

Preclinical Investigation of Goniotomy Using Four Different Techniques

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Purpose: To evaluate the tissue-level effects of goniotomy techniques on human trabecular meshwork (TM).

Design: Laboratory investigation.

Methods: The TM from human cadaveric corneal rim tissue was treated using 4 techniques: (1) microvitreal (MVR) blade; (2) 360° trabeculotomy with 5-0 prolene suture; (3) the Kahook Dual Blade (KDB) Glide[®] device; (4) TrabEx[™] device; tissue samples underwent standard histologic processing with H&E stain followed by comparative analyses.

Results: The MVR blade exhibited incision of TM extending into the scleral wall. The TrabEx device removed a small portion of TM with large leaflet tissue remnants in all treated areas. 360° suture trabeculotomy resulted in incision of the TM proximate to Schwalbe's line with no excised tissue evident in all treated areas. Areas treated with the KDB Glide device resulted in nearly complete excision of TM without injury to surrounding tissues.

Conclusion: The various methods used for performing goniotomy or trabeculotomy resulted in varying degrees of incision or excision of TM. Only the KDB Glide device resulted in reliable excision of TM with the other devices producing incision or variable excision of tissue. Clinical correlation is required to better understand the implications of the current findings when using these methods to lower intraocular pressure in eyes with glaucoma.

Keywords: glaucoma, goniotomy, trabecular meshwork

Introduction

Goniotomy—the surgical technique of incising trabecular meshwork (TM) to create a continuous opening from the anterior chamber to the Canal of Schlemm—was first described in 1936¹ and was soon relegated to the surgical management of childhood glaucomas² until a popular resurgence over recent years in modified form for adult eyes with glaucoma.^{3–6} Numerous variations on the theme of goniotomy are currently used to lower intraocular pressure (IOP) in eyes with various forms of glaucoma; these include incisional goniotomy using a microvitreal (MVR) blade or the Trabectome[®] device (MicroSurgical Technology, Redmond, WA); excisional goniotomy using the Kahook Dual Blade[®] device (KDB, New World Medical, Rancho Cucamonga, CA) or the TrabEx[™]/TrabEx+[™] device (MicroSurgical Technology); and 360° trabeculotomy (gonioscopy-assisted transluminal trabeculotomy [GATT] using a suture or the iTrack[®] device [Ellex, Adelaide, Australia]) or the TRAB[®]360/OMNI[®] system (Sight Sciences, Menlo Park, CA).

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These various procedures have differential effects on the tissues of the anterior chamber angle. In a preclinical evaluation, the histologic effects of the KDB, MVR, and Trabectome—both on the TM and neighboring tissue structures—were previously described.⁷ The TrabEx device had not been commercialized at that time and was not included in the analysis. Also, since that report, a second-generation KDB instrument (KDB Glide, New World Medical) has been developed that incorporates features intended to enhance both its performance and its ease of use. The KDB Glide has incorporated beveled edges and rounded corners to the footplate, reducing its width for enhanced fit within Canal of Schlemm to facilitate smooth passage while excising TM (Figure 1). The second-generation instrument maintains the same ramp technology and distance between the parallel dual blades (230 microns) as the original KDB.

In this report, we compare the histologic appearance of the TM and neighboring angle structures after goniotomy using the KDB Glide, MVR blade, TrabEx, and 360° trabeculotomy using a 5-0 prolene suture (in a manner

emulating gonioscopy-assisted transluminal trabeculotomy [GATT]⁸), in human eye bank eyes.

