Review

ANTERIOR SEGMENT ISCHEMIA AND STRABISMUS SURGERY: FROM THE ANATOMY TO THE CLINIC

Abraham Olvera-Barrios, Rodrigo E. Elizondo-Omaña, Verónica E. Tamez-Tamez, María de los Ángeles Garcia-Rodríguez, Eliud E. Villarreal-Silva, Santos Guzman-Lopez

Department of Human Anatomy, Faculty of Medicine, Universidad Autónoma de Nuevo León, Mexico

RESUMEN

La isquemia del segmento anterior es una complicación seria que puede presentarse después de la cirugía de estrabismo, particularmente después de desinsertar tres o cuatro músculos extraoculares, con la sección de sus respectivas arterias ciliares anteriores. Sin embargo, susceptibilidad individual y una cantidad considerable de factores de riesgo juegan también un papel importante en el desarrollo de esta condición que pone en peligro la vista. Una evaluación minuciosa es fundamental para cada paciente. Por lo tanto, conocer la irrigación del segmento anterior junto con los mecanismos que producen la isquemia de esta región del ojo es de suma importancia para evaluar a los pacientes, para planear y decidir qué procedimiento quirúrgico es el mejor para cada caso en particular, y para prevenir la ocurrencia de esta complicación. La revisión de la anatomía descriptiva y su posterior correlación con el cuadro clínico de esta entidad facilita el entendimiento de la patogénesis de la isquemia y crea conciencia acerca de la necesidad de instituir medidas preventivas.

Palabras clave: *Arterias ciliares anteriores, isquemia ocular, complicaciones quirúrgicas*

ABSTRACT

Anterior segment ischemia is a serious complication that may occur after strabismus surgery, particularly after the deinsertion of three or four extraocular muscles, with transection of their anterior ciliary arteries. However, individual susceptibility and a considerable amount of risk factors also play an important role in the development of this condition, which endangers sight. A thorough evaluation is essential for each patient. Therefore, knowing the irrigation of the anterior segment along with the mechanisms that produce ischemia of the eye region is very important to assess patients, plan and decide which surgical procedure is best for each particular case, and to prevent the occurrence of this complication. Review of the descriptive anatomy and its subsequent combination with the clinical picture of this entity facilitates understanding of the pathogenesis of ischemia and raises awareness about the need to institute preventive measures.

Keywords: *Anterior ciliary arteries, ocular ischemia, surgical complications.*

INTRODUCTION

The anterior segment ischemia (ASI) is now a well-known clinical entity that is most frequently seen after strabismus surgical procedures. Given that, this complication may become a sight-threatening condition, a better understanding of ASI by researchers and clinicians is of vital importance to prevent this rare but serious disorder. In our article we review the descriptive and functional anatomy of the anterior segment of the eye, as well as the clinical features of the condition to highlight the importance of its recognition and prevention.

---

* *Correspondence to*: **Dr. Abraham Olvera-Barrios**, Department of Human Anatomy, Faculty of Medicine, Universidad Autónoma de Nuevo León, Ave. Madero y Calle Dr. Eduardo Aguirre Pequeño s/n, Colonia Mitras Centro, Monterrey, Nuevo Leon, 64469, Mexico. a_olvera_@hotmail.com

Received: 5 October, 2014. **Revised**: 18 November, 2014. **Accepted:** 3 December, 2014.

DISCUSSION

Vascular anatomy of the anterior segment

Three main arteries supply the anterior segment of the eye: the anterior ciliary arteries, the long posterior ciliary arteries and the conjunctival arteries. Seventy to eighty percent of the arterial blood flow to this region of the eye is supplied by the anterior ciliary arteries. The long posterior ciliary arteries irrigate the majority of the remaining territory, being the conjunctival arteries just a minor component of the blood supply to the aforementioned region (Olver and Lee, 1989; Skuta et al, 2011a; Bagheri et al, 2013).

