Comparison of Microkeratomes and Femtosecond Lasers

Part 1: Physical characteristics, advantages, and disadvantages vary among the available technologies.

BY JÖRG H. KRUMEICH, MD

Use of a femtosecond laser instead of a mechanical microkeratome for corneal flap creation in refractive surgery seems to be gaining increasing acceptance. A recent comprehensive report on the global refractive surgery market forecasts that today’s mechanical microkeratome market, which is valued in the range of $44.6 million, will not increase or decrease within the next 5 years (Market Scope data). The market for femtosecond lasers, however, is $227 million per year and is forecast to increase to $300 million by 2015. This means that approximately 1,000 femtosecond lasers are sold each year, despite the tenfold greater investment required for these lasers over mechanical microkeratomes. Regardless of this apparent preference for femtosecond lasers, 65% of LASIK procedures are still performed with blade microkeratomes (Market Scope data).

This two-part article discusses the physical and clinical performance of both types of corneal flap-creation systems, highlighting the pros and cons of each, and further makes distinctions between the performance of linear and rotary microkeratomes. This first part explores the physical differences in each type of system. The second part will examine the complications and theoretical advantages of each.

HISTORY OF MICROKERATOMES

José I. Barraquer, MD, found that the cornea could be applanated, which would allow it to be treated with a device that functioned like a carpenter’s plane. Based on this principle, Barraquer developed the first manual microkeratome. Using this device, he found that a lenticule of the patient’s cornea could be excised and then frozen, reshaped, and reapplied to achieve a refractive correction.

Tissue removal in the center would flatten the cornea, reducing its refractive power and thereby correcting myopia. To steepen the cornea, tissue in the periphery was removed, correcting hyperopia. All tissue was removed from the lenticule, not from the posterior stroma. The lenticules were cut at a depth of 300 µm for myopia, allowing corrections up to 12.00 D with an optical zone of 5.5 mm. For hyperopic corrections, a 400-µm lenticule was thinned out at the periphery, correcting up to 10.00 D.

Tissue removal from the lenticule was performed with a cryolathe, on the head of which the lenticule was frozen. The amount of tissue removal required was calculated during a 40-step timed operation that included tissue freezing and defrosting and measuring the thickness of the lenticule in its unfrozen and frozen states. After the lenticule was modified, it was reapplied and sutured in place, generally with a double-running antitorque suture. Dr. Barraquer named the procedure keratomileusis.

The creation of a well-centered lenticule required a firm base, which was provided by a suction ring affixed to the perilimbal circumference. To obtain a cut parallel to the corneal surface, the microkeratome could not be permitted to move vertically; therefore, it was housed in dovetail guides inside the ring. The original microkeratome was constructed so that the whole cornea was flattened by the device’s front plate. The force to achieve applanation was applied to the cornea first with the front plate of the microkeratome before the blade in the rear performed the cut. After the applanation, there was no change in applanation forces and consequently no change in the upward forces on the suction ring. Therefore, no upward movement of the suction ring/microkeratome unit occurred during the cut. The thickness of the lenticule was determined by the difference from the front plate to the tip of the blade.

In subsequent development, an excimer laser replaced the cryolathe for modification of the corneal tissue. This was initially performed on the flap, identically to keratomileusis.¹

TAKE-HOME MESSAGE

• Linear microkeratomes flatten the entire cornea before cutting, and rotary microkeratomes applanate only the fraction of the cornea to be cut next.
• Microkeratomes enter the tissue at a flat angle of 20° to 30°.
• The IntraLase and Femto LDV use scanning raster patterns; the Femtec 520F uses a centripetal circulation and the VisuMax uses a centrifugal disc-like beam pattern configuration.

Soon thereafter, Ioannis G. Pallikaris, MD, developed LASIK, which is now the most commonly performed refractive surgical procedure. In this approach, the lenticule or flap was cut to a thickness between 140 and 180 µm, and tissue removal was performed on the posterior stromal layers while the flap remained unchanged.

Although the introduction of the excimer laser undoubtedly made the procedure more practicable and precise, the principal of the microkeratome cut also underwent modifications. Barraquer’s original microkeratome flattened the whole cornea before the cut was performed to generate the lenticule. The linear microkeratome was geared by hand until Luis Antonio Ruiz, MD, introduced the motorized microkeratome. This device still maintained complete flattening of the cornea before the cut. Rotary microkeratomes were subsequently developed, introducing the advantage of easier access, particularly in deeply situated eyes.

Because a lengthy list of complications has been attributed to blade cutting, the advent of the femtosecond laser was welcomed to help surgeons operate more safely and more confidently. With the introduction of the laser, complications of microkeratomes were not differentiated among linear and rotary devices, but instead these problems have been attributed to the whole microkeratome family. The second part of this article will attempt to draw some distinctions between the complications associated with these two types of microkeratome.

**MECHANICAL PROPERTIES**

**Linear microkeratomes.** Linear microkeratomes flatten the cornea before cutting it (Figure 1). The pressure against the corneal dome has its counterpressure at the suction ring. This pressure does not change during the entire cut (Figures 2 and 3).

The force needed to flatten the dome differs greatly from cornea to cornea and depends on the diameter of the applanated cornea, which is a mathematic parameter of the arc length. The steeper the corneal radius, the greater the resistance of the tissue; the greater its thickness, the greater the applanation force needed. To cut a buttonhole with a linear microkeratome, the suction ring must be lifted by 150 µm, given an intended flap thickness of the same amount. This rarely happens, as the situation before cutting is very stable.

