Graefe's Arch Clin Exp Ophthalmol
(2003) 241:699–702

DOI 10.1007/s00417-003-0715-8

GUEST EDITORIAL

Tarek Shaarawy
Josef Flammer

Pro: Non-penetrating glaucoma surgery—a fair chance

Received: 14 April 2003
Published online: 20 August 2003

T. Shaarawy (✉) · J. Flammer
University Eye Hospital,
Mittlere Strasse 91, 4012 Basel,
Switzerland
e-mail: tshaarawy@glaucoma-eg.com

T. Shaarawy
Glaucoma Department,
Memorial Research Institute
of Ophthalmology,
Giza, Egypt

History

Few would recall the operation proposed by Krasnov in the late 1950s, sinusotomy [16, 17, 18, 19], which is in fact the first seed of non-penetrating surgery. Believing that the maximum resistance to outflow resides at the level of sclera in glaucoma patients, Krasnov proposed excising the bulk of sclera overlying Schlemm's canal (SC). The obvious difficulty of the surgical technique, together with the lack of modern microscopes at that time, hindered the popularization of his operation. Also, in what would later be a stigma of non-penetrating surgery, he abstractly reported his success rates without fully explaining his success criteria or offering solid arguments on how his technique functioned.

Many years later Zimmerman [31, 32], benefiting from an improved understanding of outflow mechanisms, proposed what he termed ab-externo trabeculectomy. The procedure differs from sinusotomy in that Zimmermann advocated the removal of the inner wall of SC and the juxtacanalicular trabecular meshwork (JCT), as well as the creation of a superficial scleral flap guarding the sinusotomy, in the same manner as in trabeculectomy.

Kozlov [14, 15] suggested extending the dissection anteriorly to excise a portion of corneal stroma together with the deep sclera, exposing Descemet's membrane, with the aim of at creating percolation through the membrane as well. Stegmann [29], on the other hand, augmented the operation by injecting viscoelastic material in the two cut ends of SC, thus dilating it, and termed the procedure viscocanalostomy.

Thus the saga of non-penetrating surgery was forged by visionaries suggesting ideas, but not offering evidence-based medicine to substantiate their concepts. It is a fact that we are currently overwhelmed by studies reporting on the results of one technique or another, often with conflicting results, in a virtual vacuum of studies examining mechanisms of function.

The common concept

The principal common concept of non-penetration is to create filtration through a naturally occurring membrane that acts as an outflow resistance site [23], allowing a progressive decrease in intraocular pressure (IOP) and avoiding postoperative ocular hypotony. This membrane, the trabeculo-Descemet's membrane (TDM), consists of the trabecular meshwork and the peripheral Descemet's membrane. To expose the membrane a deep sclerokeratectomy should be performed, thereby also providing a postoperative scleral space. This space may act as an aqueous reservoir and as a filtration site that may reduce the need for a large subconjunctival filtration bleb thus reducing the risk of late bleb-related complications.

Mechanisms of function

There are several points of interest when studying the mechanisms of function of non-penetrating surgeries. Namely, the removal of the inner wall of SC together with adjacent trabecular tissue, the aqueous humor flow through the TDM, the aqueous resorption after its passage through the TDM, and the SC dilatation by viscoelastic injection.

Flow through the TDM

Grant [8], more than 40 years ago, demonstrated that maximum outflow resistance resides within the inner wall of SC together with the JCT. Various studies have attempted to identify the nature of the “plug” in the trabecular meshwork, but to no avail.

The JCT contains a mixture of cells, extracellular matrix, and aqueous pathways that appear as empty spaces under electron microscopy. The JCT extracellular matrix is a combination of glycosaminoglycan and proteoglycan. With its morphological structure containing relatively small openings and tortuous pathways, many studies [7, 8] have hypothesized that the JCT is the principal site of outflow resistance.

Passing through the JCT, aqueous is confronted with an anatomic barrier, namely the endothelial lining of SC. In its normal physiologic state SC is large enough not to generate significant outflow resistance. As IOP increases, the trabecular meshwork expands into the SC lumen [10], causing a concomitant significant narrowing.

In non-penetrating glaucoma surgery (NPGS) the canal is unroofed. As numerous collagenous septa between the inner and outer walls exist, it has been demonstrated [27] that the act of unroofing results in damage to the inner wall as the septa pull on it. Such damage allows aqueous access to the canal.