The muscular arteries, branches of the ophthalmic artery, supply the rectus muscles and after this has been achieved they divide into the anterior ciliary arteries. The anterior ciliary arteries travel within the rectus muscles and emerge on the surface at a short distance posterior to the transition from muscle to tendon. They advance anteriorly in a tortuous manner and give off the anterior conjunctival arteries just before they pierce the sclera to anastomose with the branches of the long posterior ciliary arteries. The anastomosis between the anterior ciliary arteries and the long posterior ciliary arteries forms the major arterial circle of the iris (MAC), which carries blood to the ciliary body, the ciliary processes and the iris. After palpebral branches of the lacrimal and nasal arteries have formed the palpebral arcades, ascending branches from the peripheral tarsal arcade advance into the superior fornix and continue to the bulbar conjunctiva as the posterior conjunctival arteries which anastomose with the corresponding anterior conjunctival arteries (Fig. 1) (Saunders et al, 1994; Hayreh, 2006).

In his vascular anatomy of the eye, Leber (Graefe et al, 1916) described two anterior ciliary arteries for each of the rectus muscles, except for the lateral rectus, which has only one. Nevertheless, the number, caliber and location of the anterior ciliary vessels have been found to be variable in different studies (Heymann et al, 1985; Mckeown et al, 1989). The oblique muscles are not irrigated by muscular arteries and do not carry anterior ciliary arteries, as a consequence, they do not contribute to the anterior segment blood supply and the transection of these muscles should not produce ASI.

The two long posterior ciliary arteries pierce the sclera at a short distance from the optic nerve and follow an anterior direction to the ciliary muscle in an intrascleral position, below the medial and lateral rectus muscles. The long posterior ciliary arteries form the intramuscular circle of the iris and its branches contribute to the formation of the usually discontinuous MAC (Skuta et al, 2011a). Anastomoses between the episcleral and subconjunctival tissue, the intramuscular circulation of the iris and the MAC provide a multichannel blood supply to the anterior segment that might prevent ASI after strabismus surgery (Fishman et al, 1990; Coats and Olitski, 2007).

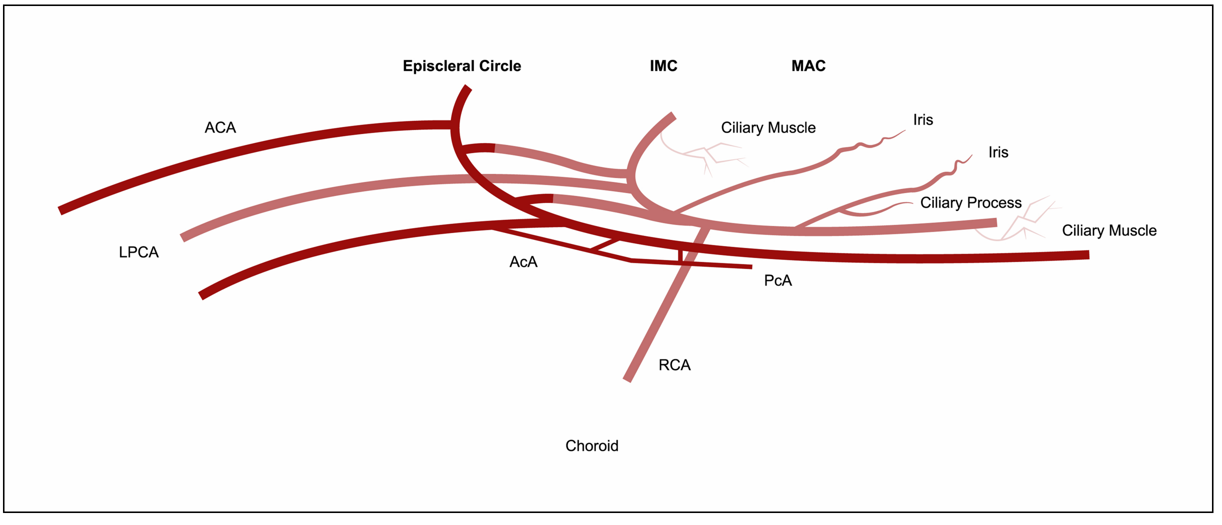

Figure 1. Schematic three-dimensional representation of the vascular anatomy of the anterior segment of the eye. Superficial vessels are represented with dark lines, whereas clear lines illustrate deeper arteries. ACA= Anterior ciliary artery; LPCA= Long posterior ciliary artery; AcA= Anterior conjunctival artery; PcA= Posterior conjunctival artery; IMC= Intramuscular circle; MAC= Major arterial circle; RCA= Recurrent ciliary artery.

