## Peer-Reviewed Literature:
## The Femtosecond Laser

The use of a laser in place of a mechanical keratome for flap creation was a turning point in the field of refractive surgery. Visible and near infrared laser light are absorbed by the refractive structures of the eye and allowed to pass freely into the eye without effect at low-power densities. At high-power densities, the nonlinear optical properties of the cornea lead to absorption, generating plasma. The infrared neodymium-glass femtosecond laser emits a wavelength similar to that of an Nd:YAG laser, which is used widely in ophthalmic surgery. Each femtosecond laser pulse is approximately 10,000 times shorter in duration compared with a Q-switched Nd:YAG laser and lasts only about 10 to 13 seconds. Unlike photothermal lasers, the peak intensities of the femtosecond laser create plasma inside transparent tissues such as the cornea, without interfering with surface tissue. Femtosecond laser pulses require significantly less energy to produce photodisruption compared with longer pulse-width lasers, such as picosecond and nanosecond. This lower energy threshold translates into smaller cavitation bubbles and allows the nearly contiguous placement of laser pulses. The femtosecond laser has been used for making flaps, creating intrastromal tunnels for intrastromal corneal ring segments, keratomileusis with lenticule removal, and intrastromal PRK in which corneal tissue is withdrawn without disturbing the epithelium.

The following articles regarding the use of the femtosecond laser were reviewed:


1. Heisterkamp A, Mamom T, Kermani O, et al. Intrastromal refractive surgery with ultrashort laser pulses: in vivo study on the rabbit eye. Graefes Arch Clin Exp Ophthalmol. 2003;241:511-517.
2. Ratkay-Traub I, Ferinez IE, Juhasz T, et al. First clinical results with the femtosecond neodymium-glass laser in refractive surgery. J Refract Surg. 2003;19:94-103.
3. Lubatschowski H, Maatz G, Heisterkamp A, et al. Application of ultrashort laser pulses for intrastromal refractive surgery. Graefes Arch Clin Exp Ophthalmol. 2000;238:33-39.
4. Nordan LT, Slade SG, Baker RN, et al. Femtosecond laser flap creation for laser in situ keratomileusis: six month follow-up of initial U.S. clinical series. J Refract Surg. 2003;19:8-14.
5. Durrie DS, Kezirian GM. Femtosecond laser versus mechanical keratome flaps in wavefront-guided laser in situ keratomileusis. J Cataract Refract Surg. 2005;31:120-126.
6. Kezirian GM, Stonecipher KG. Comparison of the IntraLase femtosecond laser and mechanical keratomes for laser in situ keratomileusisis. J Cataract Refract Surg. 2004;30:804-811.
7. Tran DB, Sarayba MA, Bor Z, et al. Randomized prospective clinical study comparing induced aberrations with IntraLase and Hansatome flap creation in fellow eyes: potential impact on wavefront-guided laser in situ keratomileusis. J Cataract Refract Surg. 2005;31:97-105.


### PROPERTIES AND USES OF THE FEMTOSECOND LASER

Heisterkamp et al1 studied 10 rabbit eyes that underwent the creation of a lamellar corneal flap and preparation of an intrastromal refractive lenticule with the help of a femtosecond laser. The flap was lifted, the lenticule was extracted, and the flap was repositioned (also known as intrastromal laser keratomileusis). The corneal samples were collected up to 120 days after treatment and processed for histopathological analysis. The surgeon was able to open the flaps and extract the prepared lenticules in one piece. The treated corneas developed a mild wound-healing reaction, comparable to that occurring after LASIK performed with a microkeratome. The wound healing was restricted to the flap-stroma interface and was most pronounced at the flaps' periphery.

