AN ANATOMICAL REEVALUATION OF RECTUS MUSCLE INSERTIONS*

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INTRODUCTION

ACCURATE KNOWLEDGE OF THE ANATOMY OF THE EXTRINSIC EYE MUSCLES IS OF prime importance to the ophthalmic surgeon, particularly the strabismus surgeon. In recent years, the increased use of certain operations has reemphasized the need for accurate measurements of rectus muscle insertions and their relationship to each other. These operations include (1) transposition of rectus muscle insertions for correction of A-V patterns and extrinsic eye muscle palsies; (2) recession of rectus muscles more than the traditional maximum amount for large deviations, dissociated vertical deviations, and thyroid ophthalmopathy; and (3) advancement of previously recessed muscles for overcorrections. The rectus muscle measurements of particular importance to the strabismus surgeon include the distances of the insertions from the limbus, length of the line ("width") of rectus muscle insertions, and distances between the insertions. Although these measurements are quoted frequently in the ophthalmic literature, a review of the primary sources of these data raises doubt as to their accuracy. The few original studies used a small sample size and are up to a century old. The present study was initiated to reexamine the data concerning the anatomy of the rectus muscle insertions in relation to the limbus and to each other.

MATERIALS AND METHODS

One hundred consecutive adult autopsy eyes were studied. The mean age of the subjects was 60.3 years, ranging from 21 to 90; standard deviation was 16 years. The sex ratio was 28 male and 22 female subjects. Forty-seven were white and three were black. No patient in the study had premortem diseases that are known to affect the size or shape of the eyes. Various

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diameters of the globe and cornea were measured to establish their normality of size and justify their entrance into the study (Table I).

Measurements on all eyes were made after fixation in formalin for four days and in 50% ethanol for one day. Volume changes have been found to be less than 5% when fixed in this manner (Robert Y. Foos, MD, unpublished data, 1967). All measurements were made to the nearest tenth of a millimeter with a standard Vernier caliper and a dissecting microscope ($7\times$).

The following data were recorded for each eye: (1) Globe diameter (anteroposterior, vertical, and horizontal); (2) Corneal diameter (vertical and horizontal); (3) Distance from the posterior corneal limbus to each rectus muscle insertion, both at the midpoint and at each end of the insertion. Measurements were made to the most anterior part of the muscle insertion. (4) Width of the anatomical limbus at a position corresponding to the midpoint of each rectus insertion. The anterior limbus was defined as the transition from clear cornea to grey, while the posterior limbus was defined as the transition from the grey cornea to white sclera. (5) Length of line ("width") of each rectus muscle insertion; (6) Distance between each rectus muscle insertion.

The data were tabulated and analyzed using standard statistical techniques for mean, range, and standard deviation. Comparative analysis of the various parameters also was performed.

RESULTS

In the interest of simplicity and conciseness all measurements, including standard deviations and ranges, are presented in tabular form. Globe and corneal dimensions, distance from the cornea to the rectus insertions, width of the limbus, length of the line (width) of the rectus muscle insertions, and the distances between the rectus muscle insertions are shown in Tables I-V and in the figure.

TABLE I: GLOBE AND CORNEAL DIMENSIONS

	Mean $\pm$ SD, mm	Range, mm
Globe		
Anteroposterior	24.7 $\pm$ 0.7	22.9-26.0
Vertical	24.4 $\pm$ 0.7	22.6-26.1
Horizontal	24.4 $\pm$ 0.7	22.4-26.0
Cornea		
Horizontal	12.3 $\pm$ 0.4	11.1-13.2
Vertical	11.9 $\pm$ 0.4	10.8-13.0

