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OCULOPLASTICS AND ORBIT

Normative measurements of inferior oblique muscle thickness in Japanese by magnetic resonance imaging using a new technique

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Abstract

Purpose To measure the thickness of the inferior oblique muscle (IOM) among Japanese by magnetic resonance imaging (MRI) using a new technique.

Methods This retrospective observational study included 78 patients (36 males and 42 females) who underwent MRI for detection of a unilateral orbital lesion or examining causes of unilateral retrobulbar pain. The thickness of the IOM was measured on the side without the orbital lesion or symptom. On the quasi-sagittal plane through the optic nerve, the major and minor axes of the cross-section of the IOM were measured. On the coronal plane, the maximum thickness perpendicular to the course of the IOM was measured. All measurements were performed using the digital caliper tool of the viewing software.

Results The major and minor axes on the quasi-sagittal plane and the maximum IOM thickness on the coronal plane were 8.00 ± 1.83 mm, 2.98 ± 0.55 mm, 3.04 ± 0.55 mm respectively. There were no significant differences in IOM thickness measurements between sexes and sides ($P > 0.050$, Student's *t*-test). No significant correlation with the major axis ($r = 0.064$, $P = 0.576$), minor axis ($r = -0.065$, $P = 0.573$) or the maximum thickness on the coronal plane ($r = -0.099$, $P = 0.387$) was found in relation to age (Pearson's correlation coefficient).

Conclusions The normative IOM thickness in Japanese was presented on MRI, which were similar among all ages irrespective of sex and side. The new technique we used is easily applicable, and the results may serve as a guide to detect IOM involvement in inflammatory and neoplastic conditions of the orbit.

Keywords Inferior oblique muscle · Thickness · Magnetic resonance imaging · Quasi-sagittal plane · Coronal plane

Introduction

The involvement of the inferior oblique muscle (IOM) has been reported in certain inflammatory and neoplastic conditions affecting the orbit. Although relatively uncommon, thyroid-associated orbitopathy [1, 2], sarcoidosis [3, 4], IgG4-related ophthalmic disease (IgG4-ROD) [5], and lymphomas [6] are among the disease entities with documented enlargement of the IOM.

Knowledge of normal IOM size can help elucidate this phenomenon. Our previous study examined the normal thickness of the IOM in Japanese, in which measurements were taken from the quasi-sagittal plane of the orbits of cadaveric specimens [7]. As tissue shrinkage is expected after formalin fixation [8], in-vivo measurements are still more reliable for clinical application.

Magnetic resonance imaging (MRI) is currently the best method to determine extraocular muscle (EOM) size in vivo as it provides better soft tissue contrast compared to other radiologic modalities [9]. This is especially important since the oblique muscles are very small and are subsequently the most difficult to measure in any plane [9, 10]. Three previous studies measured the normative IOM size by MRI using its cross-sectional area and/or volume [10–12]; however, the measurement techniques that were used are not always available. An ideal measurement method should be accessible, readily available, easy to perform, and have a short learning curve [9]. A study on Caucasians determined the normative values of IOM thickness on coronal MRI [13]. Although the measurement method used was easily accessible, IOM thickness varies depending on where the slice is made on the

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coronal plane. The sagittal plane, on the other hand, better visualizes the maximum thickness of the IOM along the axis perpendicular to the orbital floor. Moreover, significant differences in EOM thickness exist among different races [14, 15].

This study examined the normal thickness of the IOM in Japanese by MRI through the quasi-sagittal and coronal planes using a new technique.

Materials and methods

Study design, patients, and ethics approval

This study was a retrospective chart review of consecutive Japanese patients who underwent MRI for detection of a unilateral orbital lesion, including an orbital tumor, orbital haematoma, or orbital cellulitis, or for examining causes of unilateral retrobulbar pain at our department between May 2013 and October 2017. Patients with unilateral carotid cavernous fistula who underwent MRI during follow-up more than 1 year after surgical intervention were also included. Patients with autoimmune diseases, malignant lymphomas, vascular abnormalities and other systemic and orbital conditions that can bilaterally involve the EOMs were excluded [1–6, 16, 17]. Patients with high myopia (spherical power ≥ 6 diopters), which can cause elongation of the EOMs [18], and those who had undergone cataract surgery were also excluded. In addition, we excluded patients who were not cooperative with taking MRI without sedation.

