Surf's Up
Catch a Wave with the Waterjet
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Is the dawn of a new era in keratorefractive surgery upon us? The excimer laser revolutionized refractive surgery; will waterjet technology again revolutionize the field? The use of high speed jets of water to reshape and separate materials is not a new concept. Waterjets were first used thousands of years ago by the Babylonians for cleaning, then hundreds of years ago for mining and stone cutting, and recently for food processing. But like any innovation, the needs and demands fuel the creativity of discovery, and the waterjet has found its way as a promising new tool in ophthalmology.

Modern refractive corneal surgery has seen developments in incisional surgery (refractive keratotomy), in mechanical lamellar surgery (keratomileusis in situ or ALK) and in excimer laser surgery, as both surface application (PRK) and in situ application (LASIK). The waterjet technology of the HydroBlade keratome described on pages 338-356 of this issue of the Journal of Refractive Surgery offers a new technique of intrastromal surgery by using waterjets to separate and reshape the cornea.

How the waterjet differs from the scalpel or laser is a feature that makes it unique in separating tissue without friction, shearing, drag, or tissue loss. Using principles of tissue sectioning, cutting with the scalpel and ablating with the laser can be replaced by cleaving with the waterjet. This "new wave" of cutting ability brings a "high tide" to conventional ways of separating corneal tissue such that the refractive surgeon can now "catch a wave" to a new frontier in refractive surgery.

What Can Be Learned About Tissue Separation?
"Sectility" is a term we should be familiar with in refractive corneal surgery because it takes advantage of the basic anatomical structure of the cornea, that of multiple stromal lamellae. The principles of sectility are described by Eisner (Eisner G. An Introduction to Operative Technique, in Eye Surgery, Eisner G, Editor, Springer-Verlag, Berlin, Germany, 1990, pg 64). Three main mechanisms of tissue separation are cutting, cleaving (splitting), and erosion (Figure). In cutting, tissue fibers are divided by a direct, concentrated application of pressure with a sharp cutting edge. This is in contrast to cleaving (splitting) whereby a blunt wedge stretches tissue to the point of rupture along a path of low resistance (high sectility). Finally, erosion results in separation with a loss of tissue by excavating a channel through it. All three mechanisms depend on the relative sectility of the tissue being separated, and when attempting to achieve a surgical result, consideration of tissue sectility is important in selecting the right mechanism and approach.

How Does the Waterjet Separate Tissue?
The three forms of tissue separation outlined by Eisner are demonstrated well when applying the waterjet to the cornea under various threshold conditions of sectility (Table), as outlined by Gordon and coauthors (pages 338-345). They describe the HydroBlade keratome as capable of cutting a lenticule of stroma and cleaving a lamellar flap. The former requires a high threshold of water pressure due to the low sectility of cutting between lamellar layers, whereas the latter utilizes the principles of sectility by applying lower water pressures above the thresholds for lamellar separation, but below that of intralamellar cutting while under suction/tension. In addition, epithelial erosion is possible with the HydroBrush keratome which utilizes even lower water pressure with a larger jet that strikes a glass template to fan out into a water sheet beneath the glass. The template can be placed over the corneal epithelium under compression to cleanly erode the epithelium, while preserving the underlying structures of lower sectility.

Why Use a Waterjet?
The HydroBlade keratome as a new instrument offers some potential advantages over existing devices for creating a corneal lamellar flap. The HydroBlade keratome can cleave a lamellar flap without high pressure suction of the eye and without intralamellar cutting or fibrillar tearing which occurs with conventional microkeratomes. This allows for a smooth blunt dissection of the interlamellar layers for a less traumatic procedure. Even lenticular shaping is achievable with the HydroBlade, to replace not only the microkeratome, but also the laser in LASIK. The use of high pressure water is simple to implement and less expensive than that of a high powered gas laser. The small size and minimal operational cost makes the HydroBlade keratome portable and usable in the surgeon's office.

For epithelial removal during PRK, waterjets offer potential advantages that may make them
superior to that of blade scraping or other modalities. Barbara Parolini et al describe (pp 346-356) the HydroBrush keratome. It produced faster healing of the epithelium following surface removal, and resulted in preservation of not only Bowman’s layer, but also of the basal epithelial cell membrane and basement membrane with hemidesmosomes. Because these remaining structural layers are very thin, on the order of 0.5 μm each, they are negligible with regard to the multitude of PRK pulses, and yet they provide a smooth surface free of anterior tissue loss or debris. Whether this smooth surface is of sufficient quality to justify the use of a waterjet for epithelial removal is subject to clinical outcome. Besides epithelial removal for PRK, the HydroBrush can also be used for other modalities including pterygium excision. Studies using the HydroBrush to remove pterygia are currently under investigation in Mexico.

**When Will It Be Commercially Available?**

Prior to its commercial availability, both experimental and clinical studies are needed to verify safety and efficacy. The HydroBlade is being experimentally tested internally and clinical studies are anticipated at several universities later this year. Lamellar applications in the United States are expected to be done with a simple 510 K application, rather than a PMA, as occurs with many new lasers. This may ultimately speed the process of commercial availability in the United States to within the next 2 years.

Clinical studies to support the potential advantages of the HydroBrush keratome have been performed in St. Louis, New York, and New Jersey. At these locations, the HydroBrush was used to remove epithelium in patients prior to corneal transplantation as a minimal risk study. This has helped to further develop the instrumentation necessary to perform the procedure, and the device itself has been cleared by the FDA for clinical use. Further clinical trials on PRK eyes are planned for later this year.

In conclusion, although both the HydroBlade and HydroBrush keratomes are relatively new devices in refractive surgery, their unique features make them attractive as potential alternatives for stromal surgery, flap-making, and epithelial debridement. Further experimental and clinical investigations followed by peer-reviewed publication will be necessary to validate this technology, and bring it to widespread acceptance and clinical practice in the next millennium.

*(Dr. Krueger has no financial interest in the materials presented in the waterjet articles.)*