JUHANI PIETILÄ

# Flap Creation in Laser-Assisted in Situ Keratomileusis

## From microkeratome to femtosecond laser

ACADEMIC DISSERTATION
To be presented, with the permission of
the board of the School of Medicine of the University of Tampere,
for public discussion in the Main Auditorium of Building B,
School of Medicine of the University of Tampere,
Medisiinarinkatu 3, Tampere, on February 3rd, 2012, at 12 o'clock.

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ACADEMIC DISSERTATION
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This summary is based on the following original publications referred to in the text by their Roman numerals I-VI.

I Pietilä, J., Mäkinen, P., Suominen, S., Huhtala, A., and Uusitalo, H. (2005). Corneal flap measurements in laser in situ keratomileusis using the Moria M2 automated microkeratome, J. Refract. Surg. *21*, 377-385.

II Pietilä, J., Mäkinen, P., Suominen, S., Huhtala, A., and Uusitalo, H. (2006). Bilateral comparison of corneal flap dimensions with the Moria M2 reusable head and single-use head microkeratomes, J. Refract. Surg. *22*, 354-357.

III Huhtala, A., Pietilä, J., Mäkinen, P., Suominen, S., Seppänen, M., and Uusitalo, H. (2007). Corneal flap thickness with the Moria M2 single-use head 90 microkeratome, Acta Ophthalmol. Scand. *85*, 401-406.

IV Pietilä, J., Huhtala, A., Mäkinen, P., Seppänen, M., Jääskeläinen, M., and Uusitalo, H. (2009). Corneal flap thickness with the Moria M2™ microkeratome and Med-Logics calibrated LASIK blades, Acta Ophthalmol. *87*, 754-758.

V Pietilä, J., Huhtala, A., Jääskeläinen, M., Jylli, J., Mäkinen, P., and Uusitalo, H. (2010). LASIK flap creation with the Ziemer femtosecond laser in 787 consecutive eyes, J. Refract. Surg. *26*, 7-16.

VI Pietilä, J., Huhtala, A., Mäkinen, P., and Uusitalo, H., Laser *in situ* keratomileusis enhancements with the Ziemer FEMTO LDV femtosecond laser following previous LASIK. Submitted.

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## ABBREVIATIONS

| | |
|---|---|
| ACS | Automated corneal shaper |
| AK | Astigmatic keratotomy |
| ALK | Automated lamellar keratoplasty |
| AMO | Advance Medical Optics (now Abbot Medical Optics) |
| ArF | Argon fluoride |
| BSCVA | Best spectacle corrected visual acuity |
| CB | Carriazo-Barraquer |
| CK | Conductive keratoplasty |
| CLE | Clear lens extraction |
| CM | Confocal microscopy |
| CMTF | Confocal microscopy through-focusing |
| D | Diopters |
| DIFT | Difference between actual flap thickness and intended flap thickness |
| DLK | Diffuse lamellar keratitis |
| FDA | US Food and Drug Administration |
| Ho:YAG | Holmium:ytriym aluminum garnet |
| ICR | Intrastromal corneal ring |
| ICRS | Intrastromal corneal ring segments |
| IOP | Intraocular pressure |
| LASEK | Laser-assisted epithelial keratomileusis |
| LASIK | Laser-assisted in situ keratomileusis |
| LDV | Leonardo Da Vinci |
| LRI | Limbal relaxing incision |
| LTK | Laser thermokeratoplasty |
| M2 | Model Two from Moria |
| NS | Not significant |
| OCT | Optical coherence tomography |
| PARK | Photoastigmatic refractive keratectomy |
| PERK | Prospective evaluation of radial keratotomy |
| PIOL | Phakic intraocular lens |
| PMMA | Polymethyl methacrylate |
| PRK | Photorefractive keratectomy |

| | |
|---|---|
| PTK | Phototherapeutic keratectomy |
| RF | Radiofrequency |
| RK | Radial keratotomy |
| RLE | Refractive lens exchange |
| RTK | Radial thermokeratoplasty |
| SBK | Sub-Bowman’s keratomileusis |
| SD | Standard deviation |
| SE | Spherical equivalent refraction |
| SKBM | Summit Krumeich Barraquer microkeratome |
| SPK | Superficial punctuate keratopathy |
| TKP | Thermokeratoplasty |
| UCVA | Uncorrected visual acuity |
| UV | Ultraviolet |
| VHF | Very high-frequency digital ultrasound |

**ABSTRACT**

Laser-assisted in situ keratomileusis (LASIK) is the most commonly used refractive surgery technique for the correction of myopia, hyperopia, and astigmatism. The first phase of LASIK, the creation of a corneal flap, is the most critical step of LASIK and affects the visual outcome of the whole procedure. The flap creation is followed by excimer laser ablation of the exposed stroma, after which the flap is repositioned. The technological evolution of flap creation has emerged from mechanical manually guided microkeratomes to automated microkeratomes, and single-use microkeratomes and, most recently, to femtosecond laser technology.

In the present study, accuracy, predictability, complications and factors that influence the dimensions of LASIK corneal flap were evaluated when the corneal flap was created with different automated microkeratomes, a single-use microkeratome or a femtosecond laser and in reoperations performed with a femtosecond laser after previous LASIK procedure.

Four hundred fifty-four eyes were operated with the Moria M2 automated head 130 microkeratome with the attempted flap thickness of 160 µm. The achieved flap thickness was 153.3±19.0 µm (mean ± standard deviation) (range 77 to 209 µm). Complications were reported in 60 (13.2%) eyes. Increasing flap thickness was associated with increasing corneal thickness, younger patient age, and flatter keratometric $K_1$ value.

Ninety-eight eyes were operated with the Moria M2 microkeratome so that one eye was treated with the metallic head 130 and the other with plastic single-use head, both designed to create a 160 µm flap. With the head 130, mean thickness was 153.3±13.3 µm (range 102 to 179 µm). With the single-use head, mean thickness was 148.0±9.8 µm (range 120 to 170 µm). Complications occurred in 2 (2.0%) eyes with both head types. Flap thickness correlated to preoperative corneal thickness in both head types, especially in myopic eyes. The thicker the cornea, the thicker the flap.

Three hundred eyes were treated with the Moria M2 single-use head 90 microkeratome with the attempted flap thickness of 120 µm. Mean corneal thickness was 115.4±12.5 µm (range 73 to 147 µm). Complications were observed in 3 (1.0%) eyes. Patient age showed negative correlation with flap thickness. Flap thickness was positively correlated with preoperative corneal thickness. In myopic eyes, flap thickness was not correlated with keratometric power $K_1$, but in hyperopic eyes increasing flap thickness was associated with flatter keratometric power $K_1$. In clinical practice, single-use heads were easier to use, because they do not need any assembly. The translucent plastic single-use head provided a better observation view for the surgeon on the operated eye than the metallic head. The plastic head also worked more evenly than the metallic head.

One hundred eyes underwent flap creation with the Moria M2 head 130 microkeratome (intended to create 160-µm corneal flap) adjusted with the single-use Med-Logics calibrated LASIK blade Minus 20 (ML -20 cohort), designed to create a flap of thickness 140 µm. The other 100 eyes were treated with the Moria M2 head 130 microkeratome adjusted with the Med-Logics calibrated LASIK blade Minus 30 (ML -30 cohort), designed to create a flap of thickness 130 µm. In ML -20-treated right eyes, mean corneal flap thickness was 129.1±15.6 µm (range 104 to 165 µm). In ML -20-treated left eyes, mean flap thickness 111.5±14.5 µm (range 78 to 144 µm). In ML -30-treated right eyes, mean flap thickness was 127.1±16.6 µm (range 90 to 168 µm). In ML -30-treated left eyes, mean flap thickness was 109.9±16.8 µm (range 72 to 149 µm). There was no clinically relevant difference in flap thickness between ML -20 and ML -30. For both cohorts, the difference between the first and second cut was significant. The first flap was significantly thicker. There were no flap-related complications. Corneal flap thickness in ML -30 treated eyes correlated with corneal thickness, but not in ML -20-treated eyes. Flap thickness did not correlate significantly with age. Flap thickness was associated with keratometric power $K_1$ in ML -30-treated eyes in both myopic and hyperopic eyes, but not in myopic ML -20-treated eyes. Moria M2 single-use head 90 microkeratome is recommended for the making of thin flaps instead of the Moria M2 with Med-Logics calibrated LASIK blades.

Seven hundred eighty-seven eyes were treated with the FEMTO LDV femtosecond laser with the attempted flap thickness of 110 µm. The achieved flap thickness was 90.0±5.5 µm (range 67 to 107 µm) in right eyes, and in left eyes 90.1±4.6 µm (range 77 to 106 µm). The difference between right and left eye was not significant. The most common complication was bleeding from the limbal vessels (12.7%). Other complications occurred in 8.4% of the eyes, but none prevented further laser ablation. Increasing flap thickness was correlated to increasing corneal thickness in right eyes and flatter keratometric $K_1$ value in left eyes.

Eighty-five previously LASIK-treated eyes were reoperated with the FEMTO LDV for flap creation. With the intended flap thickness of 90 µm, flap thickness averaged 90.2±6.6 µm (range 80 to 122 µm). Complications were reported in 12 (14.1%) eyes. Flap thickness correlated positively with patient age and hinge length in myopic eyes. In LASIK revisions, when the flap is still readily noticeable and not too tightly adhered, flap relifting remains the recommended choice. If the primary flap has a small diameter or the old flap is tightly adhered, flap recutting is the method of choice. In LASIK revision, it is recommended the new flap should be made in a different position than the primary flap. In the cases of a primary free cap, the use of a microkeratome is recommended. In LASIK revision with femtosecond laser, surgical skill is required and special attention should be paid on the technical specificities to avoid complications in the demanding cases.

Other flap-related characteristics in these studies were as follows: Average horizontal flap diameter varied from 9.1 to 9.2 mm, and average hinge length varied from 4.0 to 4.6 mm. White-to white distance of the eyes averaged from 11.4 to 11.8 mm.

In flap creation, undercutting (*i.e.* thinner flap than intended) was the most common feature in microkeratomes. Femtosecond laser created more predictable flaps, which made thin flaps possible. The advantage of making thin flaps is that more corneal tissue is saved to avoid possible iatrogenic keratoectasia. Thin flaps also increase reoperation possibilities if needed.

# 1. INTRODUCTION

The transparent, avascular cornea and its air-tear interface provide about two-thirds of the refractive power of the eye. Its normal structure and regular curvature are primary demands for the normal refraction of the light in the fovea. Traditionally, optical devices such as spectacles and contact lenses are used to correct refractive errors. Corneal refractive surgery offers an entirely different approach to correct our vision. Today, refractive surgical procedures are one of the most widely performed procedures in medicine.

In general, refractive surgery can be divided into several categories. Contemporary corneal refractive surgery modifies corneal curvature, including incisional, thermal, ablative, and additive methods. In refractive surgery, most of the evolution has occurred during the past two decades. The potential of excimer laser was realized by the ophthalmic world after the landmark paper by Trokel and coauthors (Trokel et al., 1983) had been published in the American Journal of Ophthalmology in 1983. Trokel and colleagues had assumed correctly that the wavelength of ultraviolet (UV) light at 193 nm - previously used to make computer chips in California's Silicon Valley - could be harnessed for the ablation of the corneal tissue with a submicron precision and without thermal damage to the surrounding tissue. Subsequently, excimer laser photorefractive keratectomy (PRK) became the first laser refractive correction procedure that was adopted by ophthalmologists and patients worldwide.

The idea of being less dependent of spectacles or contact lenses allures some people to refractive surgery. Especially athletes and people with certain professions and hobbies find it easier without eye glasses or contact lenses. Earlier refractive surgery techniques, radial keratotomy (RK) which is based on radial incisions to the cornea and PRK, based on excimer laser ablation on the cornel stroma after epithelium removal, are today most commonly replaced with laser-assisted in situ keratomileusis (LASIK) (Duffey and Leaming, 2005). In LASIK, a corneal flap is created, after which the exposed corneal stroma is ablated with excimer laser and the flap repositioned. The first phase of LASIK, the creation of a corneal flap, is the most critical step of LASIK and it affects the visual outcome of the whole procedure. The technological evolution of flap creation has emerged from mechanical manually guided microkeratomes to automated microkeratomes, then single-use microkeratomes, and most recently to femtosecond laser technology. The main problems of earlier refractive techniques, such as postoperative pain, corneal haze, and myopic regression are minimized with LASIK (Ambrosio, Jr. and Wilson, 2003). Thus, today LASIK is the most frequently used laser refractive surgery procedure and it has been estimated that each year 3.6 million (2010) to 5.0 million (2015) LASIK procedures are conducted worldwide (Harmon, 2010).

In the present study, accuracy, predictability, complications and factors that influence the dimensions of LASIK corneal flap were evaluated, when the corneal flap was created with different automated microkeratomes, a single-use microkeratome or a femtosecond laser, and in reoperations performed with a femtosecond laser after previous LASIK procedure.

## 2. REVIEW OF THE LITERATURE

### 2.1. Early surgical techniques on the cornea

Refractive surgery has been performed in a number of ways for a relatively long time. Earlier techniques, e.g. keratoplastic operations for opaque corneas, date back as long as the 18th century (see Castroviejo, 1966). In the 1800s, many of the current keratotomy, thermokeratoplasty (TKP), and keratectomy techniques were described (Lans, 1898).

#### *2.1.1. Radial keratotomy (RK)*

Keratotomy was first described by the Dutch ophthalmologist Lans (Lans, 1898) and by the Japanese ophthalmologist Sato (Sato, 1939). In the late 1930s, Sato observed that spontaneous breaks in Descemet's membrane in keratoconus flattened the cornea and reduced myopia (Sato, 1939). His suggestion to make surgical incision in the cornea to treat astigmatism and myopia led to both laboratory and clinical experimentation. This resulted in the description of an operation by Sato (Sato, 1953) and Akiyama (Akiyama, 1955), known as radial keratotomy (RK), which consisted of about 35 posterior and 40 anterior equally spaced radial incisions to reduce myopia. However, Sato's technique had two drawbacks: technical difficulties and damage to the corneal endothelium (American Academy of Ophthalmology: Radial keratotomy for myopia, 1993). In the 1970's, Sato's technique was modified in the Soviet Union by Beliaev (Beliaev and Il'ina, 1972), Yenaliev (Yenaliev, 1978), and Fyodorov and Durnev (Fyodorov and Durnev, 1979), by making radial incisions only in the anterior peripheral cornea and sclera. In 1978, Bores, Myers, and Cowden began performing RK in the United States using Fyodorov's technique (Bores et al., 1981; Cowden and Bores, 1981). Since then the technique has been improved through laboratory and clinical investigations and technical innovations; e.g. the number of incisions used in RK has decreased over the years. Fyodorov used 32 incisions, but later only 16 ones after concluding that 32 were not necessary (Fyodorov and Durnev, 1979). Later work has shown that 80-90% of the corneal flattening of 16 incisions can be achieved with only eight (Salz et al., 1981; Rowsey et al., 1983). More recent reports show excellent results in the use of a nomogram calling for four incisions (Gothard et al., 1993; Jory, 1995).