Methods

Exemption for this preclinical study was in place from the Colorado Multiple Institutional Review Board (COMIRB) for the use of human material prior to initiation of this study and the tenets of the Declaration of Helsinki were followed. COMIRB instructions state that IRB exemption applies to non-human subject studies where all information is de-identified and devoid of non-public information disclosures. A total of 4 corneoscleral rims were used for this study. All tissue samples were obtained from eyes lacking any history of glaucoma or surgical procedures in the anterior chamber other than cataract surgery. After removal from storage medium, each sample was mounted on a platform oriented with the TM facing up and secured with tissue pins. Each of the four techniques assessed consisted of >180° TM treatment under microscopic visualization. MVR blade: TM was incised with an MVR blade, with effort made to maintain

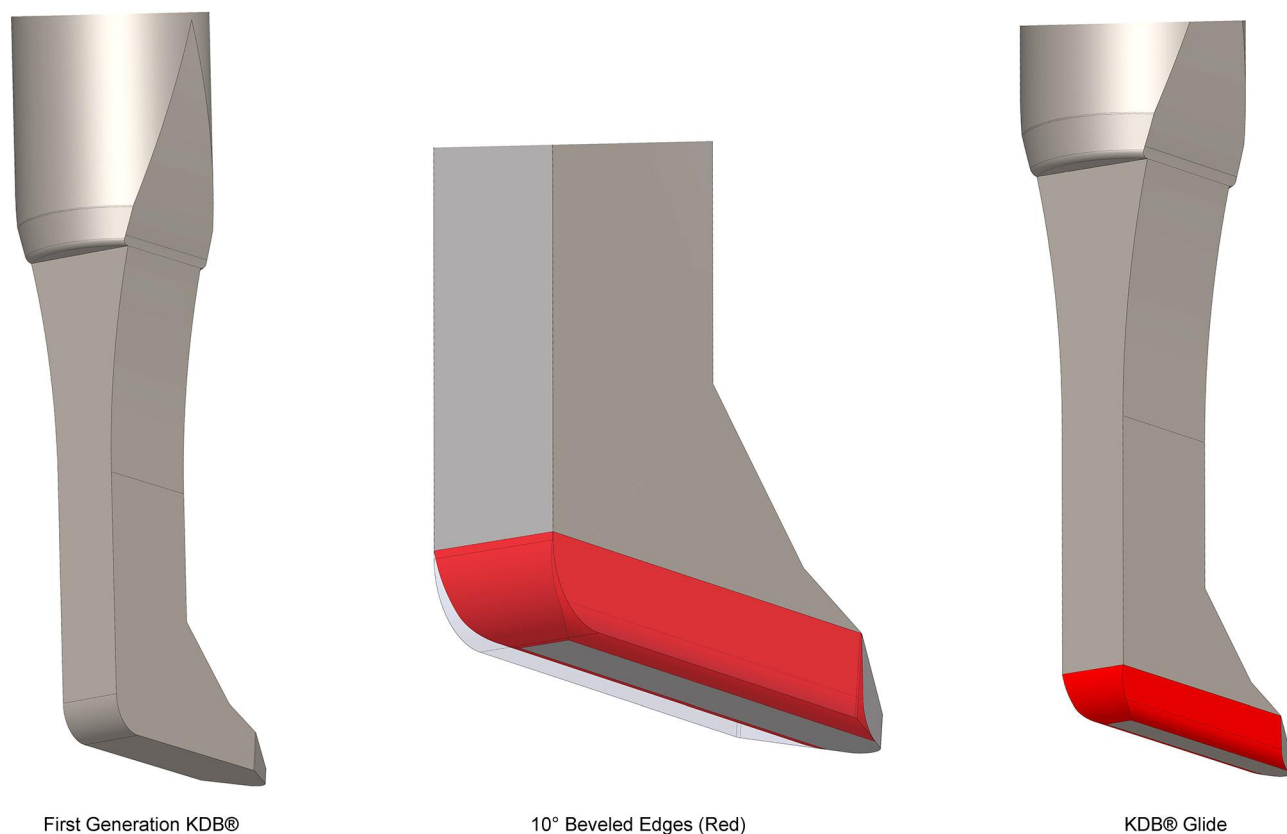


Figure 1 Schematic of the first-generation Kahook Dual Blade (KDB) on the left and the second-generation KDB Glide on the right illustrating new design features with a comparison overlay image (center), including beveled edges and rounded corners (red) at the bottom of the second-generation device to enhance passage through the Canal of Schlemm. The ramp and dual blade dimensions and design elements are conserved between the two devices.

