

CHINESE MEDICAL SCIENCES JOURNAL

ORIGINAL ARTICLE

Normative Measurements of Extraocular Musculature by Multislice Computed Tomography

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Key words: computed tomography; extraocular muscle; measurement

Objective To establish the normal measurements of diameter of extraocular muscles (EOMs) by multislice computed tomography (CT).

Methods Orbits of 50 volunteers (25 male and 25 female) were scanned with a multislice CT scanner. For each subject, one axial image at the central level of the eyeball, one coronal image about 1 cm behind globe, and two oblique sagittal images respectively along the left and right optic nerve were used for measurements of the thickness and width of EOMs. The statistic significance of measurement value between male and female and between left and right eyes was evaluated.

Results There were no significant differences in the thickness and width of superior muscle group, lateral rectus, medial rectus, lateral rectus, superior oblique, inferior oblique and the thickness of levator palpebrae superioris between the left and right eyes as well as between male and female groups (all $P>0.05$). The thickness of superior muscle group and inferior rectus had not significant difference (2.9 ± 0.7 vs. 3.3 ± 0.8 mm, $P=0.162$), while the thickness of medial rectus was significantly higher than that of lateral rectus (3.1 ± 0.5 vs. 2.2 ± 0.6 mm, $P=0.000$).

Conclusions The CT measurement of extraocular musculature is simple and time-saving and can be applied in the clinical work. The normative data obtained may be useful in determining pathologic enlargement of the EOMs in both thyroid-associated orbitopathy patients and other various orbital conditions.

Chin Med Sci J 2012; 27(4):232-236

COMPUTED tomography (CT) has been widely used in the assessment of various orbital conditions. Compared with magnetic resonance imaging (MRI), CT is cheap and fast. In thyroid

orbitopathy, volumetric measurement of the muscles by CT has been developed to study the severity of the disease and monitor its response to treatment. However, volumetric measurement is time consuming and hardware dependent. For everyday management of patients, simpler measurement should be developed to assess the extraocular muscles (EOMs) of thyroid-associated orbitopathy (TAO). With everyday clinical experience, we think of

using four CT images to measure the thickness and width of all EOMs. But as the normal value is not determined, now we hope to get the normal values in healthy volunteers.

SUBJECTS AND METHODS

The study protocol was approved by the Institutional Review Board of Peking Union Medical College Hospital. All participants were recruited after signing informed consent.

Subjects

One hundred orbits of 50 healthy volunteers (25 male, 25 female; mean age 29.2 ± 3.6 years, range 24-38 years) were scanned in the study. All participants had no clinical evidence or history of endocrine disease (e.g., thyroid), orbital disorder, muscular disease or ophthalmic disorder, and their body mass index was within normal limits (average 22.5 ± 1.2 kg/m², range 21.5-23.2 kg/m²).

CT examination

All CT scans were performed on a multislice CT scanner (Somatom Prospective, Siemens Healthcare, Forchheim, Germany). The subjects were in supine position with his or her head stabilized, maintaining forward gaze and gentle eye closure during the scans to prevent asymmetrical EOM contraction. Since every change in the window settings resulted in different measurements on CT images, all images were obtained at constant window level and width settings, 50 and 250 HU, respectively. The parameters of scan are as follows: 130 kV, 160 mAs, 32×0.6 mm, pitch 0.6. Axial and coronal images (slice thickness 3 mm, increment 3 mm), and oblique sagittal image along the optic nerve (slice thickness 1.5 mm, increment 1.5 mm) were reconstructed for measurements of the diameter of EOMs. The scan range is from above the anterior cranial fossa to the middle of the maxillary sinus.

Image analysis

All images were transferred to the picture archiving and communication system (PACS) system (FUJIFILM, China) for measurement of the diameter of EOMs. Each value was the average of three measurements. The superior rectus and the levator palpebrae superioris (LPS) were difficult to differentiate on CT image, and so they were considered together as the superior muscle group (SMG). Axial images at the central level of the eyeball, coronal images about 1 cm behind globe, and oblique sagittal images along the optic nerve of two eyes were used for measurements of the diameter of EOMs. The maximal thickness of medial rectus

(MR) and lateral rectus (LR) was measured on the axial image. The width of MR, LR, SMG and inferior rectus (IR), the width and thickness of superior oblique (SO) were measured on the coronal image about 1 cm behind globe. On the oblique sagittal image along the optic nerve, the maximal thickness of SMG and IR was measured, the thickness of LPS was measured just above the globe, and the thickness and width of inferior oblique (IO) was measured just below the globe.