This study was approved by the Institutional Review Board (IRB) of Aichi Medical University Hospital (approval number, 2017-H166) and followed the tenets of the 1964 Declaration of Helsinki. The IRB granted a waiver of informed consent for this study on the basis of the ethical guidelines for medical and health research involving human subjects established by the Japanese Ministry of Education, Culture, Sports, Science, and Technology and the Ministry of Health, Labour, and Welfare. The waiver was granted because the study was a retrospective review and not an interventional study, and because it was difficult to obtain consent from patients who had been treated several years prior to this study. Nevertheless, at the request of the IRB, we published, on the Aichi Medical University Hospital website, an outline of the study, available for public viewing. This public posting also gave patients an opportunity to decline participation, although none of the patients did so. Personal identifiers were removed from the records prior to data analysis.

Data collection

The following data were collected from the medical charts reviewed: age, sex, affected side, past medical history, refractive power, and clinical diagnosis. We also collected data on histopathological results in patients with an orbital tumor.

MRI was performed using a 1.5-Tesla scanner (Magnetom Abant™; Siemens Healthcare, Erlangen, Germany). The head of the patient was stabilized while supine. Instructions were given to look at a central fixation target (light source) to ensure the eyes were fixed in the primary position. Quasi-sagittal (parallel to the optic nerve) and coronal T1-weighted gradient-echo sequences were acquired (T1-repetition time: 500 ms, echo time: 10 ms, field of view: 140 × 140 mm, matrix: 256 × 220, section thickness: 3 mm).

The thickness of the IOM on the side without the orbital lesion was measured on a quasi-sagittal image through the optic nerve and on a coronal image. On the quasi-sagittal plane, the major and minor axes of the maximum cross-section of the IOM were measured (Fig. 1a). The minor axis was perpendicular to the major axis. On the coronal plane, the maximum thickness perpendicular to the course of the IOM was measured (Fig. 1b). All measurements were performed using the digital caliper tool of the image viewing software (ShadeQuest/ViewR; Yokogawa Medical Solutions Corporation, Tokyo, Japan) by one of the authors (YT).

Statistical analysis

Patient age and IOM thickness were expressed as means ± standard deviations. The measurements were compared between sexes and sides using Student's *t*-test. The correlation between patient age and IOM thickness was analyzed using Pearson's correlation coefficient. These statistical analyses were performed using SPSS™ version 22 software (IBM Japan, Tokyo, Japan). A P value of < 0.05 was considered statistically significant.

Results

Seventy-eight patients (36 males and 42 females; 45 right and 33 left; age, 54.2 ± 18.3 years; range: 13–92 years) were included in this study. Patient demographic data is shown in Table 1. None of the patients had high myopia (spherical power ≥ 6 diopters). The measurements and statistical comparisons are summarized in Table 2. Patient age was not significantly different between sexes ($P = 0.613$) or sides ($P = 0.895$).

The major and minor axes on the quasi-sagittal plane and the maximum thickness on the coronal plane were 8.00 ± 1.83 mm, 2.98 ± 0.55 mm, 3.and 04 ± 0.55 mm, repectively. These measurements were not significantly different between sexes or sides ($P > 0.050$). No significant correlation with the major axis ($r = 0.064$, $P = 0.576$), minor axis ($r = -0.065$, $P =$