incision depth into but not through the Canal of Schlemm. Suture trabeculotomy: A 360° ab interno trabeculotomy was performed by threading a 5-0 prolene suture into and fully around the Canal of Schlemm through a small goniotomy incision, and then applying tension to both ends to cheesewire through the complete TM circumference. This approach mimicked the GATT procedure,⁸ modified for direct visualization in this laboratory study. KDB Glide: As has been reported for the KDB,⁷ the Glide's blade tip (Figure 1) was used to incise TM and the blade's footplate positioned and then advanced along the Canal of Schlemm. At the end of the intended excision length, the device was redirected by inserting the tip just beyond the initial TM strip and moving the device in the direction of the original treatment to completely excise a whole strip of TM. TrabEx: In similar fashion to the KDB Glide, the instrument's tip (Figure 2) was used to incise TM and positioned in Canal of Schlemm. The device was then moved forward to treat an arc of TM. At the end of the intended treatment length, the device was redirected by inserting the tip just beyond the initial treated TM and moving the device in the direction of the original treatment to attempt removal of a TM strip.

Following these procedures, each corneoscleral rim was preserved in 4% paraformaldehyde/phosphate-buffered saline overnight at 4° C and then cut into quadrants with radial incisions. Rim sections were embedded in paraffin with the cut edge of the tissue facing the front of the block. Tissue sections, each 6 µm thick, were then cut from randomly selected locations across the treated areas. Sections of untreated TM were also sectioned for comparison to treated

areas. Each sample was stained using Mayer's hematoxylin-eosin Y (Richard-Allan Scientific, Kalamazoo, Michigan, USA). A Nikon Eclipse 80i microscope (Nikon, Melville, New York, USA) fitted with a Nikon D5-Fi1 color camera and a Nikon CFI 10x/Plan Fluor objective lens was used to obtain bright-field imaging. Images were then evaluated in masked fashion to qualitatively characterize the tissue effects of each technique.

Results

Systematic evaluation of tissue sections was undertaken. Findings were consistent across all sections within each eye for each procedure evaluated. The normal histology of the human anterior chamber angle is given in Figure 3, obtained from an unoperated portion of one of the four treatment samples. The iris is lost during recovery of the tissue from the donor leaving a remnant iris root; in contrast, the TM and Canal of Schlemm generally remain intact after recovery.

Figure 4 depicts the angle following MVR goniotomy. This technique created a complete incision of the full thickness of the TM (Figure 4A). TM tissue was not removed, and large tissue leaflets remained overlying Canal of Schlemm. The incision was noted to extend beyond the outer wall of the canal, producing scleral injury of variable depth along the incision (Figure 4A vs 4B).

Figure 5 depicts the angle following suture trabeculotomy. TM incision proximate to Schwalbe's line was evident; no evidence of tissue excision or neighboring tissue injury was present.

Figure 6 depicts the angle following TrabEx goniotomy. Variable portions of TM removal were evident, and

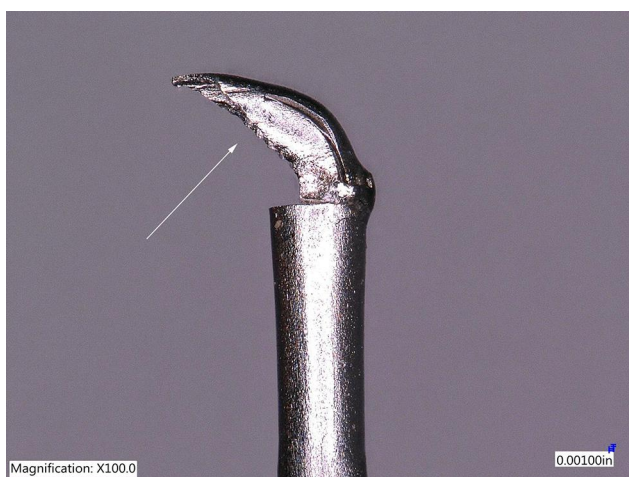


Figure 2 TrabEx blade, featuring two serrated blades (arrow) without a non-cutting ramp.

