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ORIGINAL ARTICLE

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Anatomical histological and mesoscopic study of the adipose tissue of the orbit

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Abstract Our study aimed to define the organization of the orbital adipose tissue, which is constituted from white adipose tissue. Six orbital samples were taken by dissection from fresh cadavers. After fixation and paraffin-embedding, the blocks were sectioned in the three spatial planes (two in the frontal, two in the sagittal, two in the horizontal). Semi-serial sections of 7 μm were then stained with hematein, eosin, safran or Masson trichrome green. We noticed strong areas of adhesion with orbital bones located at the lacrimal gland, the orbital trochlea and the inferior orbital fissure. Our mesoscopic and histological results allowed the description of two types of orbital adipose tissue corresponding to morpho-functional topographic variations. One was constituted of thick conjunctival septa with small adipocytes near muscles and the lacrimal gland. This was a supporting tissue that gave the points of rotation. The other was constituted of thin conjunctival septa with larger adipocytes near the optic nerve, allowing its movements in the orbit. These morphological differences appeared to be correlated with the mechanical role of these two areas. The dense appearance could correspond to the functional trochlea of rectus muscles described. In contrast we did not observe the systematic radial and concentric conjunctival meshwork classically described. This study underlines the specificity of orbital adipose tissue, which could be useful for a better understanding of its normal and pathological partition and its involvement in ocular motility.

Keywords Adipose tissue · Orbit · Anatomy · Histology · Mesoscopic

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Introduction

The adipose tissue of the orbit (ATO) or fat pad of the orbit is a white adipose tissue which plays an essential role in support, sliding and mechanical protection. The intra-orbital structures, the ocular globe, the optic nerve and the oculomotor muscles are held in place while preserving freedom of movement. The ATO thus contributes to movement by allowing displacement of these intra-orbital structures. Contrary to the majority of white adipose tissue in the body, its role as an energy reserve is completely secondary [17]. It undergoes practically no modification or diminution during periods of fasting. On the other hand, while several cases of orbital hibernomas have been described [1], this anatomical region is not a classical site for brown adipose tissue even in the newborn. The ATO is, as with all white adipose tissue, made up of lobules surrounded by conjunctival septa [4]. Koornneef [19] provided the classical description of its organization in radial septa. Some authors distinguish an outer localized fatty tissue, called extra-conical, and a central fatty tissue, called intra-conical, as a consequence of the organization of the conjunctival tissue and the cone formed by the oculomotor muscles [25]. Whatever it may be, this organization probably plays a key role in ocular movement. In addition, in certain pathological situations the ATO shows marked remodeling. For example, after enucleation, modifications of the orbital relationships lead to marked loss of this tissue. The fibrous tissue which progressively but incompletely replaces the ATO is the origin of "hollow eye syndrome" [13] in patients who have had an enucleation.

Because of the limited literature about the organization of the ATO, we undertook an anatomical, mesoscopic and histological study of it. Our study aimed to establish the organization and structure of the whole of the ATO, its extra- and intra-conical mesoscopic organization [15] and the histological distribution of the fatty lobules and separating fibrous septa.

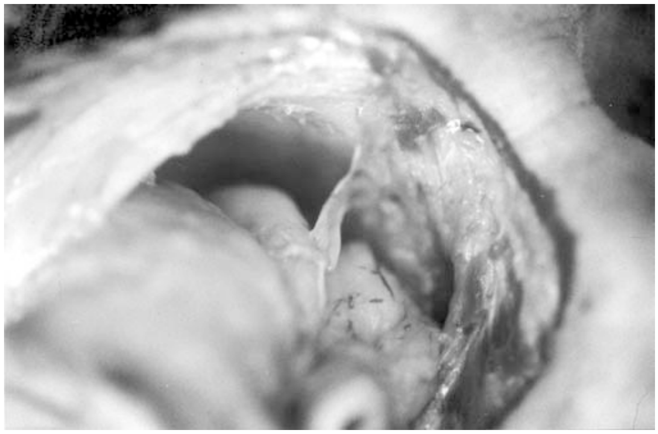

Fig. 1 Dissection of the periorbit with adhesions at the level of the trochlea of the superior oblique muscle. Magnification ×1