Furthermore, in NPGS the inner wall of the canal is peeled (ab-externo trabeculectomy). Analysis of the peeled membrane provided conclusive evidence [9] that includes aside from the inner wall of SC, the JCT, and to a lesser extent the corneoscleral trabecular meshwork. In that respect the procedure attempts to remove the external portion of the trabecular meshwork responsible for the main aqueous outflow resistance in a glaucomatous eye.

The TDM offers resistance to aqueous humor outflow that allows for a slow decrease in IOP during surgery and will account for the reliable and reproducible IOP on the first postoperative day [23]. Thus the main advantage of the TDM is to reduce the immediate postoperative complications such as hypotony, flat anterior chamber, choroidal detachments and induced cataract [3].

In an experimental model [30], the gradual decrease in IOP was studied and the resistance of the TDM calculated. Experiments were performed on enucleated human eyes unsuitable for keratoplasty. The mean IOP decrease speed was 2.7±0.6 mm Hg/min. The ocular aqueous outflow resistance dropped from a mean of 5.34±0.19 ml/min/mmHg preoperatively to a mean of 0.41±0.16 ml/min/mmHg postoperatively. The same study [30] also reported that the outflow facility increased from 0.19±0.03 to 24.5±12.6 µl/min/mmHg after deep sclerectomy.

The TDM resistance thus appears low enough to ensure a low IOP and yet sufficient to maintain the anterior chamber depth and avoid the postoperative complications in relation to hypotony.

The same study histologically [30] examined the surgical site using ocular perfusion with ferritin, demonstrating that the main outflow through the TDM occurred at the level of the trabecular meshwork, rather than Descemet’s membrane. This is in line with studies [28] reporting on the very limited permeability of Descemet’s membrane, which by itself is not enough to relieve the elevated pressure in glaucoma. In fact, most proponents of NPGS advocate [25] the creation of the Descemet’s portion of the TDM only as a window that can be punctured by Nd:YAG goniopuncture in cases of elevated postoperative intraocular pressure.

Aqueous resorption

After aqueous humor passage through the TDM, multiple mechanisms of aqueous resorption have been proposed: a subconjunctival bleb, an intrascleral bleb (intrascleral lake), suprachoroidal filtration, and an episcleral vein outflow via SC.

As after trabeculectomy, almost all patients undergoing NPGS have a diffuse, conjunctival bleb on the first postoperative day [12]. As demonstrated by ultrasound biomicroscopy (UBM) studies, successful cases show a low-profile and diffuse subconjunctival bleb even years after surgery [13, 21]. However, this bleb tends to be shallower and more diffuse than the one seen after trabeculectomy.

Although this has not been studied, subconjunctival blebs probably occur more commonly with deep sclerectomy than with viscocanalostomy. The reason for this is that in viscocanalostomy [29] the superficial scleral flap is tightly sutured, so as to force percolating aqueous into the two surgically created ostia of SC, while in deep sclerectomy, the flap is only loosely sutured [26] and a diffuse shallow bleb is desired.

In NPGS, a certain volume of sclera is removed, ranging between 5 and 8 mm^3. Provided the superficial scleral flap does not collapse, this scleral volume may be considered as an intrascleral bleb. The value of intrascleral bleb was ascertained by Roters and co-workers [24], who showed that absence of intrascleral bleb in postoperative UBM examinations correlates with lack of IOP control in viscocanalostomy.

The importance of intrascleral bleb has prompted research into ways to keep it patent. The idea of using a collagen implant was proposed by Kozlov [14, 15]. The concept is simply to occupy this space during the period of maximal healing response. After the scarring process falters, the implant is slowly resorbed 6–9 months postoperatively [2], leaving behind an aqueous lake.

The intrascleral bleb was observed [13] in more than 90% of patients who received a collagen implant and the mean volume of the intrascleral bleb was 1.8 mm^3. In the intrascleral bleb the aqueous resorption mechanism may be different from that in the subconjunctival space. The aqueous might be resorbed by new aqueous drainage vessels, as demonstrated by Delarive and co-workers [4]. This study showed that in the scleral space created after deep sclerectomy, regardless of whether or not a collagen implant was used, new aqueous humor drainage vessels were growing and resorbing the aqueous flowing through the TDM.