Statistical analysis

To assess the reliability and the repeatability of our analysis, we calculated inter- and intraobserver reliability. For interobserver reliability, a second independent observer repeated the measurement of 20 randomly selected orbits. For intraobserver reliability, the first observer repeated the measurement of the same 20 orbits after a one-month interval. Both observers did not know the volunteer's age, sex and any previous measurements.

The SPSS 17.0 software was used for statistical analysis. A paired sample *t*-test was used to compare data between the male and female's orbits, the right and the left orbits. The level of statistical significance was set at $P=0.05$.

RESULTS

The mean age of the 25 male volunteers was 29.3 ± 3.9 years, and that of the 25 female volunteers was 29.1 ± 3.6 years ($P=0.852$).

Figs. 1-3 show the measurements of the thickness and width of EOMs on axial image at the central level of the eyeball, coronal image about 1 cm behind globe, and oblique sagittal images along the optic nerve of two eyes, respectively.

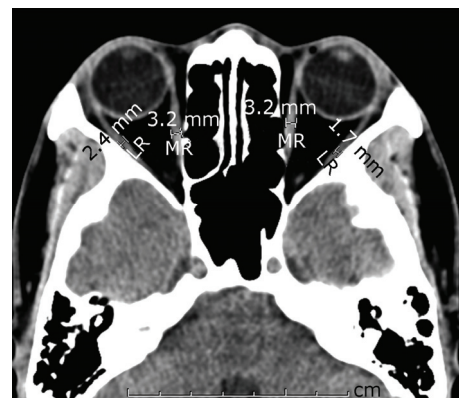


Figure 1. Maximal thickness of MR and LR was measured on the axial image at the central level of the eyeball.
MR: medial rectus; LR: lateral rectus.

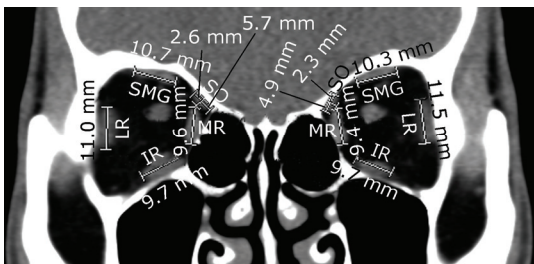


Figure 2. Width of MR, LR, SMG and IR, the width and thickness of SO was measured on the coronal image about 1 cm behind globe.
SMG: superior muscle group; IR: inferior rectus; SO: superior oblique.

For all the 100 orbits, the mean values, standard deviations, and ranges of the thickness and width of SMG, IR, MR, LR, SO, IO, and those of LPS thickness were presented in Table 1. Statistic analysis showed there were no significant differences in the above indications between the left and right eyes (all $P>0.05$, Table 2) and between male and female groups (all $P>0.05$, Table 3).

The thickness of SMG and IR had not significant difference ($P=0.162$), while the thickness of MR was significantly higher than that of LR ($P=0.000$).

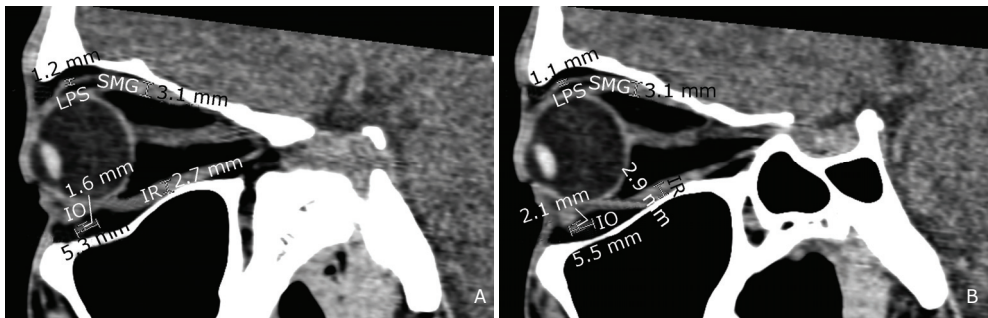


Figure 3. On the oblique sagittal image, the maximal thickness of SMG and IR was measured, the thickness of LPS was measured just above the globe, the thickness and width of IO was measured just below the globe.
A. right eye; B. left eye.
LPS: levator palpebrae superioris; IO: inferior oblique.