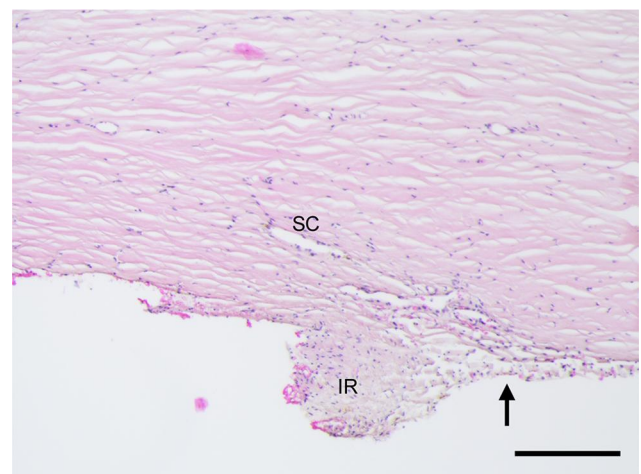


Figure 3 Histology of the intact human anterior chamber angle showing the remnant of the iris (IR), the Canal of Schlemm (SC), and the trabecular meshwork (arrow). H&E stained sections, scale bar = 200 µm.

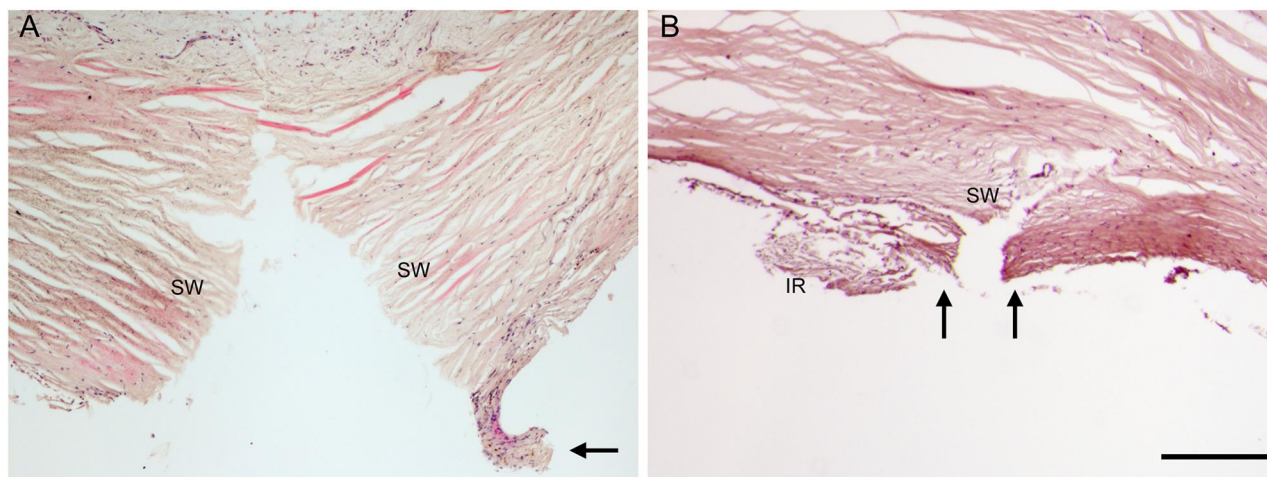


Figure 4 The anterior chamber angle following MVR goniotomy created an incision in the trabecular meshwork (TM) without removal of TM leaflets (arrows), through the Canal of Schlemm and passing to varying depths into the scleral wall (SW). In **(A)**, the incision extended deep into the scleral wall and a visible ~200 µm remnant of TM is apparent (arrow). In **(B)** the incision extends just past the outer wall of the Canal of Schlemm, also showing no excision of TM (arrows). H&E stained section, scale bar = 200 µm.