TABLE II: DISTANCE FROM LIMBUS TO RECTUS MUSCLE INSERTIONS

	Mean $\pm$ SD, mm	Range, mm
Medial Rectus Insertion		
Anterior limbus to midpoint of insertion	5.3 $\pm$ 0.7	3.6-7.0
Posterior limbus to midpoint of insertion	4.7 $\pm$ 0.6	3.0-6.4
Posterior limbus to superior border of insertion	6.2 $\pm$ 0.7	5.0-8.4
Posterior limbus to inferior border of insertion	6.9 $\pm$ 0.8	5.0-10.0
Inferior Rectus Insertion		
Anterior limbus to midpoint of insertion	6.8 $\pm$ 0.8	4.8-8.5
Posterior limbus to midpoint of insertion	5.9 $\pm$ 0.7	3.9-7.6
Posterior limbus to medial border of insertion	6.7 $\pm$ 0.9	5.0-9.7
Posterior limbus to lateral border of insertion	9.3 $\pm$ 1.0	7.2-12.0
Lateral Rectus Insertion		
Anterior limbus to midpoint of insertion	6.9 $\pm$ 0.7	5.4-8.5
Posterior limbus to midpoint of insertion	6.3 $\pm$ 0.6	4.8-7.9
Posterior limbus to superior border of insertion	8.0 $\pm$ 0.8	6.0-10.3
Posterior limbus to inferior border of insertion	7.3 $\pm$ 0.7	6.0-9.5
Superior Rectus Insertion		
Anterior limbus to midpoint of insertion	7.9 $\pm$ 0.6	6.2-9.2
Posterior limbus to midpoint of insertion	6.7 $\pm$ 0.6	5.0-8.0
Posterior limbus to medial border of insertion	7.0 $\pm$ 0.6	5.0-8.7
Posterior limbus to lateral border of insertion	9.9 $\pm$ 0.8	8.0-12.0

DISCUSSION

All eyes in the present study are from adults, and most are in the normal size range. Although one authoritative source stated that limbus-to-insertion distances may be directly proportional to axial length,¹ comparative analysis of the present data failed to reveal any such relationship. In addition, these authors quote a study by Sappey reported in 1855 that found globe and corneal diameters larger in males than in females.¹ The present study fails to reveal any significant difference between the eyes of males and females. Since only six eyes from blacks were studied, no statistically valid comparisons between eyes from blacks and from whites could be made.

Several anatomical studies measuring the distances from the limbus to the rectus muscle insertions are in the ophthalmic literature. The earliest

TABLE III: DISTANCE (WIDTH) BETWEEN ANTERIOR AND POSTERIOR LIMBUS

	Mean $\pm$ SD, mm	Range, mm
Medially	0.6 $\pm$ 0.1	0.4-0.7
Inferiorly	0.9 $\pm$ 0.2	0.8-1.2
Laterally	0.6 $\pm$ 0.1	0.4-0.7
Superiorly	1.2 $\pm$ 0.3	0.9-1.6

and most frequently quoted study was done by Fuchs² in 1884; he measured 31 autopsy and surgically enucleated eyes that were emmetropic by axial length measurements (between 23 and 25 mm in anteroposterior diameter). These measurements are quoted in many ophthalmic and anatomical textbooks.^{1,3-12} Other autopsy studies subsequently were done.¹³⁻¹⁵ The results of these studies, in addition to data from the present study, are seen in Table VI. Since the sample size in this study is larger than that of any other study, the mean values found in this study would be closer to the mean of the general population. Although the means found in this study are not much different from Fuchs' values, they are all significantly different at the 5% level of significance except for the lateral rectus muscle.

Measurements of the distance from the limbus to the insertion of horizontal rectus muscles in living persons are recorded in two studies. However, both studies involved strabismus patients rather than normal subjects. Goldstein¹⁶ operating on 64 patients with esotropia and exotropia found that the average limbus-to-insertion distance was 5.07 mm for the medial rectus muscle and 6.44 mm for the lateral rectus muscle. He also noted that the average limbus-to-insertion distance of the medial rectus muscle in patients with esotropia was significantly smaller (4.91 mm) compared to patients with exotropia (5.32 mm), but he observed no significant difference in the lateral rectus muscle measurements in esotropia compared to exotropia. The average medial rectus muscle insertion distance of 4.4 mm found by Helveston and co-workers¹⁷ in a group of 57 patients undergoing esotropia surgery likewise is significantly smaller than the average values

