·Basic Research·

# Ultrasonographic visualization of lower eyelid structures and dynamic motion analysis

*Mohammad Taher Rajabi*[1,2], *Konstantinos Papageorgiou*[1], *Shu-Hong Chang*[1], *Imran Jarullazada*[1], *Mehryar Taban*[1], *Catherine J. Hwang*[1], *Robert Alan Goldberg*[1]

[1]Division of Orbital and Ophthalmic Plastic Surgery, Jules Stein Eye Institute, University of California-Los Angeles, 100 Stein Plaza 2-267, Los Angeles, CA 90049, USA

[2]Eye Research Center, Farabi Eye Hospital, Tehran University of Medical Sciences, South Kargar St, Tehran 13345, Iran

**Correspondence to:** Mohammad Taher Rajabi. Eye Research Center, Farabi Eye Hospital, Tehran University of Medical Sciences, South Kargar St, Tehran 13345, Iran. mt_rajabi@yahoo.com

Received: 2012-10-21 Accepted: 2013-07-24

## Abstract

**• AIM: To define the ultrasonographic structure of normal lower eyelid anatomic compartments and their spacial relationship in dynamic motion.**

**• METHODS: High resolution ultrasound (15MHz) was performed on the lower eyelids of 7 normal subjects. Movements of the lower eyelid and its compartments were visualized with ultrasound. In addition, the maximal excursion area of the lower eyelid fat compartments and retractor motions was measured before and after motion.**

**• RESULTS: The orbicularis muscle could be seen as an echolucent structure between the dermis and the echodence fat pads. Lower eyelid fat pad seems to be divided into 2 compartments as range of motion and direction of movement of each of them varies. It seems that these compartments have also different behavior. The measured profile area of the visible normal lower eyelid fat pads during movement of globe from up-gaze to down-gaze decreased by 50%. Order of movement of lower eyelid structures seems to be as follows: after globe movement fist we see retractor movement, anterior orbital fat pad, then skin and septum, and finally movement of inferior fat pad.**

**• CONCLUSION: Ultrasound represents a noninvasive tool for the visualization of lower eyelid morphology. Expanding its application could help us understand the compartmental changes in physiological eyelid movement, in aging and diseased study populations, as well as assess operative outcomes.**

**• KEYWORDS:** lower eyelid; ultrasonography; dynamic motion analysis

**DOI:10.3980/j.issn.2222-3959.2013.05.07**

Rajabi MT, Papageorgiou K, Chang SH, Jarullazada I, Taban M, Hwang CJ, Goldberg RA. Ultrasonographic visualization of lower eyelid structures and dynamic motion analysis. *Int J Ophthalmol* 2013;6(5):592-595

## INTRODUCTION

Ultrasound represents a noninvasive tool for visualizing structures of the human body. Several studies have used this tool to examine normal eyelid structures and the physiology of the lacrimal pump mechanism [1-3]. Anatomic changes associated with periocular and orbital diseases such as blepharoptosis, epicanthus, eyelid lesions, and even thyroid-associated orbitopathy have also been successfully characterized with ultrasonography [4-9]. However, the complexities of lower eyelid anatomic compartments and the *in vivo* spatial relationships of these compartments in motion have not been previously studied.

In this paper, we report ultrasonographic real time analysis of lower eyelid structures and function. Specifically, we analyzed the orbicularis oculi muscle, lower eyelid retractors, lower eyelid fat pads, and their quantitative relationships during vertical motion excursions of the globe.

Ultrasonographic visualization of dynamic lower eyelid anatomy furthers our knowledge of eyelid motion physiology. This knowledge provides a foundation for understanding the anatomic, structural, and functional changes that occur in the aging eyelid as well as in diseases such as thyroid-related eyelid retraction.

## SUBJECTS AND METHODS

**Subjects** Ultrasound images of 7 normal subjects (4 male, 3 females) with ages ranging from 28-52 years (mean 36 years) were analyzed. Ultrasonographic evaluation (Logiq p6, GE Healthcare, USA) was performed by a single operator, using a 15MHz probe with linear producer. The scanner operated at a scan rate of 50 frames per second. During the assessment, the eyelids were closed and covered with methylcellulose medium for optimal signal transmission.