Material and methods

Our study was done on a sample of six orbital contents from fresh cadavers of an average age of 74 years (range 64–83 years) years. There were three males and three females who were free of any orbital or facial problems. These samples were taken through a circular cutaneous incision, following the bony margin of the orbit starting from the medial part of the eyebrow to the supra-orbital region and then following laterally over the front of the zygomatic process below along the anterior border of the orbital floor and finally medially, ending on the maxilla at the level of the anterior lacrimal crest to join the start of the incision. Dissection was carried through the superficial planes to the bony margin. Separating the orbital contents by preserving the periosteum and periorbital membranes allowed harvesting of the whole orbital contents. At the level of the orbital apex, the optic nerve was divided flush with the bony orbit as with surgical enucleation and the oculomotor muscles divided at the base of the apex with curved scissors.

The specimens were then fixed in 10% formalin and embedded in paraffin after orientation in the three anatomical planes (one specimen from a female subject and one specimen from a male subject in each of the frontal, sagittal and horizontal planes). The blocks were in semi-serial sections 7 μm thick. After staining with hematein, eosin, safran or Masson trichrome green the different orbital and ocular structures were examined with optical microscopy. The anatomical relationships of the oculomotor muscles, the optic nerve and the lacrimal gland with the different elements of the ATO were studied in the different planes of dissection. The mesoscopic study of the orbital adipose complex combined the examination of the whole of the adipose tissue at very low magnification with its microscopic study and, in particular, with the conjunctival component in contact with each of the structures of the orbit such as the oculomotor muscles, the optic nerve, the lacrimal gland and the vessels. The histological study tried to define better the structure of the adipose lobules. The size of the adipocytes and the density of the septa were estimated according to the orbital map which had been established.

Results

Anatomical results

The dissection revealed zones of firm adherence between the bony orbit and its contents. The zones made up of fibrous ridges required careful dissection. They were found in essentially three locations: two of them were situated in an anterior plane, one opposite the lacrimal gland superolaterally in the bony orbit and the other at the level of the trochlea of the superior oblique superomedially (Fig. 1). The last was situated in a more posterior plane at the level of the middle part of the orbital floor and the inferior orbital fissure.

Mesoscopic results

Each of the three planes of section allowed more precise definition of the anatomical and mesoscopic relationships of the intra-orbital structures with the ATO. The plane of the frontal section was the plane of choice to assess the arrangement around the oculomotor muscles and the optic nerve (Fig. 2). The plane of the horizontal section allowed sectioning of the oculomotor muscles in the major part of their orbital course and the medial and lateral relationships of the optic nerve were well seen. The plane of the sagittal section allowed the muscles to be followed over the whole of their orbital length and the superior and inferior relationships of the optic nerve to be determined (Fig. 3). All the data thus acquired allowed a map of the regional variation of the orbital adipose tissue to be constructed.

At the level of the oculomotor muscles, the conjunctival trusses of the ATO appeared numerous and

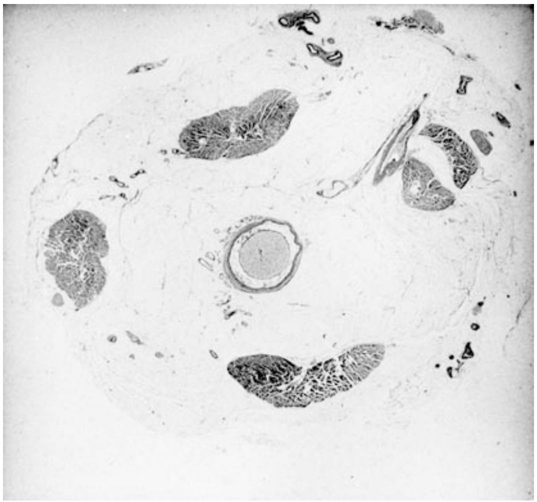

Fig. 2 Mesoscopic appearance of the orbital adipose tissue: frontal section. The central optic nerve is surrounded by the oculomotor muscles. Magnification ×1