TABLE IV: LENGTH OF LINE ("WIDTH") OF RECTUS MUSCLE INSERTIONS

	Width $\pm$ SD, mm	Range, mm
Medial rectus	11.3 $\pm$ 0.8	9.6-13.3
Inferior rectus	10.5 $\pm$ 0.8	8.8-12.8
Lateral rectus	10.1 $\pm$ 0.8	8.3-12.5
Superior rectus	11.5 $\pm$ 0.8	9.8-14.0

TABLE V: DISTANCE BETWEEN RECTUS MUSCLE INSERTIONS

	Mean $\pm$ SD, mm	Range, mm
Medial rectus to inferior rectus	5.9 $\pm$ 0.8	4.5-8.9
Inferior rectus to lateral rectus	8.0 $\pm$ 0.8	4.1-9.6
Lateral rectus to superior rectus	7.1 $\pm$ 0.8	5.0-9.6
Superior rectus to medial rectus	7.5 $\pm$ 0.8	5.6-9.5

given in the reports on autopsy eyes that had no ocular disease. One cannot clearly ascribe the smaller medial rectus muscle insertion distance in the patients with esotropia in these two studies to a smaller globe size because although most of the patients were in the first two decades of life, few were younger than three years. By this age the globe attains over 95% of its adult size.¹

Shortcomings in previous studies dealing with limbus-to-rectus muscle insertion distances deserve mention. Although measurements are reported to be made from the limbus, investigators usually fail to state from what precise location on the limbus the measurement is made. The present study shows that the distance (width) between anterior and posterior limbus can be significant (Table III) and thus must be accounted for. This distance was as much as 1.6 mm in this study. Another deficiency is the failure of authors to make clear what point on the insertion site is used for the other component of the measurement. Since the width of the area where the rectus muscle fibers insert into the sclera is approximately 1 mm, another variable must be accounted for. The measurements in the present study clearly define the distance between the anterior or posterior limbus and the anterior edge of the insertion.

The length of the line (width) of the rectus muscle insertions has been measured by some investigators. Results of three studies,^{2,13,18} compared with those in the present study, are seen in Table VII. Measurements in

TABLE VI: DISTANCE FROM THE CORNEA* TO THE MIDPOINT OF THE RECTUS MUSCLE INSERTIONS

	Number of Eyes	Medial Rectus, mm	Inferior Rectus, mm	Lateral Rectus, mm	Superior Rectus, mm
Fuchs (1884)	31	5.5	6.5	6.9	7.7
Weiss (1897)	5	5.05	6.85	6.75	8.01
Howe (1902)	21	5.7	6.7	7.4	7.6
Gat (1947)	80	5.4	6.4	6.6	7.1
Present study	100	5.3	6.8	6.9	7.9

*Authors cited in this list do not specify anterior or posterior limbus of the cornea. Measurements in the present study are from the anterior limbus to the anterior portion of the muscle insertion.

TABLE VII: LENGTH OF LINE ("WIDTH") OF RECTUS MUSCLE INSERTIONS

	Number of Eyes	Medial Rectus, mm	Inferior Rectus, mm	Lateral Rectus, mm	Superior Rectus, mm
Fuchs (1884)	31	10.3	9.8	9.2	10.6
Weiss (1897)	5	10.76	10.35	9.67	10.75
Fink (1947)	100	...	9.8	...	10.2
Present study	100	11.3	10.5	10.1	11.5

the present study are slightly larger, up to 1.3 mm for the superior rectus muscle, than those in the other three studies. The larger values found in this study were all significantly different at the 5% level, from like values in the other three studies quoted, except Weiss' value for the inferior rectus muscle. This discrepancy can be explained by the accuracy derived from using the dissecting microscope in taking the measurements. Under high magnification ($7\times$) one can see the insertion line extending slightly farther along the sclera than when little or no magnification is used.

