.org/10.1097/00002341-200207000-00004
10. Vardizer Y, Berendschot TTJM, Mourits MP. Effect of Exophthalmometer design on its accuracy. *Ophthalmic Plast Reconstr Surg* 2005; **21**: 427–30. https://doi.org/10.1097/01.iop.0000180066.87572.39
11. Park NR, Moon JH, Lee JK. Hertel Exophthalmometer versus computed tomography Scan in Proptosis estimation in thyroid-associated Orbitopathy. doi: https://doi.org/10.2147/OPTH.S216838
12. Fang ZJ, Zhang JY, He WM. CT features of Exophthalmos in Chinese subjects with thyroid-associated Ophthalmopathy. *Int J Ophthalmol* 2013; **6**: 146–49. https://doi.org/10.3980/j.issn.2222-3959.2013.02.07
13. Nkenke E, Benz M, Maier T, Wiltfang J, Holbach LM, Kramer M, et al. Relative En- and Exophthalmometry in Zygomatic fractures comparing optical non-contact, non-ionizing 3D imaging to the Hertel instrument and computed tomography. *J Craniomaxillofac Surg* 2003; **31**: 362–68. https://doi.org/10.1016/j.jcms.2003.07.001
14. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *International Journal of Surgery* 2014; **12**: 1495–99. https://doi.org/10.1016/j.ijsu.2014.07.013
15. Glantz SA. Primer of biostatistics, 4th edn. McGraw-Hill, New York, 1997.
16. Lam AKC, Lam C, Leung W, Hung P. Intra-observer and inter-observer variation of Hertel Exophthalmometry. *Ophthalmic and Physiological Optics* 2009; **29**: 472–76. https://doi.org/10.1111/j.1475-1313.2008.00617.x
17. Ramli N, Kala S, Samsudin A, Rahmat K, Abidin ZZ. Proptosis—correlation and agreement between Hertel Exophthalmometry and computed tomography. *Orbit* 2015; **34**: 257–62. https://doi.org/10.3109/01676830.2015.1057291
18. Huh J, Park SJ, Lee JK. Measurement of Proptosis using computed tomography based three-dimensional reconstruction software in patients with Graves' Orbitopathy. *Sci Rep* 2020; **10**(1): 14554. https://doi.org/10.1038/s41598-020-71098-4
19. Guo J, Qian J, Yuan Y. Computed tomography measurements as a standard of Exophthalmos? two-dimensional versus three-dimensional techniques. *Curr Eye Res* 2018; **43**: 647–53. https://doi.org/10.1080/02713683.2018.1431285