The National Eye Institute in the United States funded two large nationwide studies to examine RK: the Prospective Evaluation of Radial Keratotomy (PERK) study in 1980 and the Analysis of Radial Keratotomy in 1981. The PERK study was a prospective, collaborative study among university and private ophthalmologists in nine clinical centers to assess the efficacy, safety, predictability, and stability of RK (Waring, III et al., 1983; Waring, III et al., 1985). The PERK study incorporated the technological advantages of its time: the ultrasonic pachymetry and the diamond micrometer knife. The results at four years (Waring, III et al., 1990) and five years (Waring, III et al., 1991) after the operation have been presented along with a 10-year follow-up study (Waring, III et al., 1994). Ten years after surgery, 53% of PERK patients had 20/20 or better uncorrected vision, 85% saw 20/40 or better, and 63% of the patients <40 years of age were spectacle-independent. RK was shown to be an effective method at reducing myopia, but shortcomings were also reported by PERK. The 90% prediction interval was fairly wide at 4.42 diopters (D), and a worrisome drift toward hyperopia was revealed. An association was made between the length of the incision and the amount of hyperopic shift. Recognition of the hyperopic shift has led many surgeons to adopt intentional undercorrections, staged procedures, shorter incisions and eventually other surgical procedures (Stulting et al., 2000). Over the years, extensive information on RK has been published to help characterize its risks and benefits (American Academy of Ophthalmology: Radial keratotomy for myopia, 1993). Casebeer has pointed out the importance of standardized surgical techniques and instrumentation in the development of RK nomograms (Werblin and Stafford, 1993; Casebeer, 1994; Werblin and Stafford, 1996). Modern RK results are excellent, and it still has some advantages over more modern forms of surgical surgery: E.g., it does not involve incisions in the optical zone, the equipment is inexpensive compared to newer techniques, and it has more long-term data published than more recently popularized techniques (Stulting et al., 2000). In the United States alone, more than 2 million RK procedures have been performed.

### *2.1.2. Thermokeratoplasty (TKP)*

The ability of heat to change the shape of the cornea was first demonstrated in the late 1890s (Lans, 1898). Work in the mid-1970s and more recent studies have shown that a temperature of 65-85°C will cause maximal shrinkage rates (30-59%) of corneal collagen (Gasset et al., 1973; Shaw and Gasset, 1974). In the mid-1970s, early results of large-area TKP as a refractive treatment for patients with keratoconus were promising (Gasset and Kaufman, 1975). However, as more procedures were performed, regression and complications were reported, e.g. recurrent erosions, delayed epithelialization, stromal scarring, stromal necrosis, destruction of Bowman's layer, iritis, and vascularization (Aquavella, 1974; Keates and Dingle, 1975; Aquavella et al., 1976; Arentsen and Laibson, 1976; Arentsen et al., 1977; Fogle et al., 1977). Because of these problems, large-area TKP was replaced by other techniques. Radial thermokeratoplasty (RTK) was described by Fyodorov in 1980s (Caster, 1988). In RTK, a heated wire was applied to the cornea to produce a series of deep thermal burns in a radial pattern, causing contraction of the peripheral cornea and steepening of the central cornea. Early studies on RTK showed promising results (Neumann et al., 1990; Schachar, 1991), but soon problems were reported: regression, unstable visual acuity, undercorrection, overcorrection, and irregular astigmatism (Feldman et al., 1989; Neumann et al., 1991; Charpentier et al., 1994; Hargrave et al., 1997). The complications reported included damage to the corneal endothelium, iritis, fibrovascular ingrowth, microperforations, and permanent scarring. (Feldman et al., 1989; Feldman et al., 1990; Neumann et al., 1991; Charpentier et al., 1994; Salazar, 1994; Hargrave et al., 1997). Because of these problems, this technique is no longer considered a safe treatment option (Stulting et al., 2000).

The problems of the hot wire were reduced by the introduction of lasers that could heat the cornea in a more controlled fashion. The use of holmium:ytriym aluminum garnet (Ho:YAG) laser for hyperopic corrections, or laser thermokeratoplasty (LTK), was first reported in 1990 by Seiler et al. (Seiler et al., 1990). This laser uses infrared radiation at the wavelength of 2.06 μm, focused on the mid-stroma, thus avoiding damage to the epithelium and endothelium. Studies on LTK have been encouraging (Seiler, 1992; Durrie et al., 1994; Lim et al., 1996; Durrie et al., 1994; Alio et al., 1997a; Alio et al., 1997a; Goggin and Lavery, 1997; Ismail et al., 1998), but problems with regression and the induction of varying amounts of irregular astigmatism have also been reported (Durrie et al., 1994; Tutton and Cherry, 1996; Alio et al., 1997b). One study suggests that LTK is affected by pachymetry, age, and degree of hyperopia (Alio et al., 1997b). LTK may suit best for older people with less than +3.00 D of hyperopia and the central corneal thickness of <525 μm.

LTK with the Ho:YAG laser has received Food and Drug Administration (FDA) approval in the US.

### 2.2. Evolution of photorefractive keratectomy (PRK)

Many lasers have been used for the reshaping of the cornea. These include excimer laser, carbon dioxide laser, hydrogen fluoride laser, erbium:YAG laser, and dye laser (Bansal and Veenashree, 2001). Of these, excimer laser has shown good and consistent results and has been approved for clinical use. Excimer lasers were first developed in 1975 and were shown to be useful for etching silicon and other polymers for making microcircuits (Srinivasan, 1986). The term “excimer” is a contraction of “excited dimer”, an energized molecule of two similar components, which was the original concept of how these gas-halide lasers functioned. Clinical excimer lasers use argon and fluoride gases to generate UV radiation at the wavelength of 193 nm. The excimer laser offers entirely new corneal surgery procedures. The energy of this wavelength is high enough to break molecular bonds in the cornea and remove tissue. The ablation results in submicron tissue removal per laser pulse with minimal or no damage to the surrounding tissue (Waring, III, 1989).

Excimer laser photorefractive keratectomy (PRK) followed RK, as more precise surgical techniques were sought. PRK uses excimer laser to reshape the anterior corneal stroma by photoablation after mechanically removing the epithelium. For more than 20 years, the excimer laser has been used as a surgical instrument on the cornea. Trokel and coauthors were the first to describe corrective surgery for myopia by the excimer laser on the cornea in enucleated cow eyes in 1983 (Trokel et al., 1983). Early studies of PRK using excimer laser on rabbits (Goodman et al., 1989) and monkeys (Fantes et al., 1990; Hanna et al., 1990) showed relatively predictable and reducible corneal flattening without significant corneal haze formation. In 1988, PRK was successfully applied in sighted human eyes (McDonald et al., 1989; McDonald et al., 1991).

In the treatment of myopia, a disc-shaped photoablation is performed on the anterior stroma, and it consequently flattens the corneal curvature (Fig. 1a). In the treatment of hyperopia, PRK is performed by a circular, peripheral ablation (Fig. 1b). This technique produces central steepening of the cornea instead of flattening in the myopic PRK. To correct symmetric astigmatism, the cornea is ablated in a cylindrical fashion, known as toric photoablation (McDonnell et al., 1991). When excimer laser PRK is used to correct astigmatism errors, the procedure is referred to as photoastigmatic refractive keratectomy (PARK).

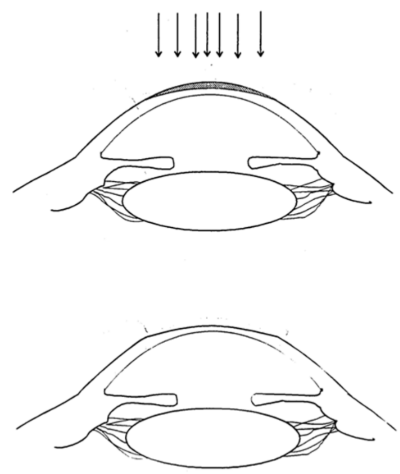

Figure 1a. PRK in the treatment of myopia. A disc-shaped photoablation is performed on the anterior stroma, and it flattens the corneal curvature.

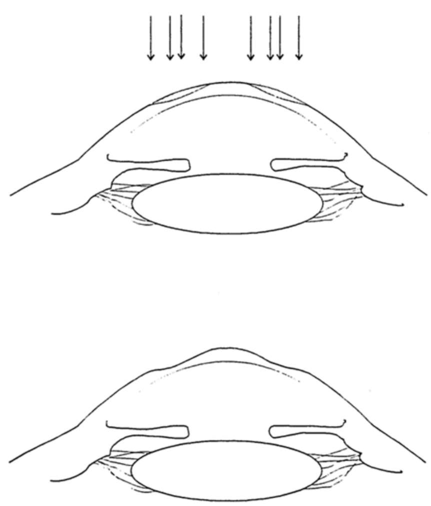

Figure 1b. PRK in the treatment of hyperopia is performed by a circular, peripheral ablation.

In the USA, PRK received FDA premarket approval for one laser in the fall of 1995 and for a second laser in the spring of 1996 to treat myopia, for one laser in the spring of 1997 and another in early 1998 to treat astigmatism (American Academy of Ophthalmology: Excimer laser photorefractive keratectomy (PRK) for myopia and astigmatism, 1999).

Earlier clinical investigators used small ablation zones, typically 4.3 to 4.5 mm in diameter, because ablation depth increases geometrically (related to the square of the ablation zone diameter) as the size of the ablation zone increases (American Academy of Ophthalmology: Excimer laser photorefractive keratectomy (PRK) for myopia and astigmatism, 1999). The general formula (1) is used to estimate the amount of tissue to be removed centrally (Munnerlyn et al., 1988):

Ablation depth (μm) = [desired refraction change in diopters/3] x [ablation diameter (mm)]$^2$ (Eq 1)

Thus, by altering the amount of stromal tissue removed and the area of tissue ablated, a desired amount of refractive change can be brought about. Epstein et al. showed good results using 4.3 to 4.5 mm diameter ablation zones (Epstein et al., 1994). However, it became obvious that glare and halos could be extensive problems for patients with large pupils (American Academy of Ophthalmology: Excimer laser photorefractive keratectomy (PRK) for myopia and astigmatism, 1999). Subsequently, surgeons began using larger ablation zones, initially 5.0 and 5.5 mm and later 6.0 mm or larger. Currently, clinical excimer lasers use a minimum of a 6.0 mm diameter ablation zones to treat low and moderate myopia, because refractive results are better and subjective complaints of night-time vision problems are fewer than in smaller-diameter ablation zones. In a prospective, randomized, double-blind study with a Summit laser, the clinical results of 5.0 mm diameter and 6.0 mm diameter ablation zones (O'Brart et al., 1995) were compared. The study showed that 6.0 mm diameter ablation zones resulted in less initial overcorrection, less corneal haze, improved refractive predictability and stability, and fewer problems with postoperative glare and halos compared to the 5.0 mm ablation zone group. In a later follow-up study, it was reported that the 6.0 mm ablation zone also required fewer retreatments than the 5.0 mm diameter ablation group (Corbett et al., 1996).

Since the 1980s, a large number of excimer laser PRK studies have been published in peer-reviewed literature. Improvements in hardware and software have paralleled the evolution of PRK. Various kinds of techniques are used for laser delivery, such as an iris diaphragm in a circular beam, a scanning-slit beam, or a flying-spot beam. The laser beam delivery system and the number of laser pulses administered are monitored by an algorithm. Laser beam quality, delivery system, pulse frequency, and algorithms have also been under development during the rapid history of PRK. There are various types of epithelial ablation in use: manual with a spatula or a rotating brush, manual after alcohol administration, laser-scrape technique and transepithelial laser removal (Stein, 2000). Cooling of the cornea before and after surgery is also possible.

The massive literature currently available of PRK-treated patients gives evidence that over 90% of myopic corrections up to -6.00 D achieve the final outcome within ±1.00 D of the targeted refraction (Taneri et al., 2004). The higher the intended corrections, the less predictable the results become, accompanied by an increase in complications. Postoperative pain, corneal haze, and myopic regression are the main problems of PRK. Pain from corneal injury is the consequence of excitation of corneal nerve terminals by a noxious stimulus or by locally released inflammatory substances (Fagerholm, 2000). The combination of preoperative and postoperative nonsteroidal drops and the use of a soft contact lens have resulted in a major decrease in pain. It has been estimated that currently about 90% of the patients are comfortable after PRK, while the 10% who experience discomfort have usually minimal to moderate discomfort overnight, which then quickly resolves in 24 to 36 hours after the procedure (Stein, 2000). Late onset corneal haze (LOCH) is a very grave complication of PRK (Epstein et al., 1994; Dutt et al., 1994; Seiler et al., 1994; Meyer et al., 1996; Lipshitz et al., 1997). It is characterized by dense subepithelial opacity along with regression and loss of best spectacle-correct visual acuity. The incidence has been reported to be around 1%, depending on several factors, such as smoothness of the laser ablation, level of correction, and variation in the wound healing response (Ambrosio, Jr. and Wilson, 2003). Regression is more likely to occur with higher degrees of myopic or astigmatic correction (Stein, 2000). Factors that may lead to regression include preoperative small keratometry values, small optical zones, single zone treatment, high myopia, and steep wound edges (Gauthier et al., 1996; Goggin et al., 1996). Pain, corneal haze, myopic regression, and a relatively long recovery period have led many surgeons to switch from PRK to other techniques. However, PRK remains a good choice for mild and moderate correction. According to current literature, there are several clinical situations in which PRK may be a better option compared to other techniques (Table 1).