Fig. 3 Mesoscopic aspect of the orbital adipose tissue: sagittal section. The orbital apex is seen behind with the optic nerve and the oculomotor muscles surrounded by the adipose tissue of the orbit (ATO) and, in front, the ATO limited by the septum and the eyelids. Magnification ×1

serrated on their extra- and intra-conical aspects (Fig. 4). Beside the aponeurosis of the superior rectus and the superior oblique muscles, the conjunctival membranes were condensed in the proximity of the muscle with small fatty lobules. This appearance was seen more clearly in the anterior orbital regions. In the midst of the conjunctival trusses numerous blood vessels were present. The fibrous septa which on the frontal sections linked the rectus muscles in a circular fashion, appeared poorly defined. No systematic arrangement of the conjunctival membranes could be found on the sections which were examined, and in particular, no distinct radial or concentric circular structure could be separated except that of the irregular fibromuscular cone.

Fig. 4 Adipose tissue with numerous septa at the level of the oculomotor muscles. Magnification ×2.5

Around the optic nerve, a wide band of loose adipose tissue separated the muscles. On the lateral aspect of the optic nerve, the conjunctival trusses of the ATO appeared slender while the thick sheath of the optic nerve was well defined (Fig. 5). Only the thicker conjunctival trusses supported the vessel.

The lacrimal gland was surrounded by an ATO which was rich in fibrous septa, with a density comparable to that of the muscles.

In relationship with the ocular glove, the loose intra-conical ATO progressively widens towards the front from the orbital apex to the posterior aspect of the sclera. The extra-conical ATO, which was richer in conjunctival trusses, was widest at the apex and then narrowed at the level of the equator and widened again towards the anterior part of the ocular globe as far as the orbital septum, creating the form of a diabolo.

Histological results

The histological analysis of the sections showed classical white adipose tissue. The adipocytes were, as expected, arranged in lobules circumscribed by conjunctival trusses in which the vessels and nerve fibers ran. The ATO, however, had two clearly different appearances according to position, with progressive passage from one appearance to the other. These two appearances differed in terms of the density of the conjunctival membranes

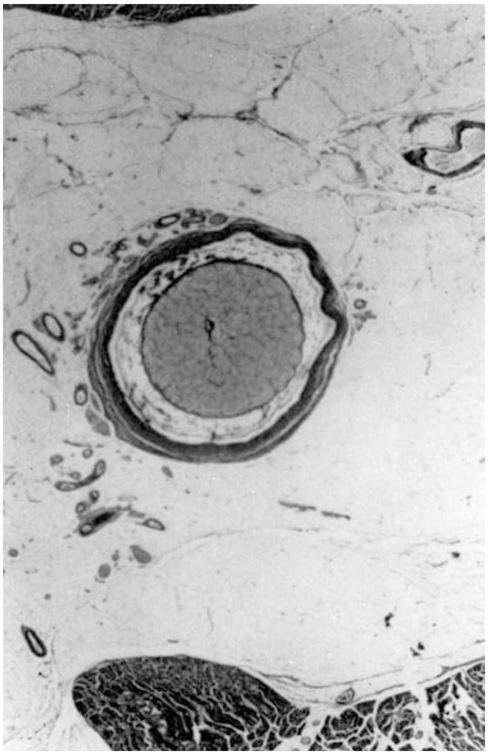

Fig. 5 Adipose tissue with few septa at the level of the posterior intra-conical part close to the optic nerve. Magnification ×2.5

that separated the lobules and the average size of the adipocytes. Thus in the posterior region of the orbit, and in particular around the optic nerve, the conjunctival membranes of the ATO were relatively loose, delimiting lobules in which the adipocytes had a diameter in the region of 75 μm. In the anterior part of the orbit, particularly around the muscular structure and the lacrimal gland, the conjunctival membranes were much denser and the adipocytes were of a smaller size with a diameter in the region of 55 μm.