**Methods** Ultrasonographic examinations were performed with the patient in a semisupine position. The probe was placed perpendicular to the area of interest and allowed visualization of the lower eyelid compartments in the mid

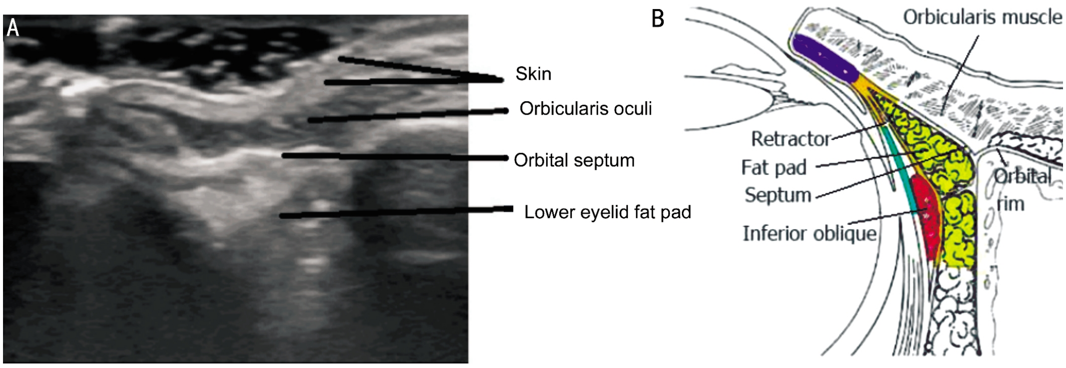


**Figure 1 Lower eyelid ultrasonic sagittal view in a 29-year old male** A: The individual structures recognized from superficial to deep are: the echodense skin, the underlying echolucent orbicularis oculi, the echodense septum, and the orbital fat pad with an echodense consistency in the anterior compartment and echolucent in the inferior eyelid compartment; B: Illustration of the same findings in A.

sagittal plane and inferiorly to the orbital rim (Figure 1). The subjects were instructed to place their eyes in maximum down-gaze and up-gaze, allowing video recording of the globe in maximum vertical excursion. Static images were extracted and used to characterize eyelid anatomical compartments during various phases of motion. For analysis, Movie MaxTRAQ 2.0 (Innoviosion systems Inc., Columbiaville, MI, USA) was used.

**RESULTS**

The lower eyelid skin and dermis appeared as echodense linear structures at the methylcellulose-eyelid interface with median thickness of 1.75mm (range 1.6-2mm). The underlying orbicularis oculi muscle was echolucent. The mean thickness of orbicularis oculi muscle in primary position was 1.12mm (range 0.8-1.6mm). The orbital septum appeared as a highly echodense structure lying just beneath the orbicularis muscle (Figure 1). The lower eyelid retractors were not easily discernible as a separate layer on static images; however, during dynamic motion, both retractors and conjunctiva were clearly appreciated by the vertical excursion changes. The retractors were seen as a continuous echodense layer within the deeper eyelid compartments. The retractors contain conjunctival attachments. Retractors and orbital septum were adjoined at the level of the inferior fornix and extended toward the lower tarsal border.

In young patients, the septal attachment to the inferior orbital rim was clearly appreciated on the inner part of the orbital rim (Figure 1). With increasing age, the echodense signal of the orbital septum was decreased (Figure 2), while its length was increased. In addition to the septal-tarsal attachment, two additional attachments were identified that extended from septum toward the skin (Figure 3). These attachments were responsible for a concave configuration of the septum on vertical gaze movement and seemed to prevent anterior displacement of the orbital fat. An inferior attachment was shorter in length and was responsible for skin dimpling on down-gaze (Figure 3A). The orbital septum appears concave in the inter-attachment space. However, inferior to the lower attachment, the orbital septum appears convex, allowing fat herniation to occur (Figure 3). This change was more pronounced in individuals with fat herniation on clinical examination.

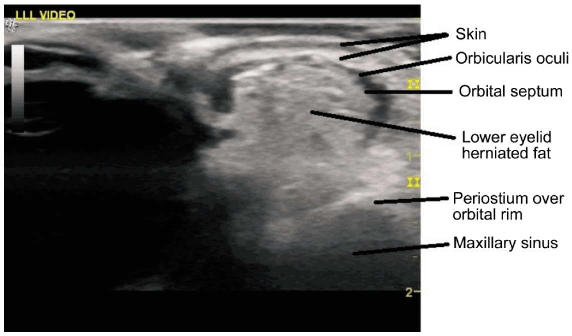


**Figure 2 Ultrasound of lower eyelid in a 53-year old man illustrating decreased echodensity of the septum compared to septum as shown in Figure 1, and also fat herniation.**