Table 1. Clinical situations where PRK may be a better option than other techniques (modified from Stein, 2000; Anderson et al., 2002; Ambrosio, Jr. and Wilson, 2003).

| |
|---|
| Patient preference because of concern about a flap |
| Thin corneas in which the residual stromal bed thickness would be less than 250 to 300 µm |
| Very steep (>48 D) or small (<41 D) keratometry values |
| Risk occupation or activity (i.e. military personnel and contact sports athletes) |
| Keratoconus suspect |
| Optic nerve disease |
| Dry eye |
| Deep orbits or tight eyelid fissure |
| Anterior basement membrane (Cogan’s) dystrophy |
| Epithelial sloughing during LASIK in the contralateral eye |
| Anterior scleral buckles |
| Previous surgery involving the conjunctiva, bleb associated with filtering procedure |

## 2.3. Technical evolution of laser-assisted in situ keratomileusis (LASIK)

### *2.3.1. The early history*

Corneal lamellar refractive keratoplasty was first introduced and developed by Barraquer in Columbia in the early 1960s (see Barraquer, 1989). According to the principle, lens refraction can be altered by adding or removing tissue from the corneal stroma. Barraquer developed myopic keratomileusis, which used a cryolathe to shape the cornea. The word keratomileusis stands for the Greek roots *keras* ("horn-like", referring to the cornea) and *smileusis* ("carving") (Bores, 1993). The main problems of myopic keratomileusis were training and experience required to manage the cryolathe and perform the keratometry effectively (Doane and Slade, 2004). Although initially good results were obtained by several investigators, the technique proved to be difficult to master for a large number of surgeons (Doane and Slade, 2004). Keratomileusis *in situ,* the concept in which the corneal cap was raised and tissue removed from the bed, was first described in 1970s (see Doane and Slade, 2004). In Bogota, Ruiz developed an advanced instrument, a microkeratome that has a geared track with an adjustable-height suction ring. The mechanized microkeratome, or automated corneal shaper, provided a more consistent thickness and diameter of the corneal disc and a smoother stromal bed (see Doane and Slade, 2004). This made automated lamellar keratoplasty (ALK) technique possible (Casebeer, 1997). A free corneal cap needing suturing after cap repositioning was replaced with a hinged corneal flap. The instrumental development and the sutureless repositioning of the flap made lamellar corneal surgery more appealing for a large number of surgeons (Doane and Slade, 2004).

Lamellar surgery combined with the ablation of the revealed stromal bed with a 193 nm argon-fluoride excimer laser was first reported by Pallikaris and Buratto in the early 1990s (Pallikaris et al., 1990; Buratto et al., 1992). In PRK the laser is applied directly to the Bowman's layer, whereas in laser in situ keratomileusis, the term used by Pallikaris and coworkers (Pallikaris et al., 1990; Pallikaris et al., 1991), laser energy is applied deeper into the midstroma after the flap has been lifted from the cornea (Figure 2).

In general, the technical evolution of microkeratomes over the decades has been towards larger flaps to increase optical zone for laser ablation and towards thinner flaps to increase the thickness of non-treated stromal bed. The residual thickness in the stromal bed after surgery is recommended to be at least 250 μm (Seiler et al., 1998; Pallikaris et al., 2001) and even more in high myopes (Magallanes et al., 2001) to avoid iatrogenic keratoectasia, a progressive corneal distortion caused by LASIK-induced weakening of corneal structure. The residual stroma of at least 250 μm does not guarantee that ectasia is avoided, but however, in some cases less than a 250-µm stromal bed has lasted for years without the development of ectasia (Klein et al., 2006; Binder, 2007; Condon et al., 2007).

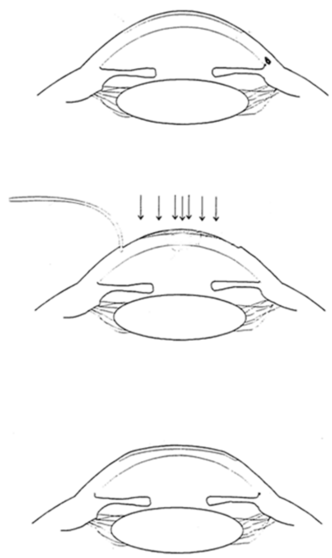

Figure 2. LASIK procedure. In the first step of LASIK, a corneal flap is cut and then the exposed stroma is ablated with excimer laser, after which the flap is repositioned.

### *2.3.2. Mechanical microkeratomes*

Methods of flap creation have changed over the years from the evolution of the mechanical microkeratomes to the introduction of the femtosecond laser keratomes, both of which have different mechanisms of action to create corneal resections. A wide variety of mechanical microkeratomes is in clinical use (Table 2). The mechanical microkeratome uses shear force through the use of oscillating blade that travels across the cornea in a torsional or translational way. The translation speed of the blade has been found to affect flap thickness: faster translation creates thinner flaps (Muallem et al., 2004). In some microkeratome systems (e.g. Moria M2) corneal curvature has been compensated for by using different suction rings (based on the keratometric value), which are known to affect flap diameter and thickness. Sterilization problems and microkeratome problems due to improper assembly of the metallic microkeratome heads can be avoided by using single-use blades. The most common problem with different microkeratomes is variations in the achieved flap thickness compared to the attempted flap thickness. The most common feature is that the achieved flap thickness is thinner than the intended one (Table 2). However, there are some exceptions. Some studies also report differences in flap thickness between the first and second eye operated with the same blade (Shemesh et al., 2002; Jackson et al., 2003; Aslanides et al., 2007; Ho et al., 2007; Muallem et al., 2004). When the same blade is used in bilateral eyes, the second cut typically creates a thinner flap.

Table 2. Flap thickness with conventional microkeratomes (in alphabetical order) in clinical studies. Typically, flap thickness was measured with subtraction ultrasound pachymetry. Exceptions are mentioned in the table. Intended flap thickness or head/plate number of the mickrokeratome is described in the second column.

| **Microkeratome** | **Intended or set flap thickness (µm)** | **No. of eyes in the study** | **Achieved flap thickness (µm) Mean±SD** | **Reference** |
|---|---|---|---|---|
| **ACS** | 130 plate | 100 | 86.6±12 | (Perez-Santonja et al., 1997) |
| | 160 | 43 | 114.1± 17 | |
| ACS | 130 plate | N/A | 131±3 | (Wang et al., 1999) |
| | 160 | N/A | 159±6 | |
| ACS | 160 | 15 | 105± 24.3 | (Durairaj et al., 2000) |
| | 180 | 64 | 125±18.5 | |
| | 200 | 17 | 144±19.3 | |
| ACS | 160 | 62 | 112± 25 CMTF | (Vesaluoma et al., 2000) |
| ACS | 160 | 12 | 132.7±12.5 CMTF | (Gokmen et al., 2002) |
| ACS | 160 depth setting | 23 | 128.3± 12.6 right eye | (Shemesh et al., 2002) |
| | | 23 | 123.0±13.3 left eye | |
| ACS | 160 | 1776 | 119.8±22.9 | (Flanagan and Binder, 2003) |
| ACS | 160 | 50 | 102.0± 24.9 CM | (Javaloy et al., 2004) |
| **Amadeus** | 140 head | 51 | 153± 18 right | (Jackson et al., 2003) |
| | | 50 | 134± 25 left | |
| | 160 | 25 | 182±26 right | |
| | | 25 | 163± 29 left | |
| | 180 | 6 | 235± 24 | |
| Amadeus | 130-2 plate thickness | 62 | 147±24 | (Solomon et al., 2004) |
| | 140 | 207 | 134±15 | |
| | 160 | 169 | 180±35 | |
| Amadeus | 160 | 25 | 140.0±16.5 central | (Guell et al., 2005) |
| | | | 152.5±29.2 superior | |
| | | | 145.0±15.7 temporal | |
| | | | 147.0±13.7 nasal | |
| | | | 128.5±21.6 inferior | |
| **Carriazo-** | 160 | 30 | 123.9±22.3 | (Vongthongsri et al., 2000) |
| **Barraquer (CB)** | 180 | 13 | 167.2±24.9 | |
| CB | 130 head | 65 | 157±40 | (Miranda et al., 2003) |
| CB | 130 plate thickness | 126 | 153±26 | (Kezirian and Stonecipher, 2004) |
| CB | 130 | 30 | 133±26.4 | (Nagy et al., 2004) |
| CB | 110 plate thickness | 13 | 165±27 | (Solomon et al., 2004) |
| | 130 | 147 | 198±26 | |
| **Carriazo-Pendular Schwind** | 110 | 22 | 118.1±8.3 VHF | (Alio and Pinero, 2008) |
| **Hansatome** | 160 plate | 63 | 124.8±18.5 | (Maldonado et al., 2000) |
| Hansatome | 160 plate | 16 | 118.8±19.8 | (Gailitis and Lagzdins, 2002) |
| | 180 | 116 | 143.2± 18.8 | |
| Hansatome | 160 depth setting | 19 | 141.2± 20.1 right eye | (Shemesh et al., 2002) |
| | | 19 | 121.0±27.0 left eye | |
| Hansatome | 160 plate | 50 | 142.6±20.8 | (Spadea et al., 2002) |
| Hansatome | 180 plate | 140 | 120.8±26.3 | (Yildirim et al., 2000) |
| Hansatome | 180 | 15 | 167.4±21.4 CM | (Gokmen et al., 2002) |

*Table continues*

| Microkeratome | Intended or set flap thickness (µm) | No. of eyes in the study | Achieved flap thickness (µm) Mean±SD | Reference |
|---|---|---|---|---|
| Hansatome | 180 head | 41 | 131±28 | (Miranda et al., 2003) |
| Hansatome | 160 plate thickness | 20 | 134.9± 24.9 CM | (Javaloy et al., 2004) |
| Hansatome | 160 | 194 | 129±21 | (Solomon et al., 2004) |
| | 180 | 283 | 136±25 | |
| Hansatome | 180 plate thickness | 143 | 156±29 | (Kezirian and Stonecipher, 2004) |
| Hansatome | 160 head | 641 | 116.4±19.8 | (Giledi et al., 2004) |
| | 180 | 116 | 117.3±18.0 | |
| Hansatome | 160 head | 138 | 124.1±17.4 | (Choudhri et al., 2005) |
| | 180 | 112 | 142.3±19.6 | |
| Hansatome | 160 head | 89 | 97± 18 | (Taneri, 2006) |
| | 180 | 128 | 111±20 | |
| | 200 | 21 | 131±20 | |
| Hansatome | 160 head | 41 | 128.9±20.4 | (Pepose et al., 2007) |
| | 180 | 34 | 143.3±21.0 | |
| Hansatome | 180 | 21 | 138±22 | (Patel et al., 2007) |
| Hansatome | 160 setting | 12 | 116±10 ultrasound<br>125±12 OCT | (Li et al., 2007) |
| | 180 | 24 | 131±17 ultrasound<br>143±14 OCT | |
| Hansatome | 160 | 20 | 149.1±24.9 | (Rosa et al., 2009) |
| **Innovatome** | 170 blade | 148 | 138.8±23.5 | (Choi et al., 2000) |
| | 190 | 120 | 148.3±25.4 | |
| **Moria LSK-One** | 160 (130 footplate) | 93 | 159±28 | (Jacobs et al., 1999) |
| LSK-One | 160 | 151 | 161±38 | (Srivannaboon, 2001) |
| LSK-One | 100 head | 924 | 139.2±27.4 | (Asano-Kato et al., 2002) |
| | 130 | 2255 | 152.2±23.5 | |
| LSK-One | <100 | 105 | 84.8±10.0 | (Cobo-Soriano et al., 2005) |
| | 100-129 | 122 | 111.0± 8.4 | |
| | >130 | 53 | 141.5±14.0 | |
| LSK-One | 100 head | 42 | 107±14 | (Duffey, 2005) |
| LSK-One | 160 (130 plate) | 25 | 151.7±26.4 central<br>161.9±26.4 superior<br>156.1±23.3 temporal<br>167.5±20.4 nasal<br>151.4±21.4 inferior | (Guell et al., 2005) |
| LSK-One | 160 (130 head) | 18<br>18 | 161 right VHF<br>166 left | (Reinstein et al., 2006) |
| LSK-One | 160 | 100 | 130±19 | (Talamo et al., 2006) |
| **Moria M2** | 110 head | 257 | 134±23 | (Miranda et al., 2003) |
| M2 | 110 head (slow translation speed) | 30<br>30 | 151.6±24.0 right<br>148.5±24.3 left | (Muallem et al., 2004) |
| | 110 head (fast translation speed) | 43<br>43 | 136.2±25.5 right<br>132.8±23.5 left | |
| | 130 head (fast translation speed) | 110<br>110 | 145.8±25.4 right<br>139.9±25.5 left | |
| M2 | 130 plate thickness | 140 | 146±32 | (Solomon et al., 2004) |
| M2 | 160 (130 head) | 20 | 147.6±15.4 CM | (Javaloy et al., 2004) |