Anterior segment ischemia

Due to the multilevel blood supply of the anterior segment, ASI is a rare, but potentially serious complication that threatens vision. The first clinical descriptions of the anterior segment changes due to ischemia made by Schmidt in 1874 (Schmidt, 1874), the studies in animal models (Chamberlain Jr, 1954; Laatikainen, 1971) and the analysis of pathological specimens (Sharp et al, 1982; Apple et al, 1984) provided a background that allowed to associate and recognize the clinical syndrome of ASI with extensive surgery of the rectus muscles in the late 1950's and early 1960's (Wilson and Irvine, 1955; Forbes, 1959; Girard and Beltranena, 1960; Nauheim, 1962; Orzalesi and Saba, 1966).

Incidence

A survey of the members of the American Association of Pediatric Ophthalmology and Strabismus estimated an incidence of ischemia, for all age groups after strabismus surgery of 1 in 13,333. In this study, 400 000 surgical procedures were documented and only 30 cases were found (France and Simon, 1986). Nevertheless, the reported incidence might underestimate its true occurrence given the lack of clinical manifestations of mild cases.

The ASI is most frequently seen after transection of three or four rectus muscles and their respective anterior ciliary arteries during strabismus surgery (Bagheri et al, 2013). It is almost exclusively found in adults and particularly in those with circulatory problems (Jacobs et al, 1976; Cullis et al, 1979; Fells, 1980; Saunders and Sandall, 1982; Wagner and Nelson, 1985; France and Simon, 1986). Yet, cases of clinically significant ASI in children who went through strabismus surgery can be found in the literature (France and Simon, 1986; Elsas and Witherspoon, 1987).

Anterior segment perfusion after strabismus surgery

Hypoperfusion of the anterior segment after strabismus surgery can be demonstrated by iris fluorescein angiography (IFA) (Hayreh and Scott, 1978a; b; Virdi and Hayreh, 1987; Chan et al, 2001). IFA is a valuable diagnostic technique that can be used to determine the etiology of different disorders that affect the anterior segment structures and their vasculature. To perform IFA, the examiner needs a fundus camera or any other specialized camera used for this purpose. After the injection into a peripheral vein of sodium fluorescein, a hydrocarbon that reacts with wavelengths of 465 to 490 nm and that fluoresces at 520-530 nm, two fluorescein matched filters of the camera (exciter and barrier) allow the blue absorbed excitation wavelength to be changed to a resultant green-yellow fluorescence. A consecutive series of pictures are taken during time to document the filling patterns of the vasculature of the anterior segment structures (Brancato et al, 1997).

If a single rectus muscle is detached from the sclera, a filling delay adjacent to the disinserted muscle will ensue. A sectorial filling delay after surgery of the vertical rectus muscles is greater than when horizontal rectus muscles are operated. In a clinical and angiographic assessment of the anterior segment circulation made in 35 patients, Olver (Olver and Lee, 1989) demonstrated that on postoperative day one, detachment of the inferior rectus muscle resulted in a larger defect of perfusion than superior rectus muscle tenotomy. Because of the transection of the anterior ciliary arteries following procedures on the rectus muscles, compensatory blood flow to the anterior segment increases in the long posterior ciliary arteries, particularly in the medial one (Hayreh and Scott, 1978b; Prakash et al, 1986; Olver and Lee, 1989). Despite this useful contribution, an experimental study showed that disruption of the blood supply of only the long posterior ciliary arteries does not lead to ASI (Virdi and Hayreh, 1987).