Information on measurements of the distance between rectus muscle insertions is meager. The distances shown in a diagram by Duke-Elder and Wybar¹ also are seen in Burian-von Noorden's *Binocular Vision and Ocular Motility* textbook,¹⁹ and in the atlas by Dyer.¹⁰ Personal communication with Mr. Kenneth Wybar (1971) indicated that the diagram in his textbook was taken from the earlier edition of the book written by Duke-Elder,²⁰ and that he was uncertain of the source of the original figures. A different set of figures is seen in a diagram in the textbook on eye anatomy by Renard, Lemasson, and Sarau²¹; the source of the single figures given is not specified. These two sets of figures are listed in Table VIII. The mean values obtained in the present study also are shown in Table VIII. They are higher than those given by Duke-Elder and Wybar¹ but lower than those presented by Renard and co-workers.²¹ At the 5% level, the mean values found in this study are significantly different from those in the other two studies. Since the measurements in this study were derived from a large sample they are offered as an appropriate set of values for interinsertional distances.

TABLE VIII: DISTANCE BETWEEN RECTUS MUSCLE INSERTIONS

	Medial Rec- tus to Inferior Rec- tus, mm	Inferior Rec- tus to Lateral Rec- tus, mm	Lateral Rec- tus to Superior Rec- tus, mm	Superior Rec- tus to Medial Rec- tus, mm
Duke-Elder, Wybar	5.5	7.0	6.5	7.0
Renard et al	...	9.0	8.0	8.0
Present study	5.9	8.0	7.1	7.5

TABLE IX: DISTANCE BETWEEN RECTUS MUSCLE INSERTIONS COMPARED TO LENGTH OF INSERTION LINE (GAT)

Distance Between Insertions, degrees		Length of Insertion Line, degrees	
Medial rectus to inferior rectus	69	Medial rectus	22
Inferior rectus to lateral rectus	67	Inferior rectus	25
Lateral rectus to superior rectus	66	Lateral rectus	21
Superior rectus to medial rectus	67	Superior rectus	23

The distances between the rectus muscle insertions also can be calculated indirectly from the study of Gat.¹⁵ Gat measured the length of the muscle insertions in degrees, by considering the insertions as formulating a circle, the center being at the central point of the cornea. His measurements indicate that the distances between the insertions are almost three times as great as the length of the insertion lines themselves (Table IX). The measurements obtained in the present study, however, establish the fact that the distance between the insertions is less than the insertion line length (see figure).

The anatomical parameters established in the present study have pertinent clinical applications. Strabismus surgeons using the limbus as a landmark for defining rectus muscle insertions need to be aware of limbal anatomy. The present study substantiates the notion already appreciated by cataract and glaucoma surgeons that the distance between the anterior and posterior limbus varies in the four areas proximal to the rectus muscle insertions; it has a mean width of 1.2 mm superiorly but can vary up to 1.6 mm (Table III). The muscle insertion site itself has a finite thickness (about 1 mm) and measurements made from the limbus *in vivo* on non-disinserted muscles using a muscle hook to delineate the insertion, are more likely to define the posterior limit of the insertion. After the muscle is disinserted the distance then may measure up to 1 mm less if one arm of the caliper is placed on the anterior edge of the insertion. Thus for the strabismus surgeon to understand measurements and data, either for his own benefit during surgery or for reporting observations, he should specify whether measurements are from the anterior or posterior limbus, taken before or after the muscle is disinserted, and if any point other than the anterior edge of the insertion is used for the measurements. These specific points of information rarely have been made in previous reports on limbus-to-rectus muscle insertion distances.

With the increased tendency of strabismus surgeons to perform recessions of the rectus muscles more than the conventional maximum amounts, the necessity for paying strict attention to the manner in which the limbus-to-insertion site distance is measured and the appreciation of accurate

FIGURE
Anatomical relationships of rectus muscle insertions and limbus.

normal values for these distances becomes a matter of practical importance to avoid excessive weakening of muscle action.