*Table continues*

| Microkeratome | Intended or set flap thickness (µm) | No. of eyes in the study | Achieved flap thickness (µm) Mean±SD | Reference |
|---|---|---|---|---|
| M2 | 160 (130 plate) | 25 | 131.7±29.0 central<br>155.5±36.9 superior<br>143.7±36.9 temporal<br>160.5±42.4 nasal<br>146.7±36.8 interior | (Guell et al., 2005) |
| M2 | 130 (single-use head) | 100 | 145±17.5 | (Kanellopoulos et al., 2005) |
| M2 | 130 | 135 | 142±24 | (Talamo et al., 2006) |
| M2 | 160 (head 130) | 10 | 148.0±16.7 CM | (Javaloy et al., 2007) |
| M2 | 90 (single-use head) | 52<br>52 | 109±18 right eye<br>103±15 left eye | (Aslanides et al., 2007) |
| M2 | 110 head | 22 | 117.5±7.8 | (Alio and Pinero, 2008) |
| M2 | 130 | 52 | 126.0±19.9 Central Horizontal OCT | (Ahn et al., 2011) |
| **Nidek MK 2000** | 160 head | 12 | 149.6±25.6 | (Vongthongsri et al., 2000) |
| MK 2000 | 130 plate | 148 | 120.5±16.5 8.5-mm ring | (Naripthaphan and Vongthongsri, 2001) |
| | 130 | 32 | 122.1±18.5 9.5-mm ring | |
| | 160 | 20 | 172.7±27.5 8.5-mm ring | |
| MK-2000 | 130 plate holder | 31 | 109.3±13.3 8.5-mm ring | (Sarkisian and Petrov, 2001) |
| | 160 | 25 | 106.7±15.3 9.5-mm ring | |
| MK 2000 | 130 depth plate<br>130<br>160<br>160 | 158<br>46<br>98<br>68 | 129±21.8 model 121<br>152±25 model 65<br>150±29.6 model 121<br>173±26.9 model 65 | (Schumer and Bains, 2001) |
| MK 2000 | 130 depth plate | 24<br>24 | 127.3±4.1 right eye<br>127.5±3.7 left eye | (Shemesh et al., 2002) |
| MK 2000 | 130 head<br>160 | 164<br>164 | 116.0±19.3<br>147.7±21.7) | (Arbelaez, 2002) |
| MK 2000 | 130 head<br>160 | 853<br>821 | 111.7±18.0<br>140.3±23.1 | (Asano-Kato et al., 2002) |
| MK 2000 | 130 plate thickness<br>145<br>160 | 118<br>61<br>81 | 111±19<br>103±15<br>121±20 | (Solomon et al., 2004) |
| **SCMD** | 150±15 plate | 69 | 137.2±33.7 | (Yi and Joo, 1999) |
| **SKBM** | 160 | 78 | 154.9±19.3 | (Ucakhan, 2002) |
| SKBM | 160 | 2652 | 160.9±24.1 | (Flanagan and Binder, 2003) |
| SKBM | 160 head | 127 | 162±21 | (Miranda et al., 2003) |
| SKBM | 160 plate thickness | 149 | 143±23 | (Solomon et al., 2004) |
| **Zyoptix XP** | 120 head<br>140 | 41<br>34 | 126.5±14.6<br>143.7±15.0 | (Pepose et al., 2007) |
| Zyoptix XP | 120 | 62<br>62 | 115.3±16.3 right<br>104.6±14.3 left | (Ho et al., 2007) |
| Zyoptix XP | 120 | 20 | 124.7±23.8 | (Rosa et al., 2009) |

*ACS, Automated Corneal Shaper from Chiron Vision, Irvine, CA/Bausch & Lomb Surgical, Claremont, CA, USA*
*Amadeus from Advanced Medical Optics, Santa Ana/Irvine, CA, USA*
*Carriazo-Barraquer (CB) from Moria SA, Antony, France*
*Carriazo-Pendular, SCHWIND eye-tech-solutions, Kleinostheim, Germany*
*CM, confocal microscopy*
*CMTF, confocal microscopy through-focusing*
*Hansatome from Bausch & Lomb Surgical, Salt Lake City, Utah; USA*
*Innovatome, Innovative Optics, New Mexico, USA*

*Table explanations continue*

*Moria LSK-One, Model Two (M2) from Moria SA, Antony, France*
*N/A, not available*
*Nidek MK-2000 from Nidek, Gamagori, Japan*
*OCT, optical coherence tomography*
*SCMD from United Development Corp., Fountain Hills, Ariz., USA*
*SKBM, Summit Krumeich Barraquer microkeratome from Alcon Laboratories, Forth Worth, Texas, USA*
*Subtraction ultrasound pachymetry, difference between preoperative corneal thickness and the thickness of corneal bed after flap lifting*
*VHF, very high-frequency digital ultrasound*
*Zyoptix XP from Bausch & Lomb, Rochester, New York, USA*

The most popular means to measure flap thickness is subtraction ultrasonic pachymetry (Price et al., 1999; Lipshitz and Dotan, 2000; Ambrosio et al., 2003). Other methods to measure flap thickness include very high-frequency (VHF) ultrasound scanning, confocal microscopy, ultrasound biomicroscopy, optical coherence tomography, and partial coherence interferometry. However, these methods can only be used pre- and postoperatively. Despite its poorer precision, ultrasonic pachymetry provides the most practical means in clinical use to measure corneal thickness intraoperatively.

The flap thickness created with mechanical microkeratomes has been found to be affected with many preoperative factors such as patient age, preoperative corneal thickness, and corneal curvature. Some studies have shown that younger patients tend to have thicker flaps (Flanagan and Binder, 2003), and that thicker corneas tend to create thicker flaps (Yi and Joo, 1999; Yildirim et al., 2000; Gailitis and Lagzdins, 2002; Flanagan and Binder, 2003; Ucakhan, 2002). Increasing flap thickness has been found to be associated with flatter keratometric values in the ACS microkeratome (Flanagan and Binder, 2003). On the other hand, in the SKBM microkeratome steeper corneal curvature has been found to be associated with thicker flaps (Flanagan and Binder, 2003).

### *2.3.3. Femtosecond laser keratomes*

Femtosecond laser keratomes represent the most recent development for corneal flap creation. The femtosecond laser achieves corneal dissection through micro-photodisruption at the predetermined depth using small pulses. The pulses are applied in a raster or spiral pattern across the surface, resulting in an almost completely planar flap (Kurtz et al., 1997). Infrared laser pulses are emitted through the transparent cornea. When photons with short duration and high power meet in the same spot, they are absorbed by the corneal tissue. This absorption process ionizes the tissue and thus generates free electrons. The produced plasma expanses and microcavitation causes disruption of the cornea at the focal point (Lubatschowski, 2008).

Commercially available femtosecond lasers are produced and marketed by Intralase (Intralase, now marketed by Advanced Medical Optics, Irvine, CA; USA), 20/10 Perfect Vision (FEMTEC, Heildelberg, Germany), Ziemer Ophthalmic Systems (FEMTO LDV, Port, Switzerland), and Carl Zeiss Meditec (VisuMax, Jena, Germany). Intralase was the first femtosecond laser keratome to be introduced in the United States in 2001 (Sugar, 2002). Shortly after the market launch of Intralase, 20/10 Perfect Vision was introduced, following FEMTO LDV in late 2005 and VisuMax in fall 2006 (Lubatschowski, 2008). The systems can be classified in two groups: one group is characterized with high pulse energy-low pulse frequency (Intralase and FEMTEC) and the other with low pulse energy-high pulse frequency (FEMTO LDV) (Lubatschowski, 2008). In the high pulse energy-low pulse frequency group, pulse energies are in the range of 1 μJ and repetition rates of the order of kHz. The low pulse energy-high pulse frequency system delivers only pulse energy of the order of nJ and uses MHz repetition rates.

A number of recently published studies with Intralase demonstrate the advantages of femtosecond lasers over mechanical microkeratomes. As the standard deviations of flap thickness in the studies conducted with mechanical microkeratomes vary around 20 μm and more (Table 2), femtosecond lasers cut more accurately and have lower standard deviations (Table 3). Furthermore, equal or better visual outcomes in the early postoperative phase are reported with Intralase femtosecond laser (Kezirian and Stonecipher, 2004; Durrie and Kezirian, 2005; Javaloy et al., 2007; Patel et al., 2007). The induced astigmatism and high-order aberrations were found smaller or equal compared to microkeratome flaps (Tran et al., 2005; Krueger and Dupps, Jr., 2007; Montes-Mico et al., 2007; Buzzonetti et al., 2008). The recovery of corneal sensitivity has been found to be faster with femtosecond laser (Lim et al., 2006).

Table 3. Flap thickness with femtosecond laser keratomes in clinical studies. Flap thickness was measured with subtraction ultrasound pachymetry, exceptions are mentioned in the table.

| Femtosecond laser | Intended or set flap thickness (µm) | No. of eyes in the study | Achieved flap thickness (µm) Mean±SD | Reference |
|---|---|---|---|---|
| **FEMTO LDV** | 110 | 111 | 106.6±12.6 | (Vryghem et al., 2010) |
| FEMTO LDV | 110 | 64 | 105.8±8.2 Central horizontal OCT | (Ahn et al., 2011) |
| **Intralase** 10 kHz | 110 | 34 | 125.0±12.0 | (Binder, 2004) |
| | 120 | 22 | 122.4±11.9 | |
| | 130 | 21 | 128.7±16.6 | |
| | 140 | 26 | 132.5±18.5 | |
| Intralase 10 kHz | 130 | 106 | 114±14 | (Kezirian and Stonecipher, 2004) |
| Intralase 10 kHz | 80 | 13 | 115.8±10.2 | (Binder, 2006) |
| | 90 | 320 | 119.2±12.4 | |
| | 100 | 140 | 129.7±14.3 | |
| | 110 | 49 | 127.4±15.2 | |
| | 120 | 31 | 133.4±22.1 | |
| | 130 | 25 | 129.6±17.1 | |
| | 140 | 38 | 130.6±19.0 | |
| Intralase 15 kHz | 90 | 249 | 115.8±10.8 | (Binder, 2006) |
| | 100 | 82 | 120.1±11.8 | |
| | 110 | 21 | 131.1±10.2 | |
| Intralase 10 kHz | 110 | 99 | 119±12 | (Talamo et al., 2006) |
| Intralase 15 kHz | 120 | 10 | 129.4±3.4 CM | (Javaloy et al., 2007) |
| Intralase 15 kHz | 120 | 21 | 143±16 CM | (Patel et al., 2007) |
| Intralase 15 kHz | 115-125 | 15 | DIFT 16.8±11.1 CM | (Hu et al., 2007) |
| Intralase 30 kHz | 115-120 | 15 | DIFT 13.9±7.1 CM | |
| Intralase 30 kHz | 110 | 22 | 115.95±6.2 | (Alio and Pinero, 2008) |
| Intralase 60 kHz | 100 | 36 | 106.2±12.8) OCT | (Kim et al., 2008) |
| | 110 | 23 | 117.8±7.8 OCT | |
| Intralase 10 kHz | 110 setting | 7 | 140±11 ultrasound<br>145±9 OCT | (Li et al., 2007) |
| | 120 | 8 | 160±19 ultrasound<br>156±11 OCT | |
| Intralase 15 kHz | 105 | 119 | 116.79±10.75 | (Sutton and Hodge, 2008) |
| Intralase 30 kHz | 115 | 141 | 114.02±9.82 | |
| Intralase 60 kHz | 120 | 20 | 143.1±18.4 | (Rosa et al., 2009) |
| Intralase 60 kHz | 110 | 50 | 130.3±13.2 Central horizontal OCT | (Ahn et al., 2011) |
| **Visumax** | 110 | 24 | 112.3±7.9 VHF | (Reinstein et al., 2010) |
| Visumax | 110 | 40 | 133.9±13.9 Central horizontal OCT | (Ahn et al., 2011) |
| Visumax | 110 | N/A | 112.8±3.95 OCT | (Ju et al., 2011) |
| | 120 | N/A | 122.5±3.98 OCT | |

*CM, confocal microscopy*
*DIFT, difference between actual flap thickness and intended flap thickness*
*FEMTO LDV from Ziemer Ophthalmic Systems Port, Switzerland*
*Intralase FS from Intralase /Advance Medical Optics (AMO), Irvine, CA, USA*
*N/A, not available*
*OCT, optical coherence tomography*
*Subtraction ultrasound pachymetry, difference between preoperative corneal thickness and the thickness of corneal bed after flap lifting*
*VisuMax from Carl Zeiss Meditec, Jena, Germany*

The biomechanical research by Marshall, Alio and colleagues (Baldwin and Marshall, 2002; Alio et al., 2000) and the growing concern about over post-LASIK keratoectasia has led many surgeons to return to surface ablation techniques (Slade, 2007). Although biomechanically more stable, these techniques have other disadvantages such as pain, haze, and slower visual recovery. A new keratomileusis that combines the biomechanical stability of surface ablation and the pain-free experience of LASIK is described as the sub-Bowman's keratomileusis (SBK) (Slade, 2007). A customized corneal flap is created with femtosecond laser. The flap diameter is based on the requirements of the patient, and an intended flap thickness varies from 90 to 110 µm. SBK aims to preserve as much Bowman's membrane as possible while avoiding disruption of lamellae in the periphery of the cornea. Early results have shown less inflammation and less dry eyes with SBK treatment (Slade, 2007).

### *2.3.4. LASIK complications*

Early intraoperative complications may result from excessive anesthetics, conjunctival chemosis, or the improper draping of eyelashes (Dayanir and Azar, 2004). Excessive anesthetics can cause superficial punctuate keratopathy (SKP) or frank epithelial defects (Melki and Azar, 2001). Conjunctival chemosis may lead to poor coupling of the suction ring to the sclera and cause an improper raising of the intraocular pressure for safe lamellar cutting. The creation of the corneal flap is a critical step since flap complications can potentially, although rarely, lead to complications and even to significant loss of the quality of vision (Ambrosio, Jr. and Wilson, 2001; Wilson, 1998). In clinical studies including more than 1,000 eyes, the incidence of intraoperative flap complications during LASIK with mechanical microkeratomes has been reported to range from 0.3 to 8.6% (Gimbel et al., 1998; Stulting et al., 1999; Lin and Maloney, 1999; Jacobs and Taravella, 2002; Lin et al., 2003). The increased volume of LASIK procedures has led to a rise in a variety of complications with conventional microkeratomes (Table 4). Postoperative flap-related complications include poorly created or wrinkled flaps (Wilson, 1998), and late flap dislocations (Melki et al., 2000).