Discussion

Classically, according to Koornneef [18, 19], the orbit is organized around the fibromuscular orbital cone which limits the intra- and extra-orbital spaces. These studies show, in addition, different radial and circular fibrous structures which insert on the periphery of the peri-orbit. Koornneef studied the orbits with their bony walls, while this study preserved only the peri-orbit, which allowed separation in an original way of the specific zones of adherence at the peri-orbital level. These adhesions are very probably generated in response to varying mechanical constraints. Thus, the point of fixation of the trochlea of the superior oblique muscle, the inferior orbital fissure, the weak point of the floor supporting the orbital structures and the latero-superior point of suspension of the lacrimal gland are the zones where marked traction forces are applied.

Mesoscopic discussion

At a tissue level, the ATO is made up of a conjunctival framework of fibrous trusses which assure mechanical support of the different orbital structures and the adipocytes that allow the degree of freedom necessary for oculomotor movements. The different planes of section allowed assessment of the map of the ATO. In agreement with Koornneef [18, 19] the results showed that the conjunctival trusses associated with the oculomotor muscles make up a cone delimiting the intra- and extra-conical spaces [10, 21, 23]. However, the systematic radial and circular arrangements described by that author were not found.

The septa were organized in a random fashion delimiting relatively large lobules; thus each structure itself contributed to the mesoscopic structure of mechanical support of the orbit. At the level of the oculomotor muscles, there was a groove along the pulleys, in particular on the anterior part. While the anatomy of the pulley of the superior oblique muscle is well known (with its trochlea of reflection) that of the rectus muscles is a new concept [5, 6]. The extra-ocular muscles have two regions: one outside the orbit and one intra-ocular. The orbital region is related to the bony walls of the orbit by the intermediary of the extra-conical ATO. The ocular region inserts onto the sclera of the ocular globe and is related to the intra-conical ATO. Demer's hypothesis is that there are active pulleys at the level of the rectus muscles in the anterior part. These are made up of condensation of conjunctival tissue in the anterior orbital region forming an active pulley which takes up the functional origin of the muscle, allowing the coordination of ocular movements in different directions of view. Results of this study on the adipose tissue are consistent with MRI observations by Ettl et al. [7, 8] and with Demer's theory elaborated by MRI [6]. Indeed the densification seen on the conjunctival trusses probably sheaths the rectus muscles and their aponeurosis and maintains them close to the adjacent orbital wall. This conjunctival condensation is more marked in the anterior part of the cone and provides the point of reflection of the pulley described by Demer. The muscle sliding in its sheath during contraction gives the impression of relative fixation seen on MRI in the posterior part [8]. Around the optic nerve, the ATO seems to be situated in a wide space with few fibrous septa. In its physiological state the optic nerve, whose intra-orbital course is sinuous, follows the ocular globe. The observation of a straight and rigid optic nerve on MRI indicates a pathological situation [9, 12]. The slender adjacent conjunctival bundles which have been observed may guarantee the freedom of movement necessary for its intra-orbital displacement. Around the lacrimal gland, the ATO is made up of small adipocytes and dense conjunctival septa. This conjunctival condensation of the ATO, which seems to support the lacrimal structure, probably corresponds to the fibrous ridges seen during dissection. In a general manner, the density of the septa translates as a functional adaptation of the ATO depending on the site. Indeed around the muscles of the lacrimal gland, the fibrous septa are more dense and more numerous than in the posterior region around the optic nerve.