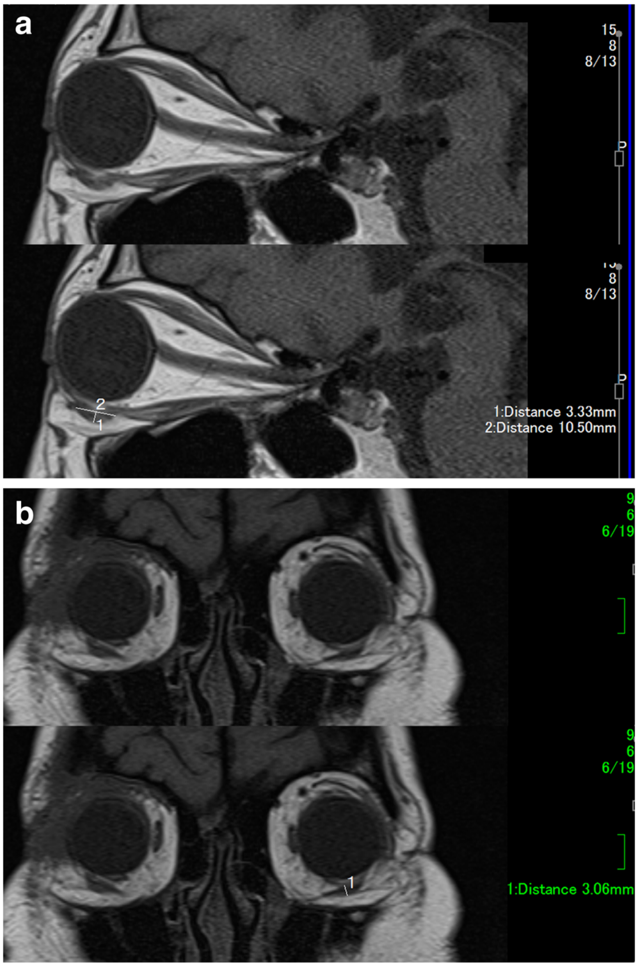

Fig. 1 Measurements of inferior oblique muscle (IOM) thickness. **a** The major and minor axes of the cross-section of the IOM on the quasi-sagittal image through the optic nerve. *1*: major axis, *2*: minor axis. **b** The maximum thickness (*1*) of the IOM on the coronal plane

0.573) or the maximum thickness on the coronal plane ($r = -0.099$, $P = 0.387$) was found in relation to age (Fig. 2).

Discussion

We have described the normative IOM thickness of Japanese through MRI measurements in the quasi-sagittal and coronal planes using a new technique.

No sex- and side-related differences were found between the thickness measurements, which are similar to earlier studies [7, 19]. The relationship between gender and EOM thickness has been described previously, in which males showed significantly larger muscle thickness than females [20–22]. However, these studies did not include measurements of the IOM. In our present and previous studies, although the measurement results were also slightly larger in males than females, this difference lacked significance [7].

Table 1 Demographic data

Number of orbits	78
Past history	
Asthma	1
Hypertension	5
Angina pectoris	1
Hepatitis C	1
Cirrhosis hepatis	1
Atopic dermatitis	1
Reduction of orbital blowout fracture	6
Sinusitis	3
Papilloma in the paranasal sinus	1
Congenital ptosis	2
(Suspension surgery)	1
Suture blepharoplasty	1
Not remarkable	56
Spherical power (range) (dioptre)	−0.53 ± 2.04 (−5.25 to 4.00)
Affected side (right/left)	45/33
Diagnosis	
Adenoid cystic carcinoma	5
Rhabdomyosarcoma	1
Adenoid cystic carcinoma from the maxillary sinus	1
Squamous cell carcinoma from the maxillary sinus	2
Undifferentiated carcinoma from the nasal cavity	1
Eyelid sebaceous gland carcinoma	1
Haemangioma	11
Meningioma	2
Schwannoma	4
Pleomorphic adenoma	1
Solitary fibrous tumor	2
Dermoid cyst	2
Simple cyst	1
Retention cyst of the lacrimal gland	1
Myxoma	1
Granulation tissue by foreign body	1
Scar tissue	1
Postoperative CCF	3
Paranasal sinus polyp	1
Choroidal melanoma	1
Orbital haematoma around orbital implant for reduction of orbital blowout fracture	7
Orbital cellulitis	7
Acute dacryocystitis	4
No detection of orbital lesion	17

Age-related changes in EOM size have been previously documented. A previous study reported a subsequent decrease in the thickness of the rectus muscles after 60 years of age, although these differences were not statistically significant

Table 2 The results of measurements and statistical comparison

	Number of orbits	Age (years)	Inferior oblique muscle thickness (mm)		
			Sagittal		Maximum thickness on coronal plane
			Major axis	Minor axis	
Total	78	54.2 ± 18.3	8.00 ± 1.83	2.98 ± 0.55	3.04 ± 0.55
Male	36	55.3 ± 18.2	8.04 ± 1.67	3.09 ± 0.51	3.14 ± 0.63
Female	42	53.2 ± 18.5	7.96 ± 1.97	2.89 ± 0.57	2.96 ± 0.46
P value	–	0.613	0.847	0.105	0.152
Right	33	51.1 ± 21.7	8.17 ± 2.15	2.90 ± 0.56	2.94 ± 0.60
Left	45	52.8 ± 20.6	7.87 ± 1.56	3.04 ± 0.54	3.12 ± 0.49
P value	–	0.895	0.483	0.278	0.135

Statistical comparison using the Student's *t*-test

[19]. Similarly, the minor axis and maximum thickness on the coronal plane were inversely correlated with age in the present study, but also lacked significance. On the contrary, other studies found that the thickness of the rectus muscles was greater among adults, which was attributed to normal muscle growth with age [19, 23]. It should be noted, however, that