Within the first few weeks after surgery the filling delay rapidly decreases, suggesting an increase in the collateral circulation. Nevertheless, the filling pattern remains the same and the last sector to fill will still correspond to the hypoperfused area. In spite of anecdotal evidence, reestablishment of the circulation of a transected anterior ciliary vessel does not occur (Olver and Lee, 1992).

Risk factors

Thanks to the anatomical and functional studies regarding anterior segment irrigation and the changes that strabismus surgery produces in this region of the eye, it has become evident that individual susceptibility and the type of surgery are important factors that condition the occurrence of ASI (Saunders et al, 1994).

Several risk factors for the development of ASI have been identified. Advanced age, surgery on the vertical rectus muscles, previous rectus muscle surgery, atherosclerosis, diabetes, hypertension, blood dyscrasias, dysthyroid ophthalmopathy, simultaneous surgery on three or four rectus muscles of the same eye, simultaneous surgery on adjacent rectus muscles and the use of a limbal incision are all determinants that place patients at risk for ischemia (Jacobs et al, 1976; Von Noorden, 1976; Hayreh and Scott, 1978b; Cullis et al, 1979; Fells, 1980; Saunders and Sandall, 1982; Simon et al, 1984; Wagner and Nelson, 1985; Fishman et al, 1990; Murdock and Kushner, 2001). Of those mentioned, the most important risk factor is the patient's age (France and Simon, 1986). In children, several rectus muscles can be detached from the sclera and it will be very rare that they develop ASI (Berens and Girard, 1950). It is therefore presumed that adults lack a sufficiently adaptable vascular system. The coexistence of two or more of the aforementioned risk factors puts the patient at greater risk and demands a careful surgical planning along with appropriate patient counseling.

Another risk factor taken into account is the fact that vortex vein occlusion could lead to the development of ASI (Hayreh and Baines, 1973; Robertson, 1975). Procedures during which vortex veins are at greater risk of lesion are recessions or resections of the superior or inferior rectus muscles, exposition of the superior oblique muscle tendon and weakening of the inferior oblique muscle (Skuta et al, 2011b).

Classification	*Clinical manifestations*
Grade I	Asymptomatic patient with reduced iris perfusion
Grade II	Asymptomatic patient with reduced iris perfusion associated with transient findings on the slit lamp examination consisting in corectopia, irregular pupil reaction and flattening of the pupil margin.
Grade III	Photophobic patient with postoperative uveitis and marked pupil signs.
Grade IV	Patient with pain and reduced vision. Keratopathy, uveitis and decreased intraocular pressure present on examination.

Table 1. Classification of anterior segment ischemia severity

Clinical manifestations

In early stages, the most common clinical findings include anterior chamber *flare* (visualization of the slit-lamp light beam as it passes through the anterior chamber because of an increase in the protein content of the aqueous humor) and *cells* (inflammatory cells visualized as white dots in the slit-lamp light beam that move along the convection currents of the aqueous humor (Wilson and Blomquist, 2009), corectopia (a pupil that is not localized in its normal central location) and a sluggish pupillary reaction to light (Bagheri et al, 2013). Olver and Lee have classified ASI into four grades of severity, representing grade I a sector filling delay in an asymptomatic patient, and grade IV as an infarction in a patient with reduced vision and pain (Olver and Lee, 1989) (Table 1). Patients with grade IV ASI can loose their vision and, in rare cases, phthisis bulbi can ensue (Girard and Beltranena, 1960). As previously stated, the collateral blood flow to the hypoperfused areas increases in the following weeks after surgery, therefore, most of the cases will improve during this period of time. Nevertheless, if significant ischemia develops, atrophy of the iris, a sluggish pupil and corectopia may remain permanently.

Treatment

Because the predominant manifestations of ASI are those of an inflammatory process, treatment consists of topic, subconjunctival and/or systemic steroids. However, there are no data about the benefits of treatment of ASI and no universal consensus about this treatment strategy exists. In a survey of the members of the American Association for Pediatric Ophthalmology and Strabismus, it was found that 21.4% of the ophthalmologists that detected a case of ASI did not use any medical treatment (France and Simon, 1986).