Histological discussion

In the adult, the ATO is morphologically comparable to the adipose tissue of other regions. However, comparison between the morphometric data concerning the abdominal adipose panniculus [4], generally taken as a reference, and the estimations of the size of the adipocytes of the ATO shows marked differences which might explain the absence of reaction of the ATO to periods of fasting. Indeed the more voluminous adipocytes in other locations release their triglycerides before the small adipocytes of the ATO mobilize theirs. Regarding the appearance of the orbital adipocytes, no difference between the extra- and intra-conical regions was shown, in agreement with the work of Wolfram-Gabel et al. [26]. This result agrees with Sires' work [22], which showed no regional difference in the structural appearance of the adipocytes and fibroblasts nor in their fatty acid protein contents. Leptin, which gives the adipose tissue the status of an endocrine cell, is classically expressed by mature adipocytes including the orbital adipocytes [2]. There is a progressive difference in size of the adipocytes and density of the conjunctival trusses between the anterior and posterior region.

Applications in orbital pathology

Certain pathological conditions such as Kobberling Dunnigan syndrome, which is characterized by quasi-absence of adipose tissue in the trunk and limbs while fat is normally developed in the face and the orbital space [14], emphasize the great similarity between the buccal and orbital fat. In thyroid pathology, the effect on the orbital tissues [24] includes, in addition to the effect on the oculomotor musculature, a lesion of the orbital tissue, in particular remodeling of the ATO. The mature adipocytes which express a receptor to thyroid simulating hormone (TSH) should be an antigenic target in Basedow orbitopathy but the pathogenesis remains poorly defined. One of the treatments of Basedow exophthalmia consists of excision of the ATO. In aging of the oculo-orbital tissues, dehiscence of the orbital septum [3] leads to migration forwards of the ATO to the preseptal region, which gives an aspect of palpable pouches. Blepharoplasties [16] correct this pathology by removing the ectopic tissue without treating the initial cause. Surgical correction of septal dehiscence is impossible because the condition recurs leading to iterative blepharoplasty. This creates a retro-septal deficit in the ATO which leads to "hollow eye" syndrome. "Hollow eye" syndrome may appear spontaneously in senile enophthalmia. The ATO seems to have sufficient qualitative similarities to the subcutaneous fat tissue for it to be used with good results [2] as a graft to palliate loss of substance in the orbital region, as for example in the correction of post-enucleation enophthalmia [11, 26]. However, Ilankovan and Soames' [13] morphometric studies on the relative volumes of collagen, the endothelial cells and the numerical density of the mastocytes in the orbital, buccal (Bichat' buccal fat pad) and subcutaneous adipose tissue show a greater similarity between the first two situations. These authors concluded that the buccal fat is a preferable donor site to replace lost orbital fat. The weaknesses of the perilacrimal conjunctival system encourage the development of ptosis of the lacrimal gland, correction of which aims to re-establish its fixation at the level of the orbit in an anatomical position.

Conclusion

The structure of the ATO has one of two appearances according to its position. The muscular and lacrimal structures are surrounded by an ATO with dense conjunctival trusses. This arrangement around the muscles could confirm Demer's theory regarding the pulleys of the rectus muscles. The optic nerve is itself surrounded by an ATO with slender conjunctival trusses which gives it support but is supple enough to ensure freedom of movement. This study did not find the radial and concentric arrangement reported in the literature. This work underlines how the different characteristics of the ATO serve as a base for a better understanding of certain pathologies and, in particular, those encountered in the surgery of oculoplastic ophthalmology.