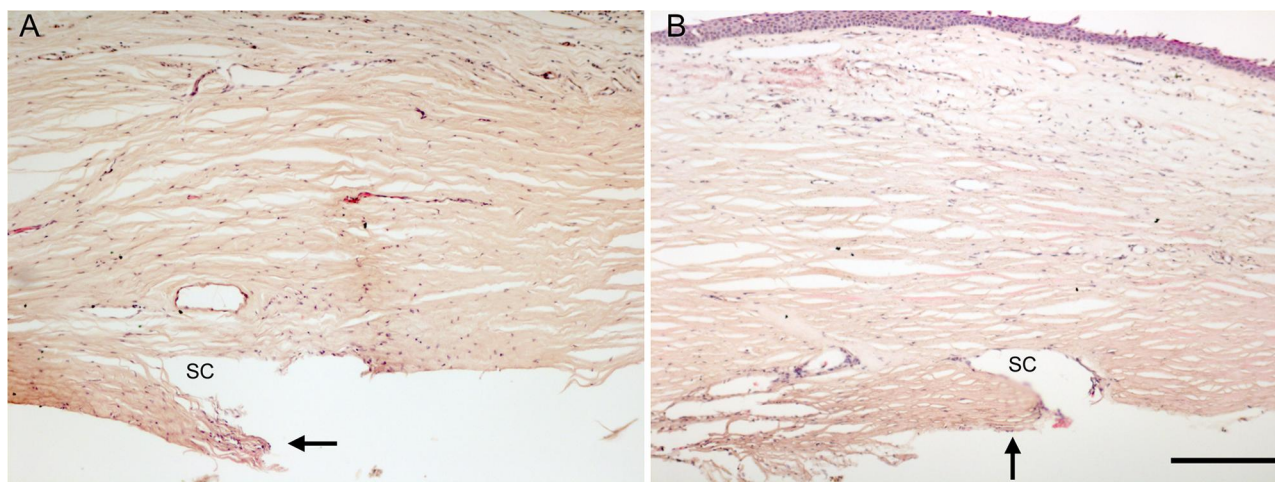


Figure 5 The anterior chamber angle following 360° Trabeculotomy resulted in incision through the trabecular meshwork (TM) proximate to Schwalbe's line with no evident excision of TM leaflets. The arrows in **(A and B)** indicate large TM flap leaflets in two distinct sections of treated tissue. There is no apparent damage to the outer wall of the Canal of Schlemm in the treated areas. H&E stained section, scale bar = 200 µm.

large leaflet tissue remnants ranging from 100 to 200 microns in total length were visible in all treated areas. No injury to neighboring tissue was present.

Figure 7 depicts the angle following goniotomy with the KDB Glide. Near complete excision of TM was noted in treatment areas, with intermittent areas of residual TM leaflet remnants of no more than 50 microns in width. No injury to neighboring tissue was present.

Discussion

The quest for a safe and effective alternative to trabeculectomy or tube-shunt implantation—specifically one that avoids the formation of a subconjunctival filtering bleb

and its short- and long-term risks^{9,10}—has renewed interest in procedures that bypass the diseased TM in eyes with open-angle glaucoma. The bypass of TM facilitates egress of aqueous humor from the anterior chamber into the Canal of Schlemm and the distal outflow system. Methods by which the TM is bypassed in these various procedures include incisional and excisional procedures that cut TM from the anterior chamber into the Canal of Schlemm (goniotomy), incisional procedures that cut TM from the Canal of Schlemm into the anterior chamber (trabeculotomy), and various implantable trans-TM devices that shunt fluid across the TM through small lumens.^{3–6}