Table 4. Corneal complications reported with conventional microkeratomes (see Ambrosio, Jr. and Wilson, 2001; Binder, 2006).

| |
|---|
| Inadequate alignment with astigmatism axis |
| Complications due to improper microkeratome assembly or defective blades |
| Decentered flaps |
| Irregular-shaped flaps |
| Incomplete flaps |
| Buttonhole flaps |
| Free caps |
| Flap laceration |
| Epithelial defects |
| Limited hinge location |
| Intraoperative bleeding |
| Intersecting microkeratome cuts |
| Poor flap thickness predictability |
| Wide range of flap thickness for an intended flap thickness |
| Achieved flap thickness less than intended |
| Flaps centrally thinner than peripherally |
| Variable hinge length |
| Blade quality affects flap thickness: second flap thinner when the same blade is used for both eyes |
| Flap thickness dependent on translation speed: faster translation creates thinner flaps |
| Sensitivity to preoperative corneal thickness: thicker corneas create thicker flaps |
| Sensitivity to preoperative corneal curvature: steeper corneas create thinner flaps |
| Gap width of microkeratome head variable affects flap thickness predictability |
| Corneal perforation with older microkeratome models |

Postoperative complications include decentration (Melki and Azar, 2001), central island (Tsai and Lin, 2000), diffuse lamellar keratitis (DKL) (Smith and Maloney, 1998), epithelial ingrowth within the flap interface (Walker and Wilson, 2000; Wilson, 1998), infectious keratitis (Sridhar et al., 2000; Garg et al., 2001), dry-eye symptoms (Yu et al., 2000; Tuisku et al., 2007), and iatrogenic keratectasia (Seiler et al., 1998; Pallikaris et al., 2001; Randleman, 2006; Wang et al., 1999). Other complications include striae, flap dislocations, interface debris, and LASIK-induced neurotrophic epitheliopathy (Ambrosio, Jr. and Wilson, 2001).

Preliminary studies with the Intralase femtosecond laser demonstrate that free flaps, irregular flaps, microperforations, decentered flaps, epithelial defects, and abrasions are significantly reduced or eliminated (Kezirian and Stonecipher, 2004; Binder, 2004; Stonecipher et al., 2006b; Durrie and Kezirian, 2005). The standard deviation of achieved flap thickness with femtosecond lasers has also been found to be narrower than with mechanical systems. As mechanical microkeratomes tend to create meniscus-shaped flaps that are thinner in the center and thicker in the periphery, femtosecond lasers tend to create more uniform planar flaps (Binder, 2006). Certain side effects are unique to the femtosecond laser (Table 5), such as transient light sensitivity syndrome (Stonecipher et al., 2006b; Munoz et al., 2006), increased corneal backscatter (Patel et al., 2007), and transient opaque bubble layers, especially with Intralase (Lifshitz et al., 2005; Srinivasan and Rootman, 2007; Srinivasan and Herzig, 2007; Kaiserman et al., 2008). The incidence of transient light sensitivity syndrome and transient opaque bubble layers have been reduced with lower energies used. In some cases of FEMTO LDV, microcrests on the corneal bed have been observed.

Table 5. Corneal complications reported with femtosecond lasers (see Lifshitz et al., 2005; Munoz et al., 2006; Patel et al., 2007).

| |
|---|
| Transient opaque bubble layers |
| Transient light sensitivity syndrome |
| Increased corneal backscatter |
| Microcrests on the corneal bed |
| Diffuse lamellar keratitis |
| Bubble escape into anterior chamber |

The ultimate goal of the evolution of LASIK from mechanical systems to femtosecond laser technology has been to provide the patients the best possible visual and refractive outcomes with as few complications as possible. However, it should be reminded that for making valid comparisons between femtosecond lasers and conventional microkeratomes, both contemporary and long-term studies are needed to compare modern microkeratomes to femtosecond lasers.

## 2.4. Other excimer laser technologies

### *2.4.1. Laser-assisted epithelial keratomileusis (LASEK)*

In 1996, Azar performed the first laser-assisted epithelial keratomileusis (LASEK) procedure, which he called “alcohol assisted flap PRK” (Azar et al., 2001). Later it was renamed LASEK by Camellin, who popularized his own technique (Camellin, 2003). Camellin reported that LASEK combines the advantages and eliminates the disadvantages of PRK and LASIK. Long-term reports are necessary to support this hypothesis. In LASEK, an epithelial flap is detached after about 30-sec application of an alcohol solution (typically 18-25%) and repositioned after laser ablation as in the LASIK procedure. The epithelium is partially removed from Bowman’s layer, connected by a hinge. Laser treatment is applied directly to the Bowman’s layer, the epithelium is replaced and covered by bandage contact lens. The hypothese is that the epithelial flap decreases changes in stromal keratocytes and reduces the production of extracellular matrix and collagen (Shah et al., 2001). Postoperatively, patients treated with LASEK are reported to have less postoperative pain, reduced haze, faster epithelial healing, and better visual acuity than in PRK-treated patients (Dastjerdi and Soong, 2002; Litwak et al., 2002; Shahinian, Jr., 2002; Anderson et al., 2002; Feit et al., 2003; Taneri et al., 2004). According to a recent literature review, epithelial closure with recovery of functional vision is completed in 4-7 days in most LASEK-treated eyes (Taneri et al., 2004). The authors also reported a tendency towards overcorrection with PRK nomograms. This tendency may be due to the decreased wound healing response, which may lead to myopic regression in PRK. Postoperative pain and prolonged visual recovery until the epithelium closes are the main disadvantages of LASEK compared to LASIK (Taneri et al., 2004). Thousands of cases with the same laser will be needed to determine that LASEK is associated with lower incidence of late haze than PRK (Ambrosio, Jr. and Wilson, 2003).

#### *2.4.2. Phototherapeutic keratectomy (PTK)*

Therapeutic refractive surgery has benefited from the development of RK, PRK, and LASIK. Phototherapeutic keratectomy (PTK) has been performed for at least 20 years (Dausch and Schröder, 1990; Sher et al., 1991; Gartry et al., 1991; Stark et al., 1992). Definitions of PTK may vary, but essentially it means excimer laser surgery in eyes with superficial opacities, surface irregularities or refractive errors due to disease, trauma or previous refractive surgery (Fagerholm, 2003). Several treatment principles are employed in PTK. The most common is plano treatment, employed to remove epithelium, basal membrane alteration, parts of Bowman's layer or a superficial stromal opacification. Recurrent corneal erosions and superficial corneal dystrophies represent the most common indications of PTK (Fagerholm, 2003).

### 2.5. Other techniques to correct refractive errors

#### *2.5.1. Intrastromal corneal ring segments (ICRS)*

In 1949, Barraquer first tried to implant material in the corneal to correct refractive errors (Burris, 1998). Since then, many materials have been tested for their biocompatibility. In 1978, an implantable corneal 360° ring for correcting myopic errors was introduced by Reynolds (Schanzlin, 1999). In 1991, phase I of human clinical studies was initiated on nonsighted eyes (Twa et al., 1999). A 330° polymethyl methacrylate (PMMA) intrastromal corneal ring (ICR) was developed to correct myopia. A 2-year phase II trial for the device was initiated in 1995 (Schanzlin et al., 1997). The design of the full-ring (KeraVision ICR, Fremont, CA) product was subsequently modified to facilitate its placement, and currently it comprises two 150° crescent-shaped inserts (Rapuano et al., 2001). Unlike ablational techniques with the excimer laser, intrastromal corneal ring segments (ICRS) spare the visual axis (Guell, 2005). There is no essential risk of haze or scarring. No tissue is removed from the cornea, but two PMMA ring segments are inserted into the peripheral stroma. The advantages of this technology compared to PRK and LASIK also include the possibility to remove the device, probably to reverse treatment effects and to achieve correction by varying the thickness of the device (Nose et al., 1996). The long-term data on ICRS in the correction of low and moderate myopia indicate that they may be comparable with LASIK (Guell, 2005). ICRS have become common to be used to reshape keratoconic corneas (Ertan and Colin, 2007). Nowadays, femtosecond lasers are used to dissect channels inside the cornea.

### *2.5.2. Conductive keratoplasty (CK)*

Conductive keratoplasty (CK) is used for the correction of hyperopia, hyperopic astigmatism, and the management of presbyopia by using controlled release of low-level radiofrequency (RF) energy, instead of a laser, to reshape the cornea (Du et al., 2007). The procedure was first used by Mendez and colleagues in 1993. Since FDA approval in 2002, conductive keratoplasty has become a promising technique to correct low to moderate hyperopia and astigmatism. It is a nonlaser, no cutting procedure that delivers RF energy to corneal stroma in a circular fashion to steepen the cornea. It is an alternative to laser-based refractive surgery with essentially no intraoperative or postoperative complications.

### *2.5.3. Astigmatic incisions*

Astigmatic keratotomy (AK) is used for the correction of high astigmatism. Although AK is rarely used, it is one of the few incisional keratotomy procedures that are still in use after the introduction of laser refractive surgeries (Assil et al., 2009). AK has remained a choice for the correction of high astigmatism that is beyond laser correction, or for the correction of lesser degrees of astigmatism in patients undergoing cataract surgery. For AK, the surgeon must screen surgical candidates for myopic and planospherical equivalents (Assil et al., 2009). The axis of astigmatism is important for the placement of AK incisions. The effect of incisional keratotomy is influenced by corneal wound healing and patient age (Assil et al., 2009). Complications of incisional keratotomy may be reduced by the adequate marking of the visual axis, adequate corneal incision shape and depth, and the avoidance of corneal perforations (Assil et al., 2009). Postoperative complications include progressive hyperopia, induced astigmatism, and contact lens intolerance (Assil et al., 2009). Femtosecond laser arcuate keratotomy is an effective alternative to AK. Limbal relaxing incisions (LRI) and arcuate corneal incisions are also used for the reduction of pre-existing corneal astigmatism at the time of cataract surgery (Rosen, 2009).

### *2.5.4. Clear lens extraction (CLE)*

Clear lens extraction (CLE), also called refractive lens exchange (RLE), means removal of a noncataractous natural lens of the eye with or without intraocular lens placement as a refractive procedure. CLE is usually used for patients with high myopia (>8 D) that is not easily managed by other refractive procedures (LASIK, PRK). However, CLE may be an even better choice for patients with high hyperopia (>4 D) than for patients with myopia, because of the smaller risk of postoperative retinal detachment and the fewer modalities available to treat patients with high hyperopia. Current evidence shows that the risk of retinal detachment after clear lens extraction for myopes is increased (O'Brien and Awwad, 2002; Packard, 2005).

### *2.5.5. Phakic intraocular lenses (PIOL)*

Phakic intraocular lenses (PIOL), which are located closer to the eye’s nodal points than to the anterior corneal surface, can provide superior optical quality for higher corrections because of retention of normal prolate corneal asphericity and larger effective optical zones (Dick and Tehrani, 2004). This procedure differs from CLE in that the eye's natural lens is left in place. Like CLE, this procedure is used primarily to treat moderate or high myopia and in the cases when there are corneal changes such as thin corneas. Improvements in the material and design of PIOLs and their insertion devices combined with advances in the understanding of the anatomical and physiological interactions with intraocular structures have increased the safety and efficacy of PIOLs. The long-term safety of these implants still remains a concern, but in several situations PIOLs are the refractive correction of choice.

## 3. AIMS OF THE STUDY

The aims of the study were to evaluate the accuracy, the predictability as well as the complications and factors that influence the dimensions of LASIK corneal flap created with different automated microkeratomes, a single-use microkeratome or a femtosecond laser and compare them with reoperations performed with a femtosecond laser after previous LASIK procedure. The specific aims were:

1. To evaluate accuracy, predictability and factors that influence the dimensions of LASIK corneal flap created with the Moria Model Two (M2) head 130 microkeratome (Moria SA, Antony, France) (I)
2. To compare complications, accuracy, predictability and safety of the procedure of LASIK corneal flaps created with the Moria M2 microkeratome with the head 130 to a disposable single-use head (II)
3. To analyze the accuracy of corneal flap thickness created using Moria M2 single-use head 90 microkeratome (III)
4. To compare potential factors that affect the accuracy of flap thickness created using the Moria M2 head 130 microkeratome with the Med-Logics calibrated blades Minus 20 (ML-20) and Minus 30 (ML-30) (Med-Logics, Inc., Laguna Hills, CS, USA) (IV)
5. To present the corneal flap characteristics and short-term efficacy and safety of the eyes operated with the FEMTO LDV femtosecond laser (Ziemer Ophthalmic Systems, Port, Switzerland) (V)
6. To present the outcomes of LASIK enhancements performed with the FEMTO LDV femtosecond laser following previous LASIK treatments in terms of accuracy, predictability, and safety (VI).

# 4. PATIENTS AND METHODS

All the eyes were operated by the author. The patients' inclusion criteria followed Kirurgipalvelu/Mehiläinen Eye Surgery Clinic's regular criteria for LASIK procedure: age $\geq$18 years, stable refraction, no keratoconus, no pregnancy at the time of the operation, no cardiac pacemaker, no corneal dystrophies, no cataract, and no proliferative retinopathy. The studies were made retrospectively and the consecutive data were collected from the database.

## 4.1. Study design and surgical techniques

### *4.1.1. Study design*

The studies I-V were conducted at Mehiläinen Kirurgipalvelu Eye Surgery Clinic, Tampere, Finland. The Study VI included Mehiläinen Eye Surgery Clinics' patients, but from both Tampere and Helsinki. The patients in Studies I-V had no earlier refractive operations and the patients in Study VI were previously treated with LASIK. In Studies I-IV the patients were treated with a microkeratome and in Studies V-VI with a femtosecond laser (Table 6). In Moria M2 microkeratome, the suction ring was chosen according to the manufacturer's monogram based on the keratometric value $K_1$.

In Study II, one eye was operated with the Moria reusable metallic head 130 and the other eye with a plastic single-use head, both designed to create a 160-µm flap.

In Study IV, 100 eyes underwent flap creation with the Moria M2 head 130 microkeratome (intended to create 160-µm corneal flap) adjusted with the single-use Med-Logics calibrated LASIK blade (Med-Logics, Inc., Laguna Hills, CS, USA) Minus 20 (ML-20 cohort), designed to create a flap of the thickness 140 µm. The other 100 eyes were treated with the Moria M2 head 130 microkeratome adjusted with the Med-Logics calibrated LASIK blade Minus 30 (ML-30 cohort), designed to create a flap of the thickness 130 µm. In additional 40 eyes, the left eye was operated first to evaluate whether the measurements were affected by the sequence of operation.

In Study V, to evaluate the surgeon's learning curve, the first 62 eyes operated during the first month (August 2007) were analyzed as a separate group.