References

1. Antillon F, Watty E, Aleman P (1979) Orbital hibernoma. Gac Med Mex 115:239–242
2. Atanassova P, Popova L (2000) Leptin expression during the differentiation of subcutaneous adipose cells of human embryos in situ. Cells Tissues Organs 166:15–19
3. Bremond-Gignac D, Deplus S, Cussenot O, Lassau J P (1994) Anatomic study of the orbital septum. Surg Radiol Anat 16:121–124
4. Brooks J, Perosio P (1992) Adipose tissue. In: Histology for pathologists. Raven Press, New York, pp 33–60
5. Demer JL (1995) The orbital pulley system: a revolution in concepts of orbital anatomy. Ann N Y Acad Sci 956:17–32
6. Demer JL (2002) Active pulley system: magnetic resonance imaging of rectus muscle paths in tertiary gazes. Invest Ophthalmol Vis Sci 43:2179–2188
7. Ettl A, Koornneef L, Daxer A, Kramer J (1998) High resolution magnetic resonance imaging of the orbital connective tissue system. Ophthalmic Plast Reconstr Surg 14:323–327
8. Ettl A, Kramer J, Daxer A, Koornneef L (1997) High-resolution magnetic resonance imaging of the normal extra-ocular musculature. Eye 11:793–797
9. Ettl A, Kramer J, Daxer A, Koornneef L (1997) High resolution magnetic resonance imaging of neurovascular orbital anatomy. Ophthalmology 104:869–877

10. Gola R, Carreau JP, Faissal A (1995) Le tissu adipeux de l'orbite. Rappel anatomique, déductions thérapeutiques. Rev Stomatol Chir Maxillofac 96:123–136
11. Gotzamanis A, Ducasse A, Brugniart C, Sayag D (2001) Greffe dermo-graisseuse: utilisation pour les reconstructions chirurgicales des cavités. J Fr Ophtalmol 24:617–622
12. Hansen HC, Helmke K (1996) The subarachnoid space surrounding the optic nerves. An ultrasound study of the optic nerve sheath. Surg Radiol Anat 18:318–323
13. Ilankovan V, Soames JV (1995) Morphometric analysis of orbital, buccal and subcutaneous fats: their potential in the treatment of enophthalmos. Br J Oral Maxillofac Surg 33:40–42
14. Jackson S, Pinkney J, Bargiotta A, et al. (1998) A defect in the regional deposition of adipose tissue (partial lipodystrophy) is encoded by a gene at chromosome 1q. Am J Hum Genet 63:534–540
15. Jimenez-Castellanos J, Carmona A, Castellanos L, Catalina-Herrera C (1995) Microsurgical anatomy of the human ophthalmic artery: a mesoscopic study of its origin, course and collateral branches. Surg Radiol Anat 17:139–143
16. Jost G, Vergnon L, Laffole P, Pelisse JM (1980) Etude anatomique de la graisse orbitaire: a propos des constations faites lors des blépharoplasties. Ann Chir Plast 25:225–229
17. Katch V, Becque M, Marks C, Moorehead C, Rocchini A (1991) Gender dimorphism in size, shape and body composition of child-onset obese and non-obese adolescents. Int J Obes 15:267–282
18. Koornneef L (1977) New insights in the human orbital connective tissue, Arch Ophthalmol 95:1269–1273
19. Koornneef L (1979) Orbital septa: anatomy and function. Ophthalmology 86:876–880
20. Rose G, Collin R (1992) Dermofat grafts to the extraconal orbital space. Br J Ophthalmol 76:408–411
21. Rouvière H (1978) Anatomie humaine descriptive, topographique et fonctionnelle, vol 3. Masson, Paris, pp 498–504
22. Sires BS, Lemke BN, Dortzbach RK, Gonnering RS (1998) Characterisation of human orbital fat and connective tissue. Ophthalmic Plast Reconstr Surg 14:403–414
23. Sobotta (1994) Atlas d'anatomie humaine, vol 2. Editions médicales internationales, Paris, pp 304–381
24. Sorisky A, Pardasani D, Gagnon A, Smith TJ (1996) Evidence of adipocyte differentiation in human orbital fibroblasts in primary culture. J Clin Endocrinol Metab 81:3428–3431
25. Testut, Latarget (1884) Les anomalies musculaires chez l'homme expliquées par l'anatomie comparée: leur importance en anthropologie. Masson, Paris
26. Wolfram-Gabel R, Kahn JL (2002) Adipose body of the orbit. Clin Anat 15:186–192