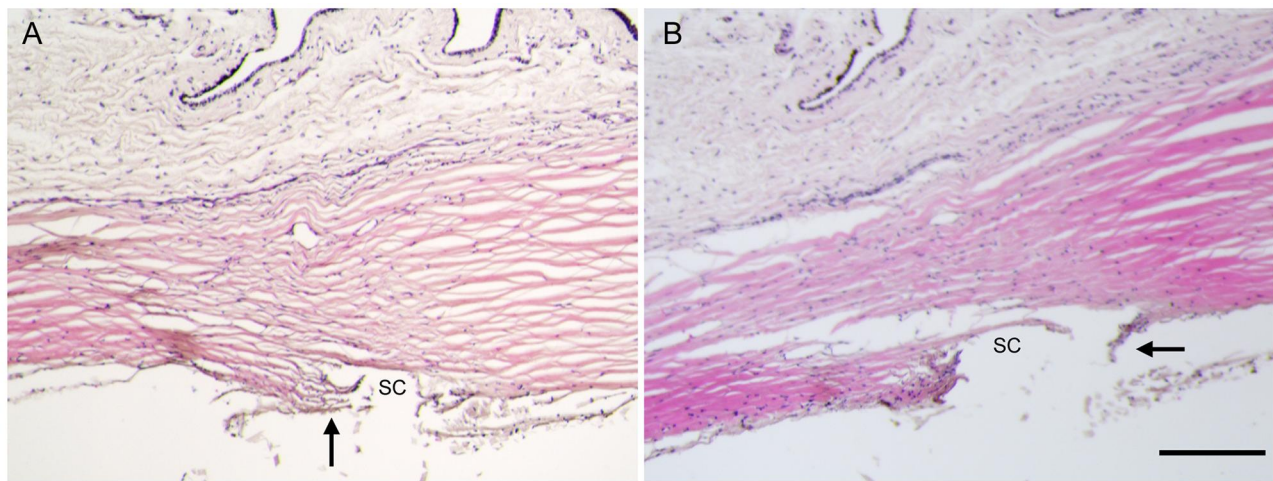


Figure 6 The anterior chamber angle following TrabEx goniotomy showed partial removal of trabecular meshwork with large leaflet tissue remnants (ranging from 100–200 μm in length, arrows) over the Canal of Schlemm (SC) in both (A and B). H&E stained sections, scale bar = 200 μm .