Table 6. Summary of the original publications.

| **Study** | **Number of patients** | **Number of eyes** | **Time of operations** | **Microkeratome or femtosecond laser** | **Intended flap thickness (µm)** |
|---|---|---|---|---|---|
| I | 243 | 454 | 8/2001 to 11/2002 | Moria M2 automated microkeratome head 130 | 160 |
| II | 49 | 98 | 8/2003 to 10/2003 | Moria M2 microkeratome reusable or single-use head 130 | 160 |
| III | 150 | 300 | 9/2004 to 2/2005 | Moria M2 microkeratome single-use head 90 | 120 |
| IV | 100 | 200 | 11/2005 to 1/2006 | Moria M2 head 130 microkeratome adjusted with the Med-Logics calibrated blade ML-20 or ML-30 | 140 or 130 |
| V | 405 | 787 | 8/2007 to 6/2008 | FEMTO Leonardo Da Vinci LDV femtosecond laser | 110 |
| VI | 62 | 85 | 8/2007 to 5/2010 | FEMTO LDV femtosecond laser | 90 |

*FEMTO Leonardo Da Vinci LDV femtosecond laser (Ziemer Ophthalmic Systems, Port, Switzerland)*
*Med-Logics calibrated LASIK blade (Med-Logics, Inc., Laguna Hills, CA, USA)*
*Moria M2 automated microkeratome (Moria SA, Antony, France)*

### *4.1.2. Preoperative examinations*

Preoperatively, all the patients had a complete ophthalmic examination, which included slit-lamp microscopy, corneal topography (TMS 2 upgraded; Computed Anatomy Inc, New York, NY, USA for studies I-III, or Allegro Topolyzer; Wavelight AG, Erlangen, Germany for studies IV-VI), determination of refraction by fogging method without sykloplegy, (however, for young hyperopic patients, the measurement of sykloplegic refraction was included), uncorrected visual acuity (UCVA) and best spectacle-corrected visual acuity (BSCVA) using Snellen Visual Acuity Chart, measurement of intraocular pressure (IOP) using applanation tonometer (Topcon Computerized Tonometer; Topcon Corp, Tokyo, Japan for studies I-IV, or Tonoref RKT-7700; NIDEK Co Ltd, Gamagori, Japan for studies V-VI) and wavefront analysis (WASCA; Asclepion-Meditech AG, Jena, Germany for studies I-III, or Allegretto Analyzer, Wavelight AG for studies IV-VI)..

Preoperatively, topical anesthetic oxybuprocain hydrochloride (Oftan Obucain; Santen Oy, Tampere, Finland) was instilled into the operated eyes.

#### 4.1.3. *Microkeratome-assisted LASIK (I-IV)*

The suction ring was chosen according to the manufacturer's recommendations (nomogram) based on the keratometric value $K_1$. The suction vacuum level was adjusted according to the manufacturer's nomograms so that the IOP increased during the suctioning phase, reaching a mean of 122.52 ± 30.40 and 160.52 ± 22.73 mm Hg during the cutting phase (Hernandez-Verdejo et al., 2007). The right eye was operated before the left eye using the same blade.

In Study II, before the operation, a notepaper representing either a metallic head or a single-use head was randomly picked by the surgeon's assistant. The right eye was operated first with the microkeratome type thus chosen.

For the laser ablation of the stromal bed, the Meditec MEL70 G-scan excimer laser (Aesculap-Meditec) (I-II), the Meditec MEL80 G-scan excimer laser (Carl-Zeiss-Meditech, Jena, Germany) (III) or the Allegretto Wave Eye-Q excimer laser (Wavelight AG) (IV) were used.

#### 4.1.4. *Femtosecond laser-assisted LASIK (V-VI)*

In Study V, LASIK flap was created with the FEMTO Leonardo Da Vinci LDV femtosecond laser (Ziemer Ophthalmic Systems, Port, Switzerland) using the intended flap thickness of 110 µm. In Study V, in most eyes, an aspirating speculum was used for eyelid opening. In 49 (6.2%) small eyes in which the cone of the FEMTO LDV did not fit, a Barraquer speculum was used. In 6 (0.8%) very small, deep set eyes canthotomy was also performed.

Before flap cutting, the surgical assistant prepared the FEMTO LDV by assembling the sterile parts of the hand piece including hand piece cover, InterShield determining flap thickness, suction ring determining flap diameter, and suction tubing and input of the patient's data. Flap thickness was determined by choosing a desired InterShield spacer (a plastic foil between the laser and the cornea) according to the patient's eyes. The InterShield could be chosen between two choices: 140 µm and 110 µm. Later the 110-µm foil was changed to induce 90-µm corneal flap thickness (VI). The individual preset vacuum levels ranged from 700 to 800 mbar (mostly 750 mbar), depending on the curvature of the cornea. The articulated hand piece, including the precisely guided cutting head, was connected to the main laser by counterbalanced mirror arm, and was positioned on the operated eye. With the help of the microscope of the excimer laser, the surgeon centered the hand piece on the patient's eye so that the pupil was in the center of the planned ablation area.

The cutting speed was set between 27 and 30 seconds. The time to create a flap from suction-on to suction-off is about 40 seconds. The attempted flap diameter varied from 8.5 mm to 9.5 mm, however, in most cases it was 9.0 mm. In bilateral operations, the same distance foil was used for both eyes.

In Study VI, the aimed flap thickness with the FEMTO LDV femtosecond laser was 90 µm in most of the eyes (81 eyes) expect for 3 eyes that were cut with the 140-µm foil. In Study VI, an aspirating speculum was used for eyelid opening in most of the eyes. Barraquer wired speculum was used in four (4.7%) small eyes that did not fit otherwise into the cone of the FEMTO LDV femtosecond laser. In one eye (case report 1), two flaps were made, the first with the 90-µm foil and the second one with 140-µm foil. The size of the suction ring was typically 9.0 mm (72 eyes), but in very flat eyes it was 9.5 mm (13 eyes). The flap was opened with the Seibel I Intralase & Retreatment Spatula so that the instrument was inserted under the flap at the position of 11 o'clock, was pulled through at 1 o'clock position, and pushed at 6 o'clock position. The flap was lifted and taco-folded at 12 o'clock position.

Stromal bed was ablated using the Allegretto Wave Concerto 500 Hz excimer laser (Wavelight AG). All operations were wavefront-optimized.

#### *4.1.5. Corneal thickness measurements*

In Studies I-III, the corneal thickness was measured with the CILCO ultrasonic pachymetry (CILCO Inc.; Huntington, WV, USA). The speed of the sound of the ultrasonic pachymetry was 1623 m/s. In Studies IV-VI, the Tomey ultrasonic pachymetry (SP-3000; Tomey Corp., Nagoya, Japan) was used. The speed of the sound of this ultrasonic pachymetry was 1640 m/s. Flap thickness was calculated by subtracting the remaining central stromal thickness after flap cutting, measured by pachymetry, from the preoperative central corneal thickness (subtraction method). The median of the three measurements before and after the cut was recorded. No moistening drops were used to obtain pachymetry readings.

### *4.1.6. Measurements of corneal flap dimensions*

The horizontal white-to-white distance of the eye, flap diameter, and hinge length were measured using a standard caliper.

### *4.1.7. Postoperative treatments*

After the operation, a single drop of 3% ofloxacin solution (Exocin; Allergan, Eastport, Co. Mayo, Ireland) and 1% diclofenac solution (Voltaren Ophtha; Novartis, Copenhagen, Denmark) were applied into the operated eyes.

Over the following 7 days after surgery, 1% dexamethason-2% chloramphenicol solution (Oftan Dexa-Chlora; Santen Oy, Tampere) was tapered from five times to twice daily, and moisturizing drops frequently.

Refraction, UCVA and BSCVA were measured 2 hours and 1 month postoperatively. All the possible complications encountered intraoperatively and during the 1-month postoperative period were recorded.

## 4.2. Statistical analysis

The mean values and standard deviations of corneal thickness, flap thickness, flap horizontal diameter, and hinge length were calculated. Unpaired or paired Student's *t*-test was used to analyze the difference between two cohorts. To determine the keratometric power K in the hinge direction, the angle between the hinge and the keratometric power $K_2$ was determined and the difference between $K_1$ and $K_2$ was calculated. Keratometric power was assumed to change linearly from $K_1$ to $K_2$. Thus, the K value in the hinge direction was determined with the following equation (Suominen et al., 2003):

$$K_{hinge} = K_2 + (K_1 - K_2) \text{ x (angle between } K_2 \text{ and hinge/90)} \qquad \text{(Eq 2)}$$

In Study I, a stepwise regression analysis was used to generate a model for flap thickness when the Moria M2 microkeratome was used for flap creation. In Studies II-VI, single-variable correlation was used to compare flap thickness with age, keratometric power $K_1$, flap diameter, or hinge length (GraphPad™ Prism 3.0, San Diego, USA, linear regression). Myopic and hyperopic groups were analyzed separately.

# 5. RESULTS

## 5.1. Preoperative characteristics

Preoperative characteristics of the operated eyes which underwent microkeratome-assisted or femtosecond laser-assisted LASIK are presented in Table 7. In Study I, the mean preoperative spherical equivalent (SE) refraction in myopic eyes was -5.07±2.22 D (mean±SD), and in hyperopic eyes +2.83±1.70 D (range -12.125 to +6.25 D). In Study II, the preoperative SE of 98 eyes varied from -11.4 to +5.4 D. Study III included 266 myopic and 34 hyperopic eyes. Preoperative SE varied from -14.00 D to +5.75 D. Study IV included 164 myopic and 36 hyperopic eyes. Study V included 787 previously unoperated eyes, of which 698 were myopic. SE in these eyes ranged from -0.13 to -17.38 D (mean: -4.92±2.67 D). In 89 hyperopic eyes, SE ranged from +0.00 to +7.63 D (mean: +2.14±1.54 D). Study VI included 85 previously LASIK-treated eyes, of which 70 were myopic.

Table 7. Preoperative characteristics of the microkeratome-assisted or femtosecond laser –assisted LASIK (I-VI).

| **Study** | **Study description** | **Number of eyes** | **Patient age (y)** | **Keratometric power $K_1$ (D)** | **Keratometric power $K_2$ (D)** | **Spherical equivalent refraction (D)** | | **Horizontal white-to-white distance of the eye (mm)** | **Corneal thickness (pachymetry, µm)** |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Myopic eyes** | **Hyperopic eyes** | | |
| I | Moria M2 head 130 | 454 | 31.3±8.8 | 44.31±1.59 | 43.32±1.54 | -5.07±2.22 | +2.83±1.70 | 11.6±0.4 | 552.4±32.5 |
| II | Moria M2 head 130 reusable head | | | | | | | | |
| | Right eye | 24 | | 44.26±1.68 | 43.23±1.51 | -4.44±2.13 | +2.44±0.52 | 11.7±0.3 | 553.4±25.9 |
| | Left eye | 25 | 31.7±9.5 | 44.16±1.32 | 43.11±1.61 | -4.30±2.37 | +2.88±1.94 | 11.5±0.3 | 552.7±36.8 |
| | Moria M2 single-use head | | | | | | | | |
| | Right eye | 25 | | 44.05±1.44 | 42.94±1.55 | -4.16±2.06 | +3.08±2.14 | 11.5±0.3 | 549.4±34.5 |
| | Left eye | 24 | | 44.41±1.96 | 43.25±1.40 | -4.35±2.13 | +2.50±0.44 | 11.7±0.3 | 554.0±25.3 |
| III | Moria M2 single-use head 90 | 300 | 34.7±10.7 | 44.42±1.54 | 43.46±1.48 | -5.04±2.26 | +2.67±1.49 | 11.6±0.4 | 548.9±32.0 |
| IV | Moria M2 head 130 with | | | | | | | | |
| | ML-20 | 100 | 36.5±11.4 | 43.8±1.6 | 42.9±1.5 | -4.15±1.85 | +2.29±1.31 | 11.7±0.5 | 565.1±22.6 |
| | ML-30 | 100 | | 43.5±1.7 | 42.7±1.6 | -4.63±2.16 | +2.98±2.00 | 11.8±0.5 | 546.0±21.7 |
| V | FEMTO LDV | 787 | 36.4±10.4 | 43.20±1.40 | 44.10±1.50 | -4.92±2.67 | +2.14±1.54 | 11.4±0.6 | 540.3±33.0 |
| VI | FEMTO LDV reoperation | 85 | 40.4±8.9 | 39.60±2.81 | 41.25±3.29 | -1.75±1.23 | +1.62±1.62 | 11.4±0.5 | 480.5±45.3 |

*Mean±SD*

## 5.2. Postoperative characteristics

Postoperative characteristics of the operated eyes that underwent microkeratome-assisted or femtosecond laser-assisted LASIK are presented in Table 8. In Study I, with the attempted flap thickness of 160 µm, the metallic Moria M2 flap thickness averaged in 454 eyes 153.3±19.0 µm (range 77 to 209 µm). In Study II, with the attempted thickness of 160 µm with the reusable head 130, mean flap thickness for all eyes was 153.3±13.3 µm (range 102 to 179 µm). With the single-use head, mean flap thickness for all eyes was 148.0±9.8 µm (range 120 to 170 µm). No statistical difference was noted in flap thickness, mean horizontal flap diameter and mean hinge length between the head types.

In Study III, with the Moria M2 single-use head 90 microkeratome and the attempted corneal flap thickness of 120 µm, the actual flap thickness averaged 115.4±12.5 µm (range 73 to 147 µm).

In Study IV, in ML -20-treated right eyes, mean corneal flap thickness was 129.1±15.6 µm (range 104 to 165 µm). In ML -20-treated left eyes, mean flap thickness was 111.5±14.5 µm (range 78 to 144 µm). The difference between right and left eyes was statistically significant ($P$<0.0001, Student's *t*-test). In ML -30-treated right eyes, mean flap thickness was 127.1±16.6 µm (range 90 to 168 µm). In ML -30-treated left eyes, mean flap thickness was 109.9±16.8 µm (range 72 to 149 µm). The difference between right and left eyes was statistically significant even in this cohort ($P$<0.0001, Student's *t*-test).

In Study IV, in the additional 40 eyes, the left eye was treated before the right eye. Mean flap thickness in ML -20-treated eyes was 145.8±14.5 µm in the 10 left eyes and 125.8±18.9 µm in the 10 right eyes. Correspondingly, mean flap thickness in ML -30-treated eyes was 135.4±21.7 µm in the 10 left eyes and 111.0±21.9 µm in the 10 right eyes. The difference in bilateral operations between first and second eyes was statistically significant in both cohorts ($P$<0.05, Student's *t*-test).