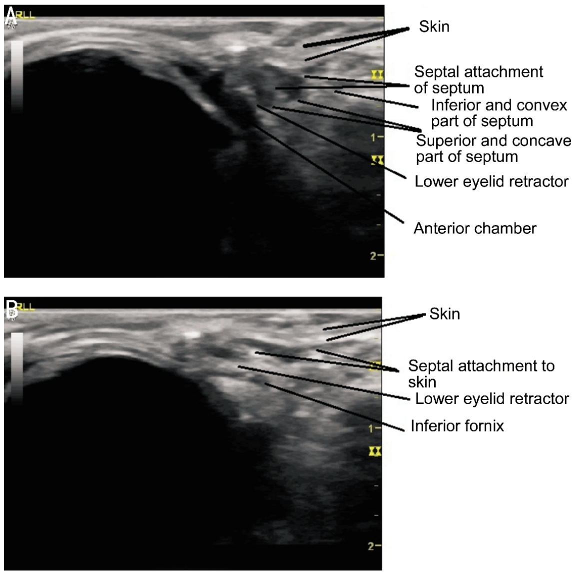


**Figure 3 Lower eyelid structures on down-gaze and up-gaze** A: Ultrasonographic image of lower eyelid on down-gaze, showing the two septum-to-skin attachments. The orbital septum appears concave in the inter-attachment space. However, inferior to the lower attachment, the orbital septum appears convex, allowing fat herniation to occur; B: Ultrasonographic evaluation of the lower eyelid on up-gaze showing the two septal skin attachment points of the same patient in Figure 3A.

The orbital fat pad was located just posterior to the orbital septum (Figure 1) and may be sub-compartmentalized into two components based on distinct motion characteristics and echogenicity. A superficial component that is in closer proximity to the globe was echodense, while a deeper postero-inferior compartment near the orbital floor was relatively echolucent (Figure 1). Motion analysis of the fat compartments during globe excursion revealed that the fat actually demonstrates multi-directional movement that can be quantified using vertical and horizontal vector calculations (Figure 4). The superficial fat component showed the greatest range of motion (mean 6.8mm) and parallel to the globe (Figure 4). The deep fat compartment appeared more echolucent, showing predominantly anterior-posterior movement (parallel to the orbital floor) and the lower range of motion. Its flexibility and conformational changes were very limited. The section close to the orbital rim showed mild torsional movement which was less than 1mm, but the deeper part showed a linear mode movement with slightly greater excursion range (mean 2.71mm) (Figure 4).

Going beyond vector analysis of fat compartment motion, the fat compartments have additional movement characteristics that may be best described with the terms "sliding" and "jelly-like or swirling." The sliding movement is seen when the 2 fat pads move across each other such that the superficial fat pad slides over the deep postero-inferior fat pad. Second, there is movement within each fat pad characterized by a jelly-like or swirling motion as would be expected from fluid composition within adipose tissue. Both of these higher order motion patterns were analyzed by taking into account the deformation of the fat components in different positions of globe excursion (Figure 4).

The maximuml area of the visible fat compartments was measured in the sagittal sections of the lower eyelid in both up-gaze and down-gaze (Figure 5). The surface area of the visible fat compartments decreased by more than 50% on down-gaze.

Dynamic motion analysis (from up-gaze to down-gaze) of the fad pads revealed a characteristic delay in their movement with the superficial anterior compartment moving first, followed by orbital septum, and finally the deep inferior compartment. Tracking of the fat compartments showed that the superficial anterior compartment's movement relates to the retraction of retractors while the displacement of the inferior compartment follows the orbital septum. With aging and occurrence of fat herniation, range of motion of deep compartment would be decreased so that in patients with large fat herniation it seems that fat has lost motion.

During vertical movements of globe, it seems that there is some delay in the eyelid movement compared to globe. It seems that, on downward, lower eyelid retractors is like a clump that on up-gaze movement, this clump should be opened and after fully opening of the retractors, the eyelid will be pulled up. On down-gaze, the lower eyelid retraction was mostly secondary to downward displacement of the globe and not due to active contraction of lower eyelid. Downward movement of the globe is due to inferior rectus activity that its work also retract lower eyelid, secondarily.