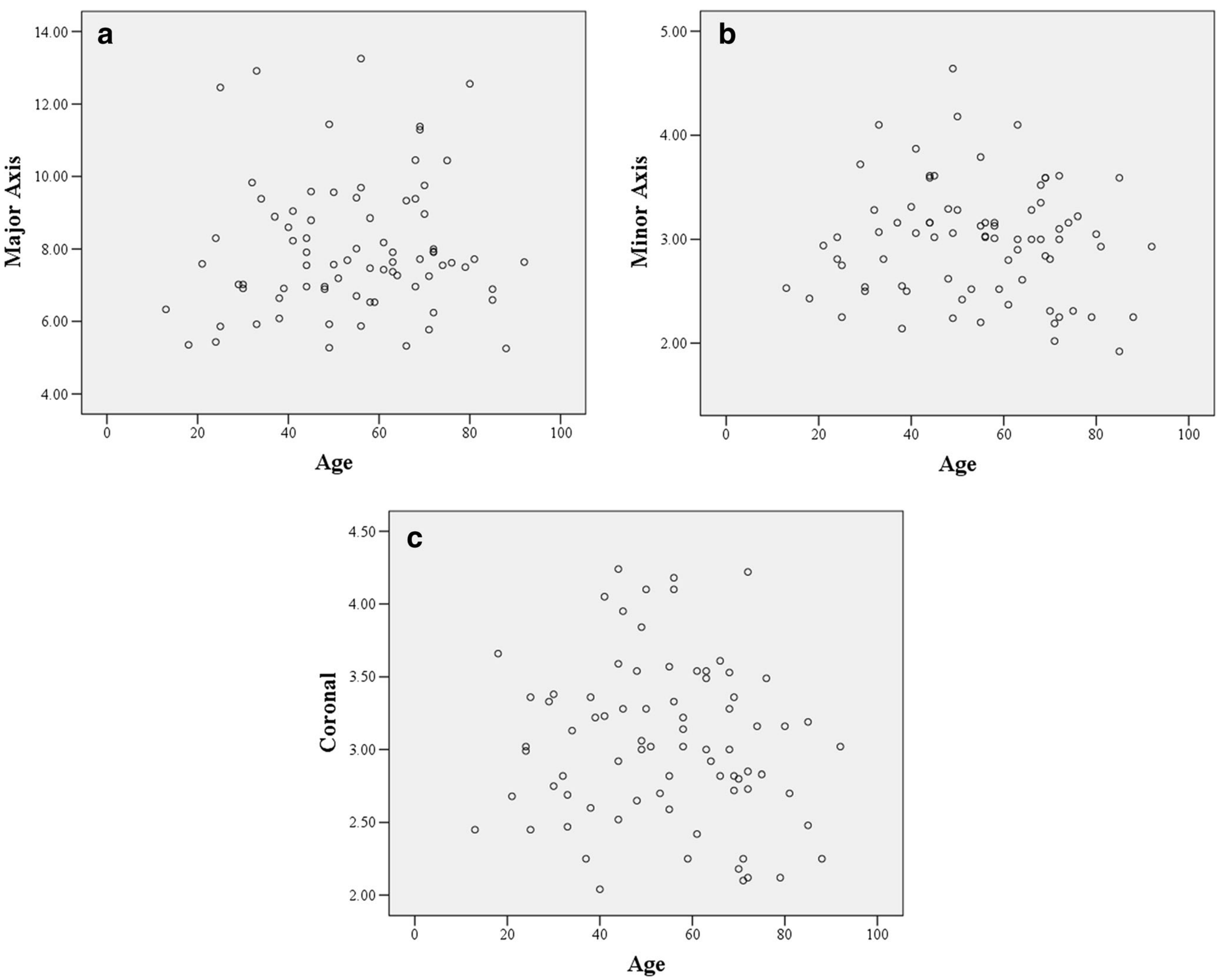

Fig. 2 Scatter diagrams between patient age (*x*-axis) and the measurement items [*y*-axis; the major axis (**a**); the minor axis (**b**); and maximum thickness on the coronal plane (**c**)]

there were only two patients under 20 years of age in the current subject pool.

The major and minor axes of the IOM on the quasi-sagittal plane through the optic nerve were both larger (major axis: 8.00 ± 1.83 mm; minor axis 2.98 ± 0.55) compared to our previous study (major axis: 7.23 ± 0.97 mm; minor axis: 2.27 ± 0.49 mm) [7]. This disparity may be explained by the expected tissue shrinkage after formalin fixation [8].