Table 8. Postoperative characteristics of the microkeratome-assisted or femtosecond laser –assisted LASIK (I-VI).

| Study | Study description | Intended flap thickness (µm) | Flap thickness (µm) both | Flap thickness (µm) right | Flap thickness (µm) left | Horizontal flap diameter (mm) both | Horizontal flap diameter (mm) right | Horizontal flap diameter (mm) left | Hinge length (mm) both | Hinge length (mm) right | Hinge length (mm) left |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I | Moria M2 head 130 | 160 | 153.3±19.0 | | | 9.2±0.2 | | | 4.6±0.3 | | |
| II | Moria M2 head 130 reusable head | 160 | | 149.7±14.6 | 156.8±11.1 | | 9.1±0.2 | 9.1±0.2 | | 4.2±0.3 | 4.2±0.3 |
| | Moria M2 single-use head | 160 | | 148.8±10.1 | 147.2±9.6 | | 9.0±0.2 | 9.0±0.2 | | 4.2±0.2 | 4.3±0.2 |
| III | Moria M2 single-use head 90 | 120 | 115.4±12.5 | 115.7±12.4 | 115.1±12.6 | 9.1±0.2 | | | 4.1±0.1 | | |
| IV | Moria M2 head 130 with | | | | | | | | | | |
| | ML-20 | 140 | | 129.1±15.6 | 111.5±14.5*** | | 9.1±0.3 | 9.1±0.3 | | 4.2±0.2 | 4.2±0.3 |
| | ML-30 | 130 | | 127.1±16.6 | 109.9±16.8*** | | 9.1±0.3 | 9.1±0.3 | | 4.2±0.2 | 4.2±0.2 |
| V | FEMTO LDV | 110 | | 90.5±5.5 | 90.1±4.6 | | 9.1±0.2 (9.0-mm suction ring) | 9.1±0.2 (9.0-mm suction ring) | | 4.0±0.4 | 3.9±0.4 |
| VI | FEMTO LDV reoperation | 90 | 90.2±6.6 | | | 9.2±0.2 | | | 4.0±0.2 | | |

*Mean±SD*
**** P<0.0001 Statistical significance between right and left eyes*

In the femtosecond laser-assisted Study V, in all eyes, the corneal thickness ranged from 67 to 107 µm (mean 90.0±5.0 µm). The difference between right and left eyes was statistically non-significant. In the first 62 eyes, mean flap thickness in the right eyes was 86.9±7.4 µm (range 74 to 103 µm) and in the left eyes 90.5±5.1 µm (range 81 to 101 µm). This difference was not statistically significant. In all the eyes treated with the 9.0-mm suction ring, the mean flap diameter in right eyes was 9.1±0.2 mm (range 8.4 to 9.9 mm) and in left eyes 9.1±0.2 mm (range 8.0 to 10.0 mm). This difference was statistically non-significant.

In Study VI, the mean flap thickness of 85 previously LASIK-treated eyes was 90.2±6.6 µm (range 80 to 122 µm). In bilateral operations, the second flap was not significantly different from the first cut flap.

## 5.3. Correlation coefficients

The correlation coefficients of variables vs flap thickness in microkeratome-assisted LASIK studies I and III are presented in Table 9a.

**Study I with the Moria M2 head 130**

When the relationship between preoperative spherical equivalent refraction and preoperative corneal thickness was studied, it was found that the greater the myopia was the greater was the preoperative corneal thickness. In hyperopic eyes, such a correlation was not found.

In the correlation study of main variables versus flap thickness, a slight statistically insignificant relationship was found between preoperative spherical equivalent refraction and corneal thickness. The trend was in myopic eyes: the greater myopia, the thinner the flap (r=0.057). In hyperopic eyes, the greater the hyperopia, the thinner the flap (r=-0.116).

Between patient age and corneal flap thickness, it was found that the younger the patient, the thicker the flap (r=-0.157, $P$<0.001). Between preoperative corneal thickness and flap thickness, we found that the thicker the cornea, the thicker the flap (r=0.531, $P$<0.0001). Increasing flap thickness was found to be associated with flatter keratometric power $K_1$ (r=-0.207, $P$<0.001). Moreover, a similar relationship was found between keratometric power K in hinge direction and corneal thickness (r=-0.110, $P$<0.05).

In Study I, in hyperopic eyes it was found that the higher preoperative refraction, the wider the flap diameter ($r=0.517$, $P<0.01$). In myopic eyes, such a correlation was not found ($r=-0.016$). Increasing corneal flap diameter did not correlate with preoperative corneal thickness ($r=0.068$) but with thinner flaps ($r=-0.148$, $P<0.01$). In hyperopic eyes, a slight correlation between increasing preoperative spherical equivalent refraction and hinge length was found ($r=0.475$, $P<0.05$). Increasing hinge length was associated with thicker corneas ($r=0.206$, $P<0.001$) and larger flaps ($r=-0.489$, $P<0.001$).

A stepwise regression analysis was used to generate a model for flap thickness when the Moria M2 microkeratome was used. The flap thickness could be predicted by the following equation:

Corneal flap thickness (μm) = 78.19 + 0.297 x mean preoperative corneal thickness – 0.245 x patient age – 1.837 x keratometric power $K_1$ (Eq 3)

The $R^2$ value for the model was 0.319, of which 0.282 (88.3%) was explained by preoperative corneal thickness.

Table 9a. Correlation coefficients of different variables vs flap thickness in microkeratome-assisted LASIK (I and III).

| **Variable** | **Moria M2 head 130** | | | **Moria M2 single-use head 90** | | |
|---|---|---|---|---|---|---|
| | **Number of eyes** | **Correlation Coefficient** | ***P* Value** | **Number of eyes** | **Correlation Coefficient** | ***P* Value** |
| Equivalent refraction (D) | | | | | | |
| All eyes | 454 | -0.052 | NS | 300 | -0.076 | NS |
| Myopic eyes | 425 | 0.057 | NS | 266 | -0.052 | NS |
| Hyperopic eyes | 29 | -0.116 | NS | 34 | -0.067 | NS |
| Corneal thickness (μm) | | | | | | |
| All eyes | 454 | 0.531 | <0.0001 | 300 | 0.555 | <0.0001 |
| Myopic eyes | 425 | 0.523 | <0.0001 | 266 | 0.567 | <0.0001 |
| Hyperopic eyes | 29 | 0.487 | <0.01 | 34 | 0.470 | <0.01 |
| Age (y) | | | | | | |
| All eyes | 454 | -0.157 | <0.001 | 300 | -0.194 | <0.001 |
| Myopic eyes | 425 | -0.126 | <0.01 | 266 | -0.211 | <0.001 |
| Hyperopic eyes | 29 | 0.192 | NS | 34 | -0.054 | NS |
| Keratometric power $K_1$ (D) | | | | | | |
| All eyes | 454 | -0.207 | <0.001 | 300 | -0.083 | NS |
| Myopic eyes | 425 | -0.221 | <0.001 | 266 | -0.039 | NS |
| Hyperopic eyes | 29 | -0.055 | NS | 34 | -0.530 | <0.01 |
| Flap diameter (mm) | | | | | | |
| All eyes | 454 | -0.148 | <0.01 | 300 | 0.040 | NS |
| Myopic eyes | 425 | -0.141 | <0.01 | 266 | 0.062 | NS |
| Hyperopic eyes | 29 | -0.324 | NS | 34 | -0.256 | NS |
| Hinge length (mm) | | | | | | |
| All eyes | 454 | 0.180 | <0.0001 | 300 | 0.091 | NS |
| Myopic eyes | 425 | 0.090 | NS | 266 | 0.113 | NS |
| Hyperopic eyes | 29 | -0.266 | NS | 34 | -0.129 | NS |

*NS=not significant*

### Study II with the Moria M2 reusable head 130 and single-use head

Flap thickness correlated to preoperative corneal thickness in both head types, especially in myopic eyes (r=0.40 for the head 130, r=0.44 for the single-use head). There was statistically no significant tendency towards thinner flaps with higher keratometric $K_1$ values in myopic eyes.

This tendency was more evident with the head 130 (r=-0.29) than with the single-use head (r=-0.11).

**Study III with the Moria M2 single-use head 90**

Preoperative spherical equivalent refraction did not correlate with preoperative corneal thickness (r=-0.040, all operated eyes).

The correlation between patient age and corneal flap thickness showed a negative correlation (r=-0.194, *P*<0.001). The younger the patient, the thicker the flap. Moreover, correlation study between corneal thickness and flap thickness showed that the thicker the cornea, the thicker the flap. There were no differences between right eyes (r=0.576, P<0.0001) and left eyes (r=0.536, *P*<0.0001). In myopic eyes, flap thickness was not correlated with keratometric power $K_1$ (r=-0.039, *P*=NS), but in hyperopic eyes increasing flap thickness was associated with flatter keratometric power $K_1$ (r=-0.530, *P*<0.01). A similar correlation was noted between keratometric power $K_2$ and corneal flap thickness (myopic eyes r=-0.015, *P*=NS, hyperopic eyes r=-0.449, *P*<0.01), mean preoperative power K and corneal flap thickness (myopic eyes r=-0.028, *P*=NS, hyperopic eyes r=-0.499, *P*<0.01), and preoperative keratometric power K in hinge direction and corneal flap thickness (myopic eyes r=-0.029, *P*=NS, hyperopic eyes r=-0.393, *P*<0.05). Increasing corneal flap diameter correlated significantly with preoperative corneal thickness in myopic eyes (r=0.229, *P*<0.001), but not in hyperopic eyes (r=-0.111, *P*>0.05). Increasing hinge length was associated with thicker corneas in myopic eyes (r=0.216, *P*<0.001), but not in hyperopic eyes (r=0.273, *P*>0.05).

**Study IV with Moria M2 head 130 and ML-20 or ML-30 blade**

Correlation coefficients of variables vs flap thickness in microkeratome-assisted LASIK study IV are shown in Table 9b. In correlation studies between flap thickness and main parameters, similar correlations were found when the eyes treated first and second were analyzed separately.

In the hyperopic eyes treated with the ML -20 blade, flap thickness was negatively correlated with keratometric value $K_1$ (r=-0.643, *P*<0.01). In ML -30-treated eyes, increasing flap thickness was associated with flatter keratometric value in both myopic eyes (r=-0.300, *P*<0.01) and hyperopic eyes (r=-0.475, $P$<0.05). In myopic ML -30-treated eyes, increasing flap thickness was associated with increasing corneal thickness (r=0.399, $P$<0.001). Flap thickness did not correlate with patient age in either cohort.

Table 9b. Correlation coefficients of different variables vs flap thickness in microkeratome-assisted LASIK (IV).

| **Variable** | **Moria M2 head 130 with** | | | | | |
|---|---|---|---|---|---|---|
| | **ML-20** | | | **ML-30** | | |
| | **Number of eyes** | **Correlation Coefficient** | ***P* Value** | **Number of eyes** | **Correlation Coefficient** | ***P* Value** |
| Equivalent refraction (D) | | | | | | |
| All eyes | 100 | 0.074 | NS | 100 | -0.101 | NS |
| Myopic eyes | 82 | 0.017 | NS | 82 | -0.140 | NS |
| Hyperopic eyes | 18 | 0.398 | NS | 18 | -0.018 | NS |
| Corneal thickness (µm) | | | | | | |
| All eyes | 100 | 0.105 | NS | 100 | 0.385 | <0.0001 |
| Myopic eyes | 82 | 0.096 | NS | 82 | 0.399 | <0.001 |
| Hyperopic eyes | 18 | 0.126 | NS | 18 | 0.280 | NS |
| Age (y) | | | | | | |
| All eyes | 100 | 0.050 | NS | 100 | 0.067 | NS |
| Myopic eyes | 82 | 0.001 | NS | 82 | 0.062 | NS |
| Hyperopic eyes | 18 | 0.373 | NS | 18 | 0.290 | NS |
| Keratometric power $K_1$ (D) | | | | | | |
| All eyes | 100 | -0.180 | NS | 100 | -0.301 | <0.01 |
| Myopic eyes | 82 | -0.055 | NS | 82 | -0.300 | <0.01 |
| Hyperopic eyes | 18 | -0.643 | <0.01 | 18 | -0.475 | <0.05 |
| Flap diameter (mm) | | | | | | |
| All eyes | 100 | -0.013 | NS | 100 | -0.132 | NS |
| Myopic eyes | 82 | 0.023 | NS | 82 | -0.212 | NS |
| Hyperopic eyes | 18 | -0.120 | NS | 18 | 0.231 | NS |
| Hinge length (mm) | | | | | | |
| All eyes | 100 | 0.163 | NS | 100 | -0.098 | NS |
| Myopic eyes | 82 | 0.541 | NS | 82 | -0.194 | NS |
| Hyperopic eyes | 18 | 0.292 | NS | 18 | 0.201 | NS |

*NS=not significant*

**Study V with the FEMTO LDV femtosecond laser**

Correlation coefficients of variables vs flap thickness in femtosecond laser-assisted LASIK studies V-VI are shown in Table 9c.