By thinning the sclera by 90%, aqueous humor outflow into the suprachoroidal space may occur; in fact on UBM, it is possible to observe fluid between the ciliary body and the remaining sclera in 45% of the patients studied years after the deep sclerectomy [13]. However, this could also indicate chronic localized ciliary body detachment with subsequent reduction of the aqueous production [23]. Further studies on aqueous dynamics following non-penetrating filtering surgery are needed to better understand the exact mechanisms of aqueous drainage and their respective importance in terms of success and complications.

When performing the deep sclerectomy dissection, SC is opened and unroofed. On either side of the deep sclerectomy the two surgically created ostia of SC may drain the aqueous humor into the episcleral veins. This mechanism is probably more important after viscocanalostomy, during which the ostia and SC are dilated.

Injection of viscoelastic material into the two surgically created ostia causes multiple ruptures in both inner and outer endothelial walls of the canal, as has been demonstrated [27] in human and monkey eyes. These ruptures extend into the JCT and may also rupture some of the meshwork itself. In that respect, viscocanalostomy seems to function as a "delicate" trabeculotomy.

The future

Although we have taken some steps in our understanding of how NPGS functions, we are still hindered by limited interest in NPGS basic research, as well as lack of overall understanding of the pathological process of glaucoma.

On the clinical side, NPGS has been proved to be a safer technique than other available surgical modalities [1, 3, 6, 22, 26], including trabeculectomy and drainage devices. The question of efficacy, nevertheless, is far from resolved.

Controversial, often contradictory [3, 6] results have been published. As one browses between results, though, one should keep in mind that it is all about technique. Issues related to which technique is superior to which in the wide spectrum of NPGS are of paramount importance. The fact of an existing long learning curve can not be overstated. It is neither meaningful nor scientifically sound to compare one's last 20 cases of trabeculectomy to one's first 20 deep sclerectomies [5, 11, 20].

With its apparent mechanisms of function that seem to target specific pathological structures in glaucoma, NPGS deserves a fair chance.

References

1. Ambresin A, Shaarawy T, Mermoud A (2002) Deep sclerectomy with collagen implant in one eye compared with trabeculectomy in the other eye of the same patient. J Glaucoma 11:214–220
2. Chiou AG, Mermoud A, Underdahl JP, Schnyder CC (1998) An ultrasound biomicroscopic study of eyes after deep sclerectomy with collagen implant. Ophthalmology 105:746–750
3. Chiselita D (2001) Non-penetrating deep sclerectomy versus trabeculectomy in primary open-angle glaucoma surgery. Eye 15:197–201
4. Delarive T, Schnyder CC Shaarawy T. Mermoud A (2001) An animal model for the study of non-penetrating glaucoma surgery. University of Lausanne
5. Dietlein TS, Luke C, Jacobi PC, Konen W, Krieglstein GK (2000) Variability of dissection depth in deep sclerectomy: morphological analysis of the deep scleral flap. Graefes Arch Clin Exp Ophthalmol 238:405–409
6. El Sayyad F, Helal M, El-Kholify H, Khalil M, El-Maghraby A (2000) Non-penetrating deep sclerectomy versus trabeculectomy in bilateral primary open-angle glaucoma. Ophthalmology 107:1671–1674
7. Ethier CR, Kamm RD, Palaszewski BA, Johnson MC, Richardson TM (1986) Calculations of flow resistance in the juxtacanalicular meshwork. Invest Ophthalmol Vis Sci 27:1741–1750
8. Grant WM (1963) Experimental aqueous perfusion in enucleated human eyes. Arch Ophthalmol 69:783–801
9. Hamard P, Valtot F, Sourdille P, Bourles-Dagonet F, Baudouin C (2002) Confocal microscopic examination of trabecular meshwork removed during ab externo trabeculectomy. Br J Ophthalmol 86:1046–1052
10. Johnstone MA, Grant WM (1973) Pressure-dependant changes in the structures of the aqueous outflow system of the human and monkey eyes. Am J Ophthalmol 75:365–383
11. Jonescu-Cuypers C, Jacobi P, Konen W, Krieglstein G (2001) Primary viscocanalostomy versus trabeculectomy in white patients with open-angle glaucoma: a randomized clinical trial. Ophthalmology 108:254–258
12. Karlen ME, Sanchez E, Schnyder CC, Sickenberg M, Mermoud A (1999) Deep sclerectomy with collagen implant: medium term results. Br J Ophthalmol 83:6–11
13. Kazakova D, Roters S, Schnyder C, Achache F, Jonescu-Cuypers C, Mermoud A, Krieglstein G (2002) Ultrasonic biomicroscopy images: long-term results after deep sclerectomy with collagen implant. Graefes Arch Clin Exp Ophthalmol 240:918–923