Ratkay-Traub et al2 used a femtosecond laser in partially sighted human eyes. They performed femtosecond laser-assisted LASIK on 46 eyes with myopia of up to -14.00D. Sixteen patients received intracorneal ring segments (ICRS). Five patients, each with one highly myopic eye, underwent femtosecond laser-assisted keratomileusis. Thirteen patients, each with one myopic or hyperopic eye, had intrastromal ablation PRK. With femtosecond laser keratomileusis, a lens-shaped block of stroma is removed manually from beneath the flap. The investigators found no differences between results obtained with LASIK performed with a femtosecond laser and a standard microkeratome. Those patients who received ICRS also received femtosecond laser-prepared channels and conventionally placed ICRS and produced the same refractive results. With ICRS placed using the femtosecond laser, no intraoperative complications occurred, and visual acuity improved immediately after surgery.

By generating microplasmas inside the corneal stroma with femtosecond pulses, it is possible to achieve a cutting effect inside the tissue while leaving the anterior layers of the eye intact. The energy threshold to generate microplasma with femtosecond pulses is some orders of magnitude lower than it is for pico- or nanosecond pulses. Use of the lower energy results in a significant reduction of the thermal and mechanical damage of the surrounding tissue. Investigators studied the cutting effect on corneal tissue from freshly enucleated porcine globes with different pulse energies of a titanium:sapphire femtosecond laser system.3 The laser-induced pressure transients and bubble formations were analyzed using a broadband acoustic transducer and flash photography. With femtosecond laser pulses, the extent of thermal and mechanical damage of the adjacent tissue was 1µm or less, comparable with tissue alterations after ArF excimer laser ablation. Thus, using pulsed energies of approximately 1 to 2µJ and a spot diameter of 5 to 10µm, one can precisely create intrastromal cuts to prepare corneal flaps and lenticules.

## CLINICAL SERIES WITH FEMTOSECOND FLAPS

Nordan et al4 performed a prospective, consecutive series in which 208 eyes (122 patients) underwent LASIK with the femtosecond laser for creation of the corneal flap. Patients were evaluated during a 6-month follow-up period to monitor complications. Analysis was carried out on a subset of 114 myopic patients. Four of 208 eyes (1.9%) lost suction during the procedure, a problem that interrupted the flap’s resection. However, re-applanation allowed the procedure to be completed successfully. No postoperative complications or adverse events were reported in these patients. In a subgroup of 96 eyes undergoing plano correction with a preoperative spherical equivalent refraction ranging from -0.63 to -12.40D, 98% achieved a UCVA of 20/40 or greater visual acuity, 79% achieved 20/25 or greater, and 55% achieved 20/20 or greater. None of the patients required a retreatment. The investigators concluded that the laser flap technique may offer both safety and performance advantages compared with current mechanical methods. The smaller hinge angle allows further reflection of the flap, producing a larger, circular bed surface area for centered ablation. In addition, the femtosecond laser produces more vertical side cuts (70º) compared with that of the microkeratome (typically 30º). The smaller hinge and vertical side cuts yield a 8.0-mm laser keratome flap comparable with a 9.5-mm microkeratome flap.

## FEMTOSECOND LASER VERSUS MECHANICAL KERATOME FLAPS

Durrie et al5 studied 51 consecutive patients who had bilateral wavefront-guided LASIK for myopia with the Ladarvision System (Alcon Laboratories, Inc., Fort Worth, TX). One eye of each patient was randomized to have a flap created with the Intralase FS laser (Intralase Corp., Irvine, CA) and the other flap using a standard compression-head Hansatome microkeratome (Bausch & Lomb, Rochester, NY). All other treatment parameters were the same. All eyes were treated based upon their aberrometry measurements without the surgeon’s adjustments. Overall, the results in both groups were excellent, with 88% of the Hansatome eyes and 98% of the Intralase eyes achieving a UCVA of 20/20 or better at 3 months. The Intralase group had significantly better mean UCVAs at all intervals from 1 day to 3 months postoperatively. The mean spheroequivalent at 3 months was more myopic with the Hansatome (-0.34D ±0.28) than with the Intralase group (0.19 ±0.24D) (P<.01). The mean residual astigmatism at 3 months was also significantly higher in the Hansatome group than in the Intralase group (0.32 ±0.25D and

0.17 ±0.20D, respectively) (P<.01). Aberrometry showed significantly higher astigmatism and trefoil in the Hansatome group. The recovery of corneal sensation and epithelial integrity was similar between the groups. The statistically better UCVA and manifest refractive outcomes after LASIK with the Intralase FS laser may be the result of differences in postoperative astigmatism and trefoil. Although nomogram adjustments may have improved the spheroequivalent results in both groups, the observed increase in astigmatism and trefoil in the Hansatome group would likely not be improved using such nomogram adjustments.