The thickness of the femtosecond lenticule is independent of the corneal thickness and has a smaller standard deviation with a linear microkeratome than with a rotary microkeratome. With a microkeratome of my own design, the Summit Krumeich-Barraquer Microkeratome (SKBM; Alcon Laboratories, Inc.), using one nonexchangeable diamond blade, we found deviations from the intended values of a mean of 10 µm in 100 consecutive cases, with a maximum deviation of 17 µm. Numerous comparisons of flap thickness differences between microkeratomes and femtosecond lasers have been published; these neither differentiate linear microkeratomes from rotary microkeratomes nor describe the outgoing radii of the corneas operated on nor the force needed to applanate.

**Rotary microkeratomes.** Rotary microkeratomes have been widely adopted because they are more practical than linear microkeratomes, as they require less space. However, they cut in a different manner from linear microkeratomes, and the cuts are generally less predictable in thickness and evenness. Also, lenticules cut by rotary microkeratomes typically display a meniscus configuration, thick at the periphery and thin in the center.

Instead of exerting the full power to flatten the corneal dome before cutting, as linear microkeratomes do, increasing power is needed to applanate during the cut. Rotary microkeratomes applanate only the fraction of the cornea to be cut next and perform the cut while only the adjacent part of the cornea is applanated (Figure 4). The force needed...
to applanate is minimal at the beginning of the cut and increases to a maximum when it reaches the center of the corneal dome (Figure 5). From there, the force needed to applanate continues to increase until the end of the cut. Upward forces on the suction ring increase correspondingly over the whole cut (Figure 6).

The suction ring is increasingly pulled upward until the maximum applanation of the dome is reached. Because the parameters of rigidity and thickness of the cornea are mostly unknown to the surgeon, he or she cannot know whether the increasing upward forces will pull the suction ring up to an amount greater than the intended flap thickness. If, for instance, the ring is pulled upward more than 150 µm with the rotary microkeratome in its grooves, a buttonhole will result.

In general, the upward movement of the suction ring is not great enough to cause a central opening, but the typical configuration of lenticules cut by rotary microkeratomes can regularly be observed. Cutting sub-Bowman lenticules of 100 µm or less with this type of microkeratome consequently entails an unavoidable risk.

Microkeratomes, whether linear or rotary, enter the tissue at a flat angle of 20° to 30°. The cut is performed with the microkeratome moving, meaning the blade causes tissue compression in the cutting direction before the cut is effected. The amount of tissue compression depends on the thickness of the cut, the sharpness of the blade, the velocity of translation of the microkeratome, and blade oscillation.

In search for the smoothest cutting surface with the SKBM, we found an optimal appearance of the surface with a translation speed of 1 to 2 mm/sec and oscillation of 6,000 rpm with diamond blades (Figure 7). With steel blades at the same translation speed, the oscillation must be set between 8,000 and 9,000 rpm to obtain the best result. Because it seems that results can be optimized with different blades by using different speeds of oscillation and translation, one must conclude that a two-motor design is necessary.

**Femtosecond lasers.** In addition to the differences between linear and rotary microkeratomes, there are also mechanical and histologic differences between the two available cutting means, mechanical and laser-based, and different methods of applanation among the femtosecond laser platforms currently on the market.
For the IntraLase (Abbott Medical Optics Inc.) and Femto LDV (Ziemer Ophthalmic Systems AG) femtosecond platforms, the mechanical principles are similar to those of linear microkeratomers, including suction ring and applanation. Both these systems applanate the full diameter of the flap and keep the cornea steady during tissue separation. The Femtosecond 520F (Technolas Perfect Vision GmbH) and VisuMax (Carl Zeiss Meditec) devices use a 3-D approach, with a medium-sized curved reference contact glass placed on the cornea.

Femtosecond lasers cut differently from microkeratomers, as they do not require a moving cutting device. The tissue compression resulting from the microkeratome movement is excluded; therefore, the cut quality is independent of tissue properties including resistance, thickness, and elasticity. Femtosecond lasers operate at the near-infrared wavelength of 1,053 nm. Physical energy properties of femtosecond lasers include derivation from mode-locked, diode-pumping lasers include derivation from mode-locked, diode-pumping and neodymium-glass lasers.

Femtosecond laser pulse duration is 10⁻¹⁵ seconds. There is a relationship between pulse duration and cell damage, which makes the femtosecond laser useful for corneal surgery. The femtosecond laser physically operates similarly to a Nd:YAG laser (10⁻⁹ seconds), but the latter photodisrupts at its focal point, spreading a cloud of free electrons and ionized molecules called plasma. Shock waves of gas bubbles from femtosecond lasers, consisting of carbon dioxide and water, affect only 1/1000th of the tissue volume that would be affected by same explosion from a Nd:YAG laser. The femtosecond laser wavelength is not absorbed by clear tissue; therefore, one is able to focus it at any depth in the cornea. Conversely, the energy per shot used is lower, 1/100th to 1/1000th that of the other lasers. Little is known about whether the way these lasers apply their pulse patterns has clinical consequences. The IntraLase and the Femto LDV use scanning raster patterns, whereas the Femtosecond 520F uses a centripetal disc-like beam pattern configuration.

The second part of this article will examine some theoretical advantages and disadvantages and the complications associated with these different modes of flap cutting.