Evidence-based strategies for prevention of ASI

In the interest of preventing cases of ASI, patients who are at risk of developing the condition should be identified and an individualized plan for the patient's surgery should be designed.

In order to reach the episcleral space and to operate on the extraocular muscles an incision in the conjunctiva and in Tenon's fascia is required. The two most common techniques that are used are the fornix conjunctival incision (Parks, 1968) and the limbal conjunctival incision (Von

Noorden, 1968). Of these two, the limbal conjunctival incision disrupts the circulation of the episcleral arterial circle and reduces, though in a minor percentage, blood flow to the multichannel level of the anterior segment of the eye. Fishman (Fishman et al, 1990) reported less events of ischemia with the fornix conjunctival incision in animal models. Therefore, when possible, a fornix conjunctival incision should be preferred in at-risk patients.

Although some authors have described the possibility to detach the four rectus muscles in children or a young adult (Girard and Beltranena, 1960; Uribe, 1968), the number of rectus muscles that are to be operated is an important determinant for the appearance of ischemic changes. In addition to the number, the combination of rectus muscles that are going to be operated is also important. An operation of the two horizontal rectus muscles in a healthy patient with a previously unoperated eye represents no risk because of the compensatory flow of the long posterior ciliary arteries and the fact that the lateral anterior ciliary artery does not contribute to the supply of the intramuscular arterial circle (Woodlief, 1980; Morrison and Van Buskirk, 1983).

Whenever possible, no more than three rectus muscles should be simultaneously operated on the same eye and if extensive surgery is needed, a staged procedure appears to be beneficial when trying to prevent ASI (Harley, 1971; Hiatt, 1978; Simon et al, 1984; Wagner and Nelson, 1985; Prakash et al*,* 1986; Olver and Lee, 1992); this presumably is because the interval of time between the operations allows for the collateral blood flow to increase. The procedures that most frequently require simultaneous detachment of three rectus muscles in an eye are those that treat paralytic strabismus (strabismus due to paralysis or weakness of one or several rectus muscles where the deviation of the affected eye varies with the different gaze positions (Harper, 2010).

Several techniques to preserve the anterior ciliary arteries during extensive strabismus surgeries have been developed. For example, in the treatment of paralytic strabismus, splitting and/or transposition of the muscle insertion sites have been the essence of some operations like the Hummelsheim (Hummelsheim, 1908) and the Jensen (Jensen, 1964) procedures. During these procedures and their further modifications, it is sought to preserve one anterior ciliary artery in each muscle.

Combining different techniques can also reduce the number of muscles that have to be operated in one eye. For example, vertical rectus muscle transposition in the paretic eye and rectus muscle recession or resection in the contralateral eye on patients with sixth cranial nerve palsy, or combinations of rectus muscle recession or resection with vertical or horizontal transposition in complicated incomitant strabismus (Buckley and Townshend, 1991).

The toxin produced by the gram-negative bacteria *Clostridium botulinum* presents as an important alternative in patients who require rectus muscle recession in complex strabismus surgeries. The botulinum toxin has seven serotypes (A, B, C1, D, E, F, G), form which the type A botulinum toxin is the most studied and therefore, the most used (Aoki and Guyer, 2001). The most common indication to use botulinum toxin in strabismus patients is acute sixth cranial nerve palsy (Fitzsimons et al, 1988; Biglan et al, 1989; Fitzsimons et al, 1989). Even though the paralytic effect of the toxin ranges from 1 to 2 months, the results are good and complications are rare. Though more complicated and time demanding, dissection of the anterior ciliary vessels prior to muscle tenotomy emerges as a relevant alternative for patients who are at risk. This technique was first described by McKeown (Mckeown et al, 1989) and adaptations to use magnifying glasses instead of the dissecting microscope have been suggested (Freedman et al, 1992). The importance of these anterior ciliary arteries preservation techniques is that no cases of ASI have been reported when implem-enting these procedures and postoperative evaluations with IFA have demonstrated normal filling patterns (Mckeown et al, 1989; Aguirre Vila-Coro, 1990; Wright and Lanier, 1991).