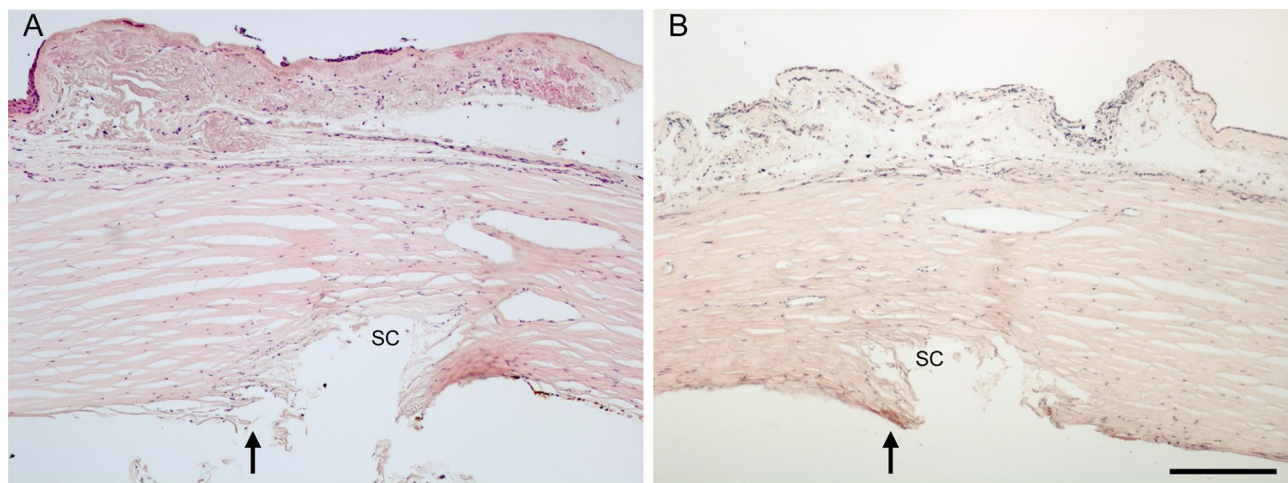


Figure 7 The anterior chamber angle following KDB Glide goniotomy showing near-complete excision of TM overlying the Canal of Schlemm (SC) in both (A and B) with minimal leaflet tissue remnants (ranging from 0 to 50 μm , arrows). H&E stained sections, scale bar = 200 μm .

Each of these surgical approaches produces an opening in the TM with unique characteristics, some of which have a significant impact on the aqueous flow capacity and thus potentially on IOP reduction. Incisional techniques disrupt but do not remove TM tissue, leaving remnants of tissue on either side of the incision that can reapproximate and close the ostomy.^{7,11} Excisional techniques remove or ablate a strip of TM, typically of 90°–180°. Ideally, the strip would be uniform in width and adequately wide to prevent reapproximation of remnant tissue leaflets; however, the strip can be variable in width over the course of the excision,⁷ producing ostomies of variable size. Devices such as the trabecular microbypass (iStent[®] and iStent Inject[®] stents, Glaukos, San Clemente, CA) produce

small stented apertures in TM (80–120 microns in diameter¹²) without tissue removal; histological analysis has revealed a basement membrane like layer of fibrous tissue overlying the internal ostomy of this device in some eyes post-implantation.¹³

In the current study, of the 4 techniques evaluated, only two—the KDB Glide and TrabEx—perform excisional goniotomy. The KDB Glide produced an excisional opening in TM of consistent width along its entire length and did so without obvious damage to neighboring structures. This finding is consistent with a prior study of the original KDB instrument in cadaver eyes.⁷ The TrabEx device produced an excisional opening of variable width, leaving large (up to 200 microns) tissue leaflet remnants which can

reapproximate to close the opening.^{7,11} While these devices have two blades, other key design features likely account for these histological differences. The KDB Glide features a non-cutting ramp that elevates, stretches, and guides TM to two parallel blades before any parallel incisions are created in the TM. The ramp's role in putting TM on stretch before excision maximizes the width of the excised TM strip and minimizes residual TM tissue leaflets that could reapproximate and close the excisional ostomy between the anterior chamber and the lumen of Canal of Schlemm. The footplate of the KDB devices is designed to allow for proper fit and stability during the procedure which also likely leads to a more uniform treatment of tissue. In contrast, the TrabEx features two parallel serrated blades that extend to the tip of the device. The lack of a non-cutting ramp, as is found in KDB, leads to TM tissue cutting being initiated upon insertion of the device tip into the canal without the tissue being elevated and stretched. The TrabEx device also does not have a distinct footplate that would allow for evenly positioning the device on the anterior wall of the canal of Schlemm while advancing forward for treatment. These differences appear to lead to inconsistent excision of TM tissue along its path. The KDB Glide also improves on the original KDB by incorporating smoothed and rounded contours and a narrower footplate (203 microns compared to the TrabEx base width of 330 microns) to facilitate intra-canal passage (Figure 1). The diameter of Canal of Schlemm has been estimated to be approximately 240 microns or less;¹⁴ instruments less wide than this dimension should thus engage and move within the canal more easily than oversized instruments.

In summary, the various methods used for performing goniotomy or trabeculotomy resulted in varying degrees of incision or excision of TM. Only the KDB Glide device resulted in reliable excision of TM, with the other devices producing incision or variable excision of tissue. Clinical correlation is required to better understand the implications of the current findings when using these methods to lower IOP in eyes with glaucoma.

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Disclosure

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