The maximum lateral rectus muscle recession traditionally has been 7 mm. Although a few ophthalmic surgeons for years have recessed the lateral rectus muscle 8 to 10 mm,²² in recent years more ophthalmologists have begun to perform these large recessions commonly for sizeable exotropias,^{19,23} even in children.²⁴ Recessions of the medial rectus muscle more than the conventional amounts of 5 to 5.5 mm also are being performed more frequently, particularly for large angle childhood esotropia.²⁵⁻²⁷ In performing full or extra-large recessions of the medial rectus muscle, several authors recommend measuring the recession distance from the limbus rather than from the original insertion site because of its potential for variation (confirmed in this study, Table II).^{17,25} Recessions of the vertical rectus muscles more than the ordinary maximum amount are

done regularly now by ophthalmic surgeons. In thyroid ophthalmopathy, the inferior rectus muscle, normally recessed up to 5 mm, may be recessed 6 mm or more. In dissociated vertical divergence, recessions of the superior rectus muscle 8 mm or more, rather than the usual limit of 5 mm, have been found effective by some strabismus surgeons.^{30,31}

Another situation in which the surgeon needs knowledge of the exact location of the insertion site is in reoperation for overcorrection after recession. When an advancement is carried out, an important point of reference for the surgeon would be the original insertion line indicated in Table II.

Transposition operations in which insertions of horizontal and vertical rectus muscles are moved to improve horizontal and vertical deviations have represented a notable advance in strabismus surgery during the past 20 years. Much of the credit for presenting and popularizing these concepts belongs to Knapp.^{32,33} Transpositions of rectus muscle insertions nowadays are done regularly by strabismus surgeons. These procedures have been effective in certain cases of A-V patterns, small concomitant vertical imbalances where no dysfunction of any specific vertically-acting muscle is apparent, double elevator or depressor paralysis, third and sixth cranial nerve paralysis, residual horizontal deviation after maximum horizontal muscle surgery, and Duane's syndrome. In addition to the papers by Knapp already cited, other selected publications that deal with this subject are suggested.* Pertinent to this paper, however, is the matter of the amount of rectus muscle insertion displacement. Except for the cases of very small concomitant vertical imbalances, a general opinion among strabismus surgeons is that the minimal amount of effective muscle insertion displacement is about 5 mm ("approximately half the muscle width") to a maximum amount of 10 mm ("about one muscle width"). The anatomical data gathered in this study show that if the normal insertion distance from the limbus is to be maintained, it is not possible to displace any rectus muscle its full width without impinging on the adjacent muscle (Tables IV and V). Even half a tendon insertion width, on the average, is more than three-quarters the distance between insertions, if the full width of the insertion is maintained. With this knowledge in mind, the ophthalmic surgeon must decide not only the distance he wishes to displace the rectus insertion, but also the extent he wishes to alter the width of the new insertion to maintain the desired arc of contact on the globe.

*References: 19(pp348-351, 575-578), 12(pp72-74, 165-175), 34-40.

SUMMARY

Certain strabismus operations require a thorough knowledge of the anatomy of rectus muscle insertions. Earlier anatomical studies were based on a small sample size and did not use precise microscopic techniques for measurements. To obtain accurate measurements of rectus muscle insertion relationships, 100 consecutive normal adult autopsy eyes were examined with a Vernier caliper and a dissecting microscope for high magnification.

Statistical analysis of these data provided a set of normal values for (1) distances from anterior and posterior limbus to rectus muscle insertions, (2) distances between anterior and posterior limbus, (3) length of line ("width") of rectus muscle insertions, and (4) distances between rectus muscle insertions. Although most of the determinations were somewhat similar to previous studies, statistically they were significantly different.

The ophthalmologist can make use of the revised set of figures for rectus muscle insertion relationships in operations such as transposition procedures for A-V patterns and cranial nerve palsies, large recessions, and advancements in reoperations after recessions.

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