The anterior segment of the eye is provided with a rich blood supply deriving mainly from the anterior ciliary arteries system and receiving contribution, in order of importance, from the long posterior ciliary arteries and the conjunctival arteries. Because of anastomotic rings that occur in this region, ASI may be rare but when present, represents a serious complication that can lead to blindness. Though the patients that are at greater risk are those of advanced age and those who submit to procedures in which three or four rectus muscles have to be operated simultan-eously, individual susceptibility plays an important role in the occurrence of this condition. There are different strabismus surgery techniques that can be used to treat a specific type of strabismus. Therefore, careful evaluation with identification and stratification of risk factors in each patient should be done in order to perform the surgical procedure that represents the best option for the patient, a “made-to-measure-suit” surgery.

Conflict of Interests
The authors report no financial or other relevant conflict of interest to the subject of this article.

Funding
None declared

Informed consent
None declared

Ethical Approval
None declared

Contributions
Abraham Olvera Barrios: Contributed with the idea, planning of the work schedule, and wrote in each section of the article.
Rodrigo E. Elizondo Omaña: Reviewer, editor and coordinator of the work schedule.
Verónica E. Tamez Tamez: Reviewer on the clinical section of the article.
María de los A. Rodríguez García: Reviewer of the clinical section of the article.
Eliud E. Villarreal Silva: Contributed with the idea. Reviewer of the anatomic section of the article.
Santos Guzmán López: Reviewer of the anatomic section of the article

REFERENCES

Aguirre Vila-Coro, A. 1990. Vascular microdissection in strabismus surgery. Arch Ophthalmol. 108: 1034-36.
Aoki KR, Guyer B. 2001. Botulinum toxin type A and other botulinum toxin serotypes: a comparative review of biochemical and pharmacological actions. Eur J Neurol 8: 21-29.
Apple D, Craythorn J, Olson R, Little L, Lyman J, Reidy J, Loftfield K. 1984. Anterior segment complications and neovascular glaucoma following implantation of a posterior chamber intraocular lens. Ophthalmology 91: 403-19.
Bagheri A, Tavakoli M, Torbati P, Mirdehghan M, Yaseri M, Safarian O, Yazdani S, Silbert D. 2013. Natural course of anterior segment ischemia after disinsertion of extraocular rectus muscles in an animal model. J AAPOS 17: 395-401.
Berens C, Girard L. 1950. Transplantation of the superior and inferior rectus muscles for paralysis of the lateral rectus. Am J Ophthalmol 33: 1041.
Biglan AW, Burnstine RA, Rogers GL, Saunders RA. 1989. Management of strabismus with botulinum A toxin. Ophthalmology, 96: 935-43.
Brancato R, Bandello F, Lattanzio R. 1997. Iris fluorescein angiography in clinical practice. Surv Ophthalmol 42: 41-70.
Buckley EG, Townshend LM. 1991. A simple transposition procedure for complicated strabismus. Am J Ophthalmol 111: 302-06.
Chamberlain Jr WP. 1954. Ocular Motility in the Horizontal Plane: An Experimental Study of the Primary and Secondary Horizontal Rotators of the Rhesus Monkey. Trans Am Ophthalmol Soc 52: 751.
Chan TK, Rosenbaum AL, Rao R, Schwartz SD, Santiago P, Thayer D. 2001. Indocyanine green angiography of the anterior segment in patients undergoing strabismus surgery. Br J Ophthalmol 85: 214-18.
Coats DK, Olitski SE. 2007. Strabismus Surgery and its Complications. 1st ed. Berlin Heidelberg: Springer 1-311.
Cullis CM, Hines DR, Bullock JD. 1979. Anterior segment ischemia: classification and description in chronic myelogenous leukemia. Ann Ophthalmol 11: 1739-44.
Elsas FJ, Witherspoon CD. 1987. Anterior segment ischemia after strabismus surgery in a child. Am J Ophthalmol 103: 833-34.
Fells P. 1980. Anterior segment ischaemia. Lens changes after strabismus surgery. Trans Ophthalmol Soc UK, 100: 398-99.
Fishman PH, Repka MX, Green WR, D'Anna SA, Guyton D. 1990. A primate model of anterior segment ischemia after strabismus surgery. The role of the conjunctival circulation. Ophthalmology 97: 456-61.
Fitzsimons R, Lee J, Elston J. 1989. The role of botulinum toxin in the management of sixth nerve palsy. Eye 3: 391-400.
Fitzsimons R, Lee J, Elston J. 1988. Treatment of sixth nerve palsy in adults with combined botulinum toxin chemodenervation and surgery. Ophthalmology 95: 1535-42.
Forbes SB. 1959. Muscle transplantation for external rectus paralysis; report of case with unusual complications. Am J Ophthalmol, 48: 248-51.
France TD, Simon JW. 1986. Anterior segment ischemia syndrome following muscle surgery: the AAPO&S experience. J Pediatr Ophthalmol Strabismus 23: 87-91.
Freedman HL, Waltman DD, Patterson JH. 1992. Preservation of anterior ciliary vessels during strabismus surgery: a nonmicroscopic technique. J Pediatr Ophthalmol Strabismus 29: 38-43.
Girard LJ, Beltranena F. 1960. Early and late complications of extensive muscle surgery. Arch Ophthalmol 64: 576-84.
Graefe A, Saemisch T, Hess C, Elschnig A, Bernheimer S, Leber T. 1922. Handbuch der gesamten Augenheilkunde. 2nd ed. Leipzig, Wilhelm Engelmann, pp 1-239.