Table 1. Thickness and width of extraocular muscles of healthy volunteers detected by multislice computed tomography ($n=100$, mm)

Item	Thickness		Width	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
SMG	2.9 $\pm$ 0.7	1.7-4.2	9.2 $\pm$ 1.1	7.4-11.5
LPS	1.3 $\pm$ 0.2	0.9-1.6	-	-
IR	3.3 $\pm$ 0.8	1.7-4.5	8.2 $\pm$ 0.9	6.3-9.9
MR	3.1 $\pm$ 0.5	2.4-4.0	8.7 $\pm$ 0.9	6.5-10.9
LR	2.2 $\pm$ 0.6	1.2-2.9	10.1 $\pm$ 1.3	7.3-13.8
SO	2.6 $\pm$ 0.8	1.6-3.7	5.1 $\pm$ 0.8	3.5-6.8
IO	2.1 $\pm$ 0.6	2.0-3.1	6.3 $\pm$ 0.8	4.3-8.5

-: stands for not measured.

Table 2. Comparison of thickness and width of extraocular muscles of healthy subjects between right and left eyes ($n=50$, mm)

Group		SMG		LPS	IR		MR		LR		SO		IO	
		Thickness	Width	Thickness	Thickness	Width	Thickness	Width	Thickness	Width	Thickness	Width	Thickness	Width
Right	Means±SD	2.8±0.7	9.2±1.3	1.3±0.2	3.3±0.6	8.1±0.9	3.0±0.5	8.7±1.0	2.3±0.5	10.2±1.5	2.3±0.5	5.1±0.9	2.0±0.8	6.4±1.2
Eye	Range	2.1-4.2	7.3-11.5	0.9-1.6	2.1-4.3	6.5-9.7	2.4-3.9	7.2-10.8	1.3-2.9	7.2-13.5	1.6-3.6	3.4-6.5	1.5-3.0	4.2-8.5
Left eye	Mean±SD	3.0±0.7	9.4±1.2	1.3±0.3	3.2±0.8	8.3±1.1	3.1±0.6	8.6±1.2	2.2±0.6	10.1±1.1	2.7±0.6	5.1±0.8	2.1±0.6	6.2±0.8
	Range	1.6-4.0	7.3-10.9	1.0-1.5	1.7-4.5	6.3-9.9	2.3-4.1	6.5-10.9	1.3-2.7	8.1-12.9	1.5-3.8	3.4-6.8	1.0-3.3	4.5-7.5
P value		0.189	0.232	0.702	0.582	0.220	0.475	0.501	0.541	0.493	0.196	0.932	0.357	0.952

Table 3. Comparison of thickness and width of extraocular muscles of healthy subjects between males and females ($n=50$, mm)

Group		SMG		LPS	IR		MR		LR		SO		IO	
		Thickness	Width	Thickness	Thickness	Width	Thickness	Width	Thickness	Width	Thickness	Width	Thickness	Width
Male	Means±SD	2.9±0.6	9.8±1.5	1.4±0.2	3.2±0.7	8.4±1.0	3.1±0.5	8.8±1.0	2.2±0.3	10.3±1.1	2.4±0.3	4.9±0.9	2.1±0.5	6.2±0.9
	Range	2.2-4.1	8.2-12.0	1.0-1.7	2.1-4.5	7.1-10.0	2.6-4.1	6.8-11.0	1.5-2.8	8.1-11.9	1.8-3.5	3.4-6.5	1.4-3.2	4.3-8.2
Female	Mean±SD	3.0±0.5	8.9±0.8	1.3±0.1	3.3±0.9	7.9±1.1	3.0±0.3	8.6±1.0	2.3±0.4	10.2±1.6	2.4±0.7	5.2±0.9	2.0±0.6	6.4±1.0
	Range	1.8-4.1	7.4-10.3	0.8-1.4	1.7-4.5	6.3- 9.9	2.5-4.1	7.3-10.5	1.2-2.7	7.4-13.2	1.6-3.8	3.4-6.2	1.0-2.9	4.5-8.3
P value		0.876	0.051	0.112	0.745	0.065	0.258	0.653	0.146	0.493	0.734	0.085	0.240	0.231