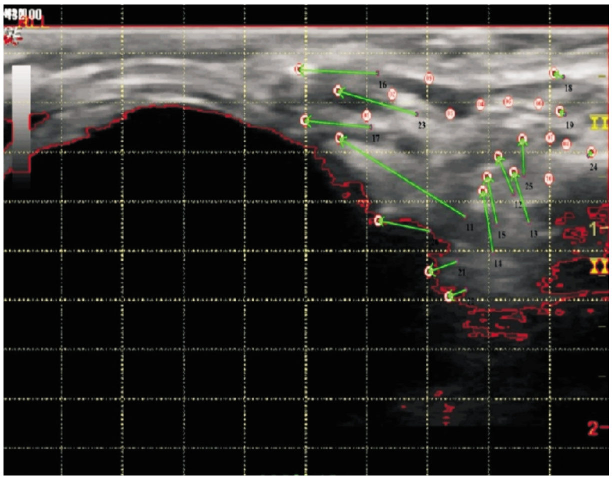

**Figure 4 Ultrasonographic image shows vectors and range of excursions of the eyelid fat compartments during vertical globe rotation** The superficial compartment moves in a superior-inferior (or cranio-caudal) direction and had the greatest excursional range of motion, whereas the deep compartment demonstrated anterior-posterior (or dorsal-ventral) displacement.

## DISCUSSION

High resolution ultrasonography represents a reliable technique for evaluating the anatomical structures and motion configuration of the lower eyelid compartments.

All lower eyelid structures were appreciated in cross sections with distinct echogenic densities. On motion analysis and gaze tracking from up-gaze to down-gaze, the maximal visible area of the central fat compartment is clearly noticeable. The presence of 2 fat subcompartments, one superficial or in close proximity to the globe and one inferior, close to the orbital floor were further distinguished by their divergent dynamic behavior. This compartmentalization might be related to fibrous extensions on the undersurface of the orbital septum. The movement of the inferior fat compartment was delayed compared to the superficial one. Tracking of these fat subcompartments showed that the anterior compartment's movement relates to the retraction of retractors and globe movement while the displacement of the inferior compartment follows the orbital septum.

The observation on down-gaze, of a maximal surface area reduction of orbital fat pads of greater than 50%, indicates a physiological mechanism of displacement or compression of the lower eyelid fat. During downward movement, the globe exerts a tractional effect on the lower eyelid retractors, which is subsequently transmitted to the anterior fat compartment attached to the retractors. Retraction of the retractors exerts downward traction on tarsus and orbital septum. Subsequently, traction of the orbital septum and skin (*via* its attachments) exerts displacement of the inferior compartment.

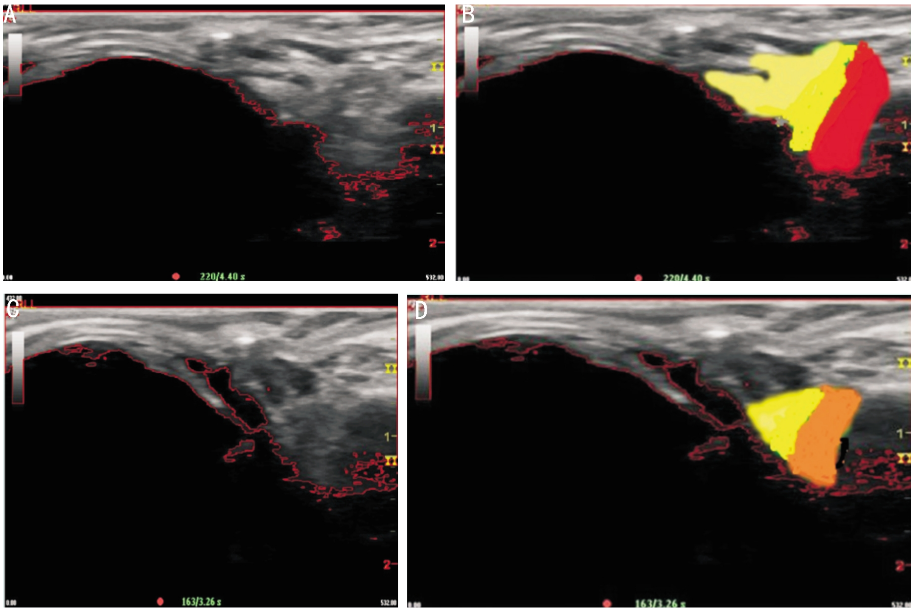


**Figure 5 Ultrasonographic images showing lower eyelid fat compartments on up-gaze and down-gaze** A: Ultrasonographic image on up-gaze; B: Overlay on ultrasonographic image on up-gaze. Colored area corresponds to the lower eyelid fat compartments. The anterior section is highlighted in yellow, the deep inferior compartment in red; C: Ultrasonographic image with the globe in down-gaze of the same patient; D: Overlay on ultrasonographic image with the globe in down-gaze. The most distal visible section of the anterior fat pad in proximity to the orbicularis muscle showed the greatest conformational changes from up-gaze to down-gaze.