Harley RD. 1971. Complete tendon transplantation for ocular muscle paralysis. Ann Ophthalmol, 3: 459-63.

Harper RA. 2010. Basic Ophthalmology. 9th ed. United States of America: American Academy of Ophthalmology, 1-240.

Hayreh SS. 2006. Orbital vascular anatomy. Eye, 20: 1130-44.

Hayreh SS, Baines JA. 1973. Occlusion of the vortex veins. An experimental study. Br J Ophthalmol, 57: 217-38.

Hayreh SS, Scott WE. 1978. Fluorescein iris angiography. I. Normal pattern. Arch Ophthalmol 96: 1383-89.

Hayreh SS, Scott WE. 1978. Fluorescein iris angiography. II. Disturbances in iris circulation following strabismus operation on the various recti. Arch Ophthalmol 96: 1390-1400.

Heymann V, George JL, Sirbat D, Rauber G, Raspiller A. 1985. Arterial supply to the anterior segment of the eye. Radioanatomical study of a series of 25 human eyes. J Fr Ophtalmol 8: 697-703.

Hiatt RL. 1978. Production of anterior segment ischemia. J Pediatr Ophthalmol Strabismus 15: 197-204.

Hummelsheim E. 1908. Weitere Erfahrungen mit partieller Sehnenüberpflanzung an den Augenmuskeln. Arch Augenheilkd 62: 71-74.

Jacobs DS, Vastine DW, Urist MJ. 1976. Anterior segment ischemia and sector iris atrophy: after strabismus surgery in a patient with chronic lymphocytic leukemia. Ophthalmic Surg, 7: 42-48.

Jensen CD. 1964. Rectus muscle union: A new operation for paralysis of the rectus muscles. Trans Pac Coast Otoophthalmol Soc Annu Meet 45: 359-87.

Laatikainen L. 1971. Perilimbal vasculature in glaucomatous eyes. Acta Ophthalmol 111(suppl): 54.

McKeown CA, Lambert HM, Shore JW. 1989. Preservation of the anterior ciliary vessels during extraocular muscle surgery. Ophthalmology 96: 498-506.