The normal cross-sectional shape of the EOMs is a thin ellipse on imaging studies [20]. In thyroid-associated orbitopathy, lymphocytic infiltration or mucopolysaccharide deposition promote greater elongation along the minor axis compared to the major axis of the EOMs, resulting in a round cross-sectional shape [7, 20]. The minor axis on the sagittal plane and the ratio of the minor and major axes are, therefore, more practical indicators for detecting IOM involvement in thyroid-associated orbitopathy [20]. These dimensions are likewise useful in detecting IOM involvement in other inflammatory disorders such as sarcoidosis [3, 4] and IgG4-ROD [5], as well as neoplastic conditions such as lymphoma [6], since these may also cause tendon-sparing or diffuse enlargement of the IOM [3, 5, 6]. Indeed, IOM enlargement may occur and may occasionally be the only presenting sign in some inflammatory or neoplastic diseases of the orbit.

The morphology and function of the IOM are also important to consider in certain types of strabismus and neuro-ophthalmological diseases affecting this muscle. For example, reduced IOM size was observed among cases of clinically diagnosed IOM palsy, supporting the concept of isolated IOM weakness without involvement of other structures innervated by the oculomotor nerve [11].

The technique we used to evaluate IOM thickness is readily available and easy to perform. The size of the IOM has been previously described through the measurement of its cross-sectional area or volume through high-resolution MRI [10–12], but this requires additional tools and expertise. In our technique, identification of the IOM on MRI may be initially difficult because it is small and follows an oblique course [13]. However, the IOM can be identified on the quasi-sagittal plane as it follows a straight path perpendicular to this plane at and medial to the inferior rectus (IR) crossing [24]. Thus, the maximum thickness of the IOM can be measured parallel to the orbital axis at the part passing through the centre of the IR muscle that travels in this plane [11]. More temporal image planes are unreliable to use because of the curved path of the IOM that becomes tangential to the image plane [11]. On the coronal plane, the IOM follows a straight path from its origin on the nasal orbital wall to the region of the IR pulley [24].

In this study, the digital caliper tool of the image viewing software was used to determine the thickness of the IOM, which is relatively straightforward. The software used in this study is part of the picture archiving and communication system module of the hospital. If this is not available, a ruler is a suitable alternative for this purpose since it is more accessible. Similar techniques involving direct measurements of muscle diameter on MRI have been employed by other studies [20, 21]; however, neither included measurements of the IOM and these were done on a different subset of individuals.

This study has some limitations. First, this is a retrospective study. Although the patients were instructed to look at a central fixation target, their position is ideally confirmed by checking the scans during the acquisition of images. However, this was not possible due to the retrospective nature of the study. It should also be recognized that this technique may not be applicable to patients who are not cooperative enough to take an MRI and maintain a straight gaze during the procedure. Second, the study was done on Japanese individuals. Since there are known racial differences in EOM size [14, 15], the findings presented here may not be applicable to other races. Third, we included patients with a unilateral orbital lesion, although taking MRI in normal volunteers is ideal for examining extraocular muscle morphology. The extraocular muscles in the unaffected side are expected to be overactive by Hering's law. However, as IOM thickness was measured on MRI taken in the primary eye position, the influence of Hering's law was small. Another limitation is the involvement of a single examiner in the measurement of IOM thickness, which could affect the reliability of this study.

In conclusion, we have presented the normative IOM thickness in Japanese individuals using MRI, which were similar among all ages irrespective of sex and side. The new technique we used is easily applicable, and the results may serve as a guide to detect IOM involvement in inflammatory and neoplastic conditions of the orbit.

Authors' contributions All authors qualify for authorship based on contributions to the conception and design (YT), acquisition of data (YT), literature search (MSS and YT), and analyses and interpretation of data (MSS, HK, and YT). All authors contributed to drafting the article and revising it critically for important intellectual content and final approval of the version to be published.

Compliance with ethical standards

Conflicts of interest All authors have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

Ethics approval All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

Informed consent The Institutional Review Board granted a waiver of informed consent for this study based on the ethical guidelines for medical and health research involving human subjects established by the

Japanese Ministry of Education, Culture, Sports, Science, and Technology and by the Ministry of Health, Labor, and Welfare. The waiver was granted because the study was a retrospective chart review, not an interventional study, and because it was difficult to obtain consent from patients who had been treated several years ago. Nevertheless, at the request of the Institutional Review Board, we published an outline of the study, available for public viewing, on the Aichi Medical University website; this also gave patients the opportunity to decline participation in the study. None of the patients declined to participate. Personal identifiers were removed from the records prior to data analysis.

Other contributors None.

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