This compartment exhibits a vertical direction of movement, while the superficial anterior moves mainly in the Z axis.

Observation of fat pad movement showed there were two types of movement within lower eyelid far pad. First, sliding movement that in sliding or shearing movement, two fat compartments slide over each other. Second, swirling movement that in this movement, it seems that within each sub-compartment, fat particles shake or jiggle.

This study showed that the lower eyelid orbital septum has 3 attachments after going up from inferior orbital rim. There are 2 attachments between orbital septum and skin. Inferior attachment is short and during downward movement cause skin dimpling and retraction. The final attachment of orbital septum is its join with lower eyelid retractors. Between these attachments, orbital septum can be seen concave, but inferior to inferior skin attachment, it is going to be convex toward skin. This is the area subject for fat herniation. It seems that this area is useful for study about septum tightening in patient with lower eyelid fat herniation. In young persons, the septum can be seen easily, however in older ages, it cannot be seen easily that is due to decreased in echogenicity or attenuation of the septum. On the other hand, in patients with lower eyelid fat herniation, range of motion of fat in deeper compartment would be decreased so that in some patients, it seems that the herniated fat is fixed. This finding may be due to losing of septal attachments of the fat.

Our preliminary ultrasonographic study provides a unique insight on a noninvasive tool for the evaluation of the lower eyelid structure. Based on these observations one can postulate that changes in the retractor-septum structure and the motion range of the lower eyelid fat compartments could relate to lower eyelid pathological or aging changes. Although our study is a preliminary evaluation of ultrasonographic application in the lower eyelid, it highlights the potential for assessing its anatomic and physiological characteristics in a variety of disorders. Thyroid associated lower eyelid retraction, entropion or post surgical structural changes are potential fields for its application. Further evaluation of its diagnostic precision and investigation of larger numbers of healthy and diseased subjects is mandatory.

**REFERENCES**

1 Byrne SF, Green RL. Ultrasound of the eye and orbit. St. Louis: Mosby, 2002

2 Demirci H, Nelson CC. Ultrasound biomicroscopy of the upper eyelid structures in normal eyelids. *Ophthal Plast Reconstr Surg* 2007;23(1):122-125

3 Pavlidis M, Stupp T, Grenzebach U, Busse H, Thanos S. Ultrasonic visualization of the effect of blinking on the lacrimal pump mechanism. *Graefes Arch Clin Exp Ophthalmol* 2005;243(3):228-234

4 Hoşal BM, Ayer NG, Zilelioglu G, Elhan AH. Ultrasound biomicroscopy of the levator aponeurosis in congenital and aponeurotic blepharoptosis. *Ophthal Plast Reconstr Surg* 2004;20(4):308-311

5 Lee HS, Lew H, Yun YS. Ultrasonographic measurement of upper eyelid thickness in Korean children with epicanthus. *Korean J Ophthalmol* 2006;20(2):79-81

6 Kikkawa DO, Ochabski R, Weinreb RN. Ultrasound biomicroscopy of eyelid lesions. *Ophthalmologica* 2003;217(1):20-23

7 Furuta M, Shields CL, Danzig CJ, Eagle RC Jr, Shields JA. Ultrasound biomicroscopy of eyelid eccrine hidrocystoma. *Can J Ophthalmol* 2007;42(5):750-751

8 Bajaj MS, Aalok L, Gupta V, Sen S, Pushker N, Chandra M. Ultrasound biomicroscopic appearances of eyelid lesions at 50MHz. *J Clin Ultrasound* 2007;35(8):424-429

9 Given-Wilson R, Pope RM, Michell MJ, Cannon R, McGregor AM. The use of real-time orbital ultrasound in Graves' ophthalmopathy: a comparison with computed tomography. *Br J Radiol* 1989;62(740):705-709