Morrison JC, Van Buskirk EM. 1983. Anterior collateral circulation in the primate eye. Ophthalmology 90: 707-15.

Murdock TJ, Kushner BJ. 2001. Anterior segment ischemia after surgery on 2 vertical rectus muscles augmented with lateral fixation sutures. J AAPOS 5: 323-24.

Nauheim JS. 1962. Marginal keratitis and corneal ulceration after surgery on the extraocular muscles. Arch Ophthalmol 67: 708-11.

Olver JM, Lee JP. 1989. The effects of strabismus surgery on anterior segment circulation. Eye 3: 318-26.

Olver JM, Lee JP. 1992. Recovery of anterior segment circulation after strabismus surgery in adult patients. Ophthalmology 99: 305-15.

Orzalesi N, Saba V. 1966. Un caso di atrofia segmentaria dell'iride conseguente ad intervento di trapianto muscolare secondo O'Connor. Boll Ocul 45: 871-78.

Parks MM. 1968. Fornix incision for horizontal rectus muscle surgery. Am J Ophthalmol 65: 907-15.

Prakash P, Verma D, Menon V. 1986. Anterior segment ischemia following extraocular muscle surgery. Jpn J Ophthalmol 30: 251-56.

Robertson DM. 1975. Anterior segment ischemia after segmental episcleral buckling and cryopexy. Am J Ophthalmol 79: 871-74.

Saunders RA, Bluestein EC, Wilson ME, Berland JE. 1964. Anterior segment ischemia after strabismus surgery. Surv Ophthalmol 38: 456-66.

Saunders RA, Sandall GS. 1982. Anterior segment ischemia syndrome following rectus muscle transposition. Am J Ophthalmol 93: 34-38.

Schmidt H. 1874. Beitrag zur Kenntniss der Embolie der Arteria centralis retinae. Graefes Arch Clin Exp Ophthalmol 20: 287-307.

Sharp D, Bell R, Cruess A. 1982. Anterior segment necrosis following cyclocryotherapy. Can J Ophthalmol 17: 268.

Simon JW, Price EC, Krohel GB, Poulin RW, Reinecke RD. 1984. Anterior segment ischemia following strabismus surgery. J Pediatr Ophthalmol Strabismus 21: 179-85.

Skuta GL, Cantor LB, Weiss JS. 2011a. Orbit, Eyelids and Lacrimal System. 2010-2011 major revision. Singapore: American Academy of Ophthalmology, 1-318.

Skuta GL, Cantor LB, Weiss JS. 2011b. Fundamentals and Principles of Ophthalmology. 2010-2011 major revision. Singapore: American Academy of Ophthalmology, 1-449.

Uribe LE. 1968. Muscle transplantation in ocular paralysis. Am J Ophthalmol, 65: 600-07.

Virdi PS, Hayreh SS. 1987. Anterior segment ischemia after recession of various recti. An experimental study. Ophthalmology 94: 1258-71.

Von Noorden GK. 1968. The limbal approach to surgery of the rectus muscles. Arch Ophthalmol 80: 94-97.

Von Noorden GK. 1976. Anterior segment ischemia following the Jensen procedure. Arch Ophthalmol 94: 845-47.

Wagner RS, Nelson LB. 1985. Complications following strabismus surgery. Int Ophthalmol Clin 25: 171-78.

Wilson FM-II, Blomquist PH. 2009. Practical Ophthalmology: A Manual for Beginning Residents. 6th ed. United States of America: American Academy of Ophthalmology 1-319.

Wilson W, Irvine S. 1955. Pathologic changes following disruption of blood supply to iris and ciliary body. Am Ac Ophthalmol Otolaryngol 59: 501.

Woodlief NF. 1980. Initial observations on the ocular microcirculation in man. I. The anterior segment and extraocular muscles. Arch Ophthalmol 98: 1268-72.

Wright KW, Lanier AB. 1991. Effect of a modified rectus tuck on anterior segment circulation in monkeys. J Pediatr Ophthalmol Strabismus 28: 77-81.