The inter- and intraobserver reliability of most measurements were excellent, with the intraclass correlation coefficient ranging from 0.82 to 0.97. The intraclass correlation coefficient of four measurements had only moderate to good agreement: thickness of the LPS (0.47) and the thickness of the IR (0.61) and MR (0.63).

DISCUSSION

Ultrasound, CT, and MRI have been widely used in orbital imaging of TAO patients. Ultrasound is highly dependent upon experience of the examiners. As for MRI, although EOMs can be evaluated on both plain scan and contrast enhanced scan with high soft tissue contrast and intensity characteristics,¹⁻³ it is expensive and time-consuming. With multislice CT, after very quick axial image scan, we can reconstruct symmetric axial, coronal and oblique sagittal images, with soft tissue windows and width, and the EOMs can be clearly shown. And radiotherapy may be prescribed to the TAO patients,⁴ so a small amount of ionization radiation can be neglected compared with the patient's diseases. So as a cheap and convenient imaging modality, multislice CT can be used for orbital imaging of TAO patients.

For years, doctors and specialists home and abroad have made several studies on the imaging of EOMs with CT, concentrating on EOMs volume measurement,⁵⁻⁷ either with manual or semiautomatic drawing of the contour of EOMs, but these methods are very time-consuming and can be hardly applied in everyday clinical practice. So in clinical practice, we developed a simple method to measure all the EOMs, with just four images, one axial, one coronal, and two oblique sagittal images. It had shown great convenience in our everyday clinical work, either for evaluating the enlargement of EOMs, or for the follow-up after therapy. But the normative value is not determined. Although there are some papers studying the normative values, they are data either obtained from MRI scans⁸ or that do not include all the EOMs.⁹

In our study, we selected 50 normal volunteers, in-

cluding 25 male and 25 female, with a mean age of 29.2 $\pm$ 3.6 years and range of 24-38 years, because it was said that Grave's ophthalmopathy mainly affects people 20 to 40 years old, and Graves' disease is a main part of TAO. Furthermore, according to the study by Shen *et al*,⁸ there is no significant difference in EOM thickness between 21-30, 31-40, 41-50 and 51-60 year old people groups. So the values we obtained from these 50 volunteers can be representative for the normative value of EOMs.

In most of the previous studies,^{8,9} only the thickness of SMG, MR, LR, IR are concerned, the width of these muscles and the thickness and width of both SO and IO are not studied, but in clinical practice, SO and IO can also be enlarged. We found the coronal image can show the cross section of SO and the oblique sagittal image can show the cross section of IO, so we measured them and get normal values.

A lot of TAO patients may have retraction of the upper eyelid,¹⁰ it was shown that the LPS of these patients is thickened. On the oblique sagittal image, the thin layer of LPS can be easily seen and the thickness can be easily measured, because LPS will be broadened when it goes forward,¹¹ the width of LPS may have variation, we do not measure the width of it.

In our study, it showed that there was no significant difference in the values of EOMs between the right eyes and left eyes, and between the males and females. Our normative value was correlated well with the value of previous study. So these normative values can be used among both male and female TAO patients, only paying a little attention to the thickness of SMG, IR and LPS.

Our study also showed that although there was no significant difference between the thickness of SMG and IR, there was significant difference between the thickness of MR and LR, and the thickness of MR was higher than that of LR, it may demonstrate that as people often see close things, MR should be contracted to let the two pupils converge, so MR is more used than LR, so it is thicker.

In conclusion, the measurement of all the EOMs is greatly simplified, with only 4 images to evaluate all the

EOMs, and it can be easily applied in clinical practice. And the normative values we obtained may be a useful guide both for the evaluation of the enlargement of EOMs of TAO patients and for the follow-up after treatment. These values can also be applied in the evaluation of other diseases of EOMs, such as inflammatory pseudotumor of EOMs.

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