A retrospective study done by Kezirian et al6 compared LASIK outcomes with the Intralase FS laser to those with the Carriazo-Barraquer microkeratome (Moria, Antony, France) and the Hansatome microkeratome. All three groups were matched for enrollment criteria and were operated on under similar conditions by the same surgeon. The investigators studied 106 eyes in the Intralase group, 126 eyes in the Carriazo-Barraquer group, and 143 eyes in the Hansatome group. One day postoperatively, the UCVA results in the three groups were similar. At 3 months, the UCVA and BSCVA results were not significantly different. A manifest spheroequivalent of ±0.50D was achieved in 91% of eyes in the Intralase group, 73% of eyes in the Carriazo-Barraquer group, and 74% of eyes in the Hansatome group ($P<.01$). Intralase flaps were significantly thinner ($P<.01$) and varied less in thickness ($P<.01$) than flaps created with the other devices. The mean flap thickness was 114µm ±14 with the Intralase programmed for a 130-µm depth, 153 ±26µm with the Carriazo-Barraquer using a 130-µm plate, and 156 ±29µm with the Hansatome using a 180-µm plate. Loose epithelium was encountered in 9.6% of eyes in the Carriazo-Barraquer group and 7.7% of eyes in the Hansatome group, but in no eyes in the Intralase group ($P=.001$). Surgically induced astigmatism in sphere corrections was significantly less with the Intralase than with the other devices ($P<.01$). The investigators concluded that the Intralase produced more predictable flap thickness, better astigmatic neutrality, and less epithelial injury than mechanical microkeratomes.

## INDUCED ABERRATIONS WITH INTRALASE AND HANSATOME FLAPs

Tran et al7 performed a randomized prospective study of nine patients (18 eyes) treated with a two-step LASIK procedure: lamellar keratectomy with a Hansatome microkeratome or the Intralase FS laser in the fellow eye followed by nonwavefront-guided excimer laser treatment 10 weeks later.8 The fellow eyes were matched within of 0.75D sphere and 0.50D of cylinder. Patients were followed for 3 months after excimer laser treatment. Wavefront aberrometry and manifest refraction were evaluated before and after flap creation. Statistically significant changes were seen in defocus wavefront aberrations after Hansatome ($P=.004$) and Intralase ($P=.008$) flap creation. A hyperopic shift in manifest refraction was noted in the Hansatome group after the corneal flap was created ($P=.04$), while no statistically significant changes in the manifest refraction were seen in the Intralase group. Statistically significant changes in total higher-order aberrations (trefoil and quadrafoil) occurred following flap creation in the Hansatome group ($P=.02$). No significant changes in higher-order aberrations were noted after flap creation in the Intralase group.

## THE BOTTOM LINE

- Femtosecond lasers produce precise intrastromal incisions, which improves safety and reduces the incidence of corneal trauma, partial resections, or sterilization issues.
- The femtosecond laser may be a better option than the Hansatome microkeratome for treating and preventing higher-order aberrations after LASIK.
- Additional comparative studies of PRK and femtosecond laser-assisted LASIK could help determine which treatment modality is best for wavefront-guided treatments.
- The femtosecond laser has the potential to create intrastromal refractive lenticules for complete refractive procedures, such as intrastromal laser keratomileusis.
- Femtosecond laser-assisted ICRS is associated with a speedy recovery of vision and minimal surgical trauma compared with using a blade to make a channel.
- The laser also allows surgeons to control the channel’s width precisely, perhaps thereby optimizing the rate and stability of visual recovery after ICRS surgery.

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