14. Kozlov VI, Bagrov SN, Anisimova SY, Osipov AV, Mogilevtsev VV (1990) Deep sclerectomy with collagen. Eye Microsurgery 3:44–46
15. Kozlov VI, Bagrov SN, Anisimova SY, Osipov AV, Mogilevtsev VV (1990) Nonpenetrating deep sclerectomy with collagen (in Russian). Eye Microsurg 3:157–162
16. Krasnov MM (1968) [The technic of sinusotomy and its variants]. Vestn Oftalmol 81:3–9
17. Krasnov MM(1968) Externalization of Schlemm's canal (sinusotomy) in glaucoma. Br J Ophthalmol 52:157–161
18. Krasnov MM (1972) Symposium: microsurgery of the outflow channels. Sinusotomy. Foundations, results, prospects. Trans Am Acad Ophthalmol Otolaryngol 76:368–374
19. Krasnov MM (1988) [Current technic of sinusotomy (externalization of Schlemm's canal) without resection of the sclera]. Vestn Oftalmol 104:10–12
20. Luke C, Dietlein TS, Jacobi PC, Konen W, Krieglstein GK (2002) A prospective randomized trial of viscocanalostomy versus trabeculectomy in open-angle glaucoma: a 1-year follow-up study. J Glaucoma 11:294–299
21. Marchini G, Marraffa M, Brunelli C, Morbio R, Bonomi L (2001) Ultrasound biomicroscopy and intraocular-pressure-lowering mechanisms of deep sclerectomy with reticulated hyaluronic acid implant. J Cataract Refract Surg 27:507–517
22. Mermoud A (2000) Sinusotomy and deep sclerectomy. Eye 14:531–535
23. Mermoud A, Ravinet E (2001) In: Mermoud A, Shaarawy T (eds) Non-penetrating glaucoma surgery, 1st edn. Martin Dunitz, London, pp 57–66
24. Roters S, Luke C, Jonescu-Cuypers CP, Engels BF, Jacobi PC, Konen W, et al (2002) Ultrasound biomicroscopy and its value in predicting the long term outcome of viscocanalostomy. Br J Ophthalmol 86:997–1001
25. Shaarawy T (2001) In: Mermoud A, Shaarawy T (eds) Non-penetrating glaucoma surgery. Martin Dunitz, London, pp 125–136
26. Shaarawy T, Karlen M, Schnyder C, Achache F, Sanchez E, Mermoud A (2001) Five-year results of deep sclerectomy with collagen implant. J Cataract Refract Surg 27:1770–1778
27. Smit BA, Johnstone MA (2002) Effects of viscoelastic injection into Schlemm's canal in primate and human eyes: potential relevance to viscocanalostomy. Ophthalmology 109:786–792
28. Spiegel D, Schefthaler M, Kobuch K (2002) Outflow facilities through Descemet's membrane in rabbits. Graefes Arch Clin Exp Ophthalmol 240:111–113
29. Stegmann R, Pienaar A, Miller D (1999) Viscocanalostomy for open-angle glaucoma in black African patients. J Cataract Refract Surg 25:316–322
30. Vaudaux J (1999) Aqueous dynamics after deep sclerectomy: in vitro study. Ophthalmic Practice 16:204–209
31. Zimmerman TJ, Kooner KS, Ford VJ, Olander KW, Mandlekorn RM, Rawlings EF, et al (1984) Trabeculectomy vs. nonpenetrating trabeculectomy: a retrospective study of two procedures in phakic patients with glaucoma. Ophthalmic Surg 15:734–740
32. Zimmerman TJ, Kooner KS, Ford VJ, Olander KW, Mandlekorn RM, Rawlings FE, et al (1984) Effectiveness of nonpenetrating trabeculectomy in aphakic patients with glaucoma. Ophthalmic Surg 15:44–50