Table 9c. Correlation coefficients of different variables vs flap thickness in femtosecond laser-assisted LASIK (V-VI).

| **Variable** | **FEMTO LDV** | | | **FEMTO LDV reoperation** | | |
|---|---|---|---|---|---|---|
| | **Number of eyes** | **Correlation coefficient** | ***P* Value** | **Number of eyes** | **Correlation coefficient** | ***P* Value** |
| Equivalent refraction (D) | | | | | | |
| All eyes | 787 | 0.023 | NS | 85 | 0.076 | NS |
| Myopic eyes | 698 | 0.031 | NS | 70 | 0.009 | NS |
| Hyperopic eyes | 89 | 0.101 | NS | 15 | 0.263 | NS |
| Corneal thickness (μm) | | | | | | |
| All eyes | 787 | 0.114 | <0.01 | 85 | 0.202 | NS |
| Myopic eyes | 698 | 0.107 | <0.01 | 70 | 0.195 | NS |
| Hyperopic eyes | 89 | 0.164 | NS | 15 | 0.196 | NS |
| Age (y) | | | | | | |
| All eyes | 787 | -0.165 | NS | 85 | 0.274 | <0.05 |
| Myopic eyes | 698 | -0.009 | NS | 70 | 0.328 | <0.01 |
| Hyperopic eyes | 89 | -0.116 | NS | 15 | -0.202 | NS |
| Keratometric power $K_1$ (D) | | | | | | |
| All eyes | 787 | -0.097 | <0.01 | 85 | 0.099 | NS |
| Myopic eyes | 698 | -0.084 | <0.05 | 70 | 0.014 | NS |
| Hyperopic eyes | 89 | -0.196 | NS | 15 | 0.425 | NS |
| Flap diameter (mm) | | | | | | |
| All eyes | 766 | -0.161 | <0.0001 | 85 | 0.190 | NS |
| Myopic eyes | 681 | -0.163 | <0.0001 | 70 | 0.162 | NS |
| Hyperopic eyes | 85 | -0.138 | NS | 15 | 0.417 | <0.005 |
| Hinge length (mm) | | | | | | |
| All eyes | 766 | -0.025 | NS | 85 | 0.350 | <0.01 |
| Myopic eyes | 678 | -0.024 | NS | 70 | 0.391 | NS |
| Hyperopic eyes | 85 | -0.045 | NS | 15 | 0.397 | NS |

*NS=not significant*

In Study V, corneal flap thickness was dependent on corneal thickness in right eyes (r=0.131, *P*=0.009). The thicker the cornea, the thicker the flap. A similar, but statistically not significant tendency was found in left eyes (r=0.094, *P*=0.064). Corneal flap thickness was not dependent on keratometric power $K_1$ in right eyes (r=0.055, *P*=0.273)), but in left eyes increasing flap thickness was associated with flatter keratometric value (r=0.149, *P*=0.003). Corneal flap thickness was negatively correlated with flap diameter in myopic eyes (r=-0.163, *P*<0.0001). The greater the flap diameter, the thinner the flap thickness. Corneal flap thickness was not correlated with preoperative spherical equivalent refraction, patient age, or hinge length.

In Study V in myopic eyes treated with the 9.0-mm suction ring, increasing flap diameter was associated with increasing preoperative spherical equivalent refraction, both in right eyes (r=0.219, *P*<0.0001) and left eyes (r=0.223, *P*<0.0001). In all eyes treated with the 9.0-mm suction ring, increasing flap diameter was associated with steeper keratometric value $K_1$, both in right eyes (r=0.389, *P*<0.0001) and left eyes (r=0.363, *P*<0.0001). In hyperopic eyes, increasing flap diameter was also associated with increasing hinge length both in right eyes (r=0.588, *P*<0.0001) and left eyes (r=0.559, *P*<0.0001).

**Study VI with the FEMTO LDV reoperation**

Flap thickness correlated positively with patient age in 67 myopic eyes (r=0.33, *P*<0.01). Hinge length correlated positively with flap thickness in 57 myopic eyes that were treated with a 9.0-mm suction ring (r=0.39, *P*<0.01).

## 5.4. Safety

The changes in the Snellen lines of BSCVA of the Studies I, III, V and VI are shown in Table 10. In Study I, the BSCVA after 1 month improved by 2 Snellen lines in 0.4% of the eyes. 0.9% of the eyes lost ≥2 lines.

In Study III, refractive, UCVA and BSCVA outcomes 1 month after LASIK were available for 298 eyes (149 patients). The number of eyes within ±0.50 D target refraction was 244 (92.4%) in the myopic group, and 33 (97.1%) in the hyperopia group. After 4 weeks, 97.3% of myopic eyes achieved UCVA ≥20/40. The corresponding percentage for hyperopic eyes was 88.2%. Mean BSCVA improved slightly, compared to baseline values. None of the eyes lost ≥2 Snellen lines. One (0.4%) myopic eye gained 2 Snellen lines and 68 (25.8%) myopic eyes gained 1 line. Two (5.9%) hyperopic eyes gained 1 line. In 205 (68.3%) eyes no changes were noted in Snellen lines for BSCVA.

Table 10. Changes in Snellen lines of best corrected visual acuity 1 month after surgery.

| **Changes in Snellen lines** | **Study I Moria M2 head 130 Number of eyes (%)** | **Study III Moria M2 single-use head 90 Number of eyes (%)** | **Study V FEMTO LDV Number of eyes (%)** | **Study VI FEMTO LDV reoperation Number of eyes (%)** |
|---|---|---|---|---|
| Loss ≥2 | 4(0.9) | 0(0) | 0(0) | 1(1.3) |
| Loss 1 | 23(5.1) | 22(7.4) | 1(0.2) | 0(0) |
| No change | 380(83.7) | 205(68.8) | 474(74.6) | 67(85.9) |
| Gain 1 | 45(9.9) | 70(23.5) | 156(24.6) | 10(12.8) |
| Gain ≥2 | 2(0.4) | 1(0.3) | 4(0.6) | 0(0) |

In Study IV, clinical outcomes for UCVA and BSCVA as well as refractive predictability did not differ significantly between the two cohorts.

In Study V in the series of 787 eyes, at the time of analysis there was 1-month data for 635 eyes: 570 myopic eyes and 65 hyperopic eyes. In myopic eyes, 2 (0.4%) eyes gained 2 Snellen lines, 150 (26.3%) eyes gained 1 line and 1 (0.2%) eye lost 1 line. In hyperopic eyes, 2 (3.1%) eyes gained 2 lines and 6 (9.2%) eyes gained 1 line. No change in Snellen lines occurred in 417 (73.2%) myopic eyes and 57 (87.7%) hyperopic eyes.

In Study VI in the series of reoperated 85 eyes, it was possible to analyze the visual functions one month after the surgery in a total of 78 eyes. There were no changes in Snellen lines of BSCVA in 67 (85.9%) eyes. Two Snellen lines were lost in one (1.3%) eye. One Snellen line was gained in 10 (12.8%) eyes.

## 5.5. Complications

Complications in microkeratome-assisted LASIK are shown in Table 11a. All complications were considered mild and none of the complications prevented further treatment with excimer laser. In Study I, no intraoperative complications occurred. Iron particles were observed in the interface in 5.5% of the eyes. Epithelial ingrowth in the edge occurred in 7.7% of the eyes, but they did not require flap lifting and epithelium removal.

Table 11a. Flap-related complications in microkeratome-assisted LASIK (I–IV).

| **Complication** | **Moria M2 head 130 Number of eyes (%)** | **Moria M2 head 130 with reusable and single-use head Number of eyes (%)** | **Moria M2 single-use head 90 Number of eyes (%)** | **Moria M2 head 130 and ML-20 or ML-30 Number of eyes (%)** |
|---|---|---|---|---|
| Iron particles | 25(5.5) | 2(2.0) | 3(1.0) | 0(0) |
| Epithelial ingrowth | 35(7.7) | 0(0) | 0(0) | 0(0) |
| Epithelial dots at the wound edge | 0(0) | 1(1.0) | 0(0) | 0(0) |
| Flap wrinkles/striae | 0(0) | 1(1.0) | 0(0) | 0(0) |
| **Sum** | **60/454(13.2%)** | **4/98(4.0%)** | **3/300(1.0%)** | **0/200(0%)** |

In Study II, no significant complications were noted in this study. Occasional iron particles were noted in 1.0% of the eyes with both head types. Epithelial dots at the wound edge (but not real epithelial ingrowth) were noted in 1.0% of the eyes operated with the single-use head. Flap wrinkles/striae were noted in 1.0% of the eyes operated with the single-use head.

In Study III, there were no intraoperative complications in the study. Occasional iron particles were observed in 1.0% of the eyes. In Study IV, there were no intraoperative complications.

Flap-related complications in femtosecond laser –assisted LASIK are presented in Table 11b. None of the complications prevented further treatment with excimer laser.

Table 11b. Flap-related complications in femtosecond laser –assisted LASIK (V-VI).

| **Complication** | **FEMTO LDV Number of eyes (%)** | **FEMTO LDV reoperation Number of eyes (%)** |
|---|---|---|
| Decentered flap | 16(2.0) | 1(1.2) |
| True free cap | 4(0.5) | 0(0) |
| Preserved free cap | 17(2.2) | 0(0) |
| Pseudo buttonhole | 10(1.3) | 0(0) |
| Buttonhole | 0(0) | 1(1.2) |
| Flap in two parts | 2(0.3) | 0(0) |
| Epithelial defect | 5(0.6) | 0(0) |
| Adhesion | 8(1.0) | 7(8.2) |
| Bubbles under epithelium | 1(0.1) | 0(0) |
| Flap displacement* | 3(0.4) | 0(0) |
| Rough striae | 0(0) | 1(1.2) |
| Flap opening via old flap | 0(0) | 2(2.4) |
| **Sum** | **66/787(8.4%)** | **12/85(14.1%)** |

**Occurred 1 to 2 hours after surgery and was easily replaced.*

In Study V in the first 62 eyes, there were 1 (1.6%) free cap, 2 (3.2%) decentered flaps and bleeding in 13 (21.0%) eyes. Bleeding from the limbal vessels was mainly associated with the larger 9.5-mm suction ring used in the first series of eyes. In all 787 eyes, the percentage of complications was 8.4%. The individual complication percentages were: free caps 0.5%, preserved free caps 2.2%, pseudo buttonholes (partial thickness buttonholes) 1.3%, flap in two parts in 0.3% of the eyes, decentered flaps 2.0%, adhesions 1.0%, and epithelial defects 0.6%. Bleeding from the limbal vessels occurred in 100 (12.7%) eyes. In the preserved free caps, the FEMTO LDV cut a complete flap without a hinge, but the surgeon preserved a hinge of 3 to 4 mm when opening the flap. Flap decentration was defined by >0.5 mm. None of the decentrations prevented treatment with excimer laser.

In Study VI, intraoperative flap-related complications occurred in 14.1% of the eyes. Adhesion/tight opening was reported in 8.2% of the eyes, rough striae in 1.2% of the eyes, buttonhole in 1.2% of the eyes (case report 1), decentration in 1.2% of the eyes, and flap opening via the old flap in 2.4% of the eyes (case reports 2-3). Bleeding occurred in 11 (12.9%) eyes.

## 6. DISCUSSION

This dissertation consists of 1924 LASIK-operated eyes of 1009 patients, of which 454 eyes were treated with the Moria M2 automated microkeratome with the head 130; 98 eyes were treated with either the Moria M2 microkeratome with the head 130 or the single-use head; 300 eyes were treated with the Moria M2 single-use head 90; 200 eyes were treated with the Moria M2 head 130 microkeratome adjusted with either the Med-Logics calibrated LASIK blade ML-20 or ML-30; 787 eyes were treated with the FEMTO LDV femtosecond laser; and 85 previously LASIK-treated eyes were operated with the FEMTO LDV.

In these studies, flap thickness was based on ultrasound pachymetry measurements. Ultrasonic pachymetry has been reported to have axial resolution with the precision of 12 µm (Wheeler et al., 1992). Thus, it should be reminded that the limited accuracy of ultrasound measurements and subtraction pachymetry precludes determination of flap accuracy beyond certain limits.

### 6.1. Microkeratome-assisted LASIK

In Study I with the Moria M2 head 130, the 19.0-µm SD was relatively small compared to other reports published on microkeratomes (see Table 2, range up to ±40 µm). Both undercutting and overcutting were noticed in Study I, and the range varied from 77 to 209 µm. In 5 (1.1%) eyes, corneal flap was <100 µm. On the other hand, corneal flap thickness was >190 µm in 3 (0.7%) of the eyes. There were no >10.0-mm diameter flaps. A flap diameter <8.5 mm occurred in one eye only. Increasing hyperopia was associated with increasing flap diameter. Thus, the flap diameter created with the Moria microkeratome M2 head 130 was also large enough for the wider ablations needed in hyperopic eyes.

It is highly valuable for surgeons to know how preoperative parameters the affect actual flap thickness. In Study I, a mathematical formula for the Moria M2 head 130 microkeratome was generated to evaluate which preoperative parameters in the best way predicted the actual flap thickness. It was found that corneal thickness, patient age, and corneal curvature predicted in the best way the actual flap thickness. An increase in flap thickness correlated with thicker preoperative corneal thickness and younger age. Increasing flap thickness was also related to flatter preoperative keratometric $K_1$ power. This may be due to the fact that suction ring in the Moria automated microkeratome M2 system is chosen according to the manufacture's recommendation (nomogram), which is based on the keratometric $K_1$ value.

During the past few years, a large number of studies evaluating different microkeratomes have been published (see Table 2). Variations in flap thickness occur with the attempted flap thickness using the same microkeratome. Undercutting has been shown to be the most common problem. Some studies also report differences between the first and second eye operated with the same blade. When the same blade is used in bilateral eyes, the second cut typically creates thinner flap. This was also found in our studies.

In clinical studies evaluating the flap dimensions with the Moria LSK-1 microkeratome, the achieved flap thicknesses 159 µm (Jacobs et al., 1999) and 161 µm (Srivannaboon, 2001) were very close to the 160-µm flap thickness intended. However, unlike in our study, Jacobs et al. found no significant correlation between preoperative corneal thickness or mean keratometry and flap thickness when using the Moria LSK-1 (Jacobs et al., 1999). On the contrary to other microkeratomes, Moria microkeratome systems rely on suction rings, which are chosen based on keratometric value $K_1$.

According to Yi and Joo, in the SCMD microkeratome there is a significant positive correlation between corneal thickness and flap thickness, but no correlation between flap thickness and the steepening of the cornea (Yi and Joo, 1999). Gailitis and Lagzdins evaluated the Hansatome microkeratome and also found a positive correlation between flap thickness and corneal thickness, but no correlation between flap thickness and patient age or average keratometric power (Gailitis and Lagzdins, 2002). Smemesh et al. found a statistically significant difference between the first and second eye operated with the same blade using the Hansatome and ACS microkeratomes, but no such difference was seen when using the Nidek MK 2000 microkeratome (Shemesh et al., 2002). Spadae et al. evaluated the Hansatome microkeratome and found statistically significant correlations between mean keratometric power and hinge length, and mean keratometric power and flap diameter (Spadea et al., 2002). In accordance with Study I, they also found a correlation between corneal thickness and hinge length. The thicker the cornea, the longer the hinge length. However, they did not find correlation between flap thickness and corneal steepening or corneal thickness (Spadea et al., 2002). Yildirim et al. have found a positive correlation between flap thickness and corneal thickness with the Hansatome microkeratome, but no correlation with keratometric value (Yildirim et al., 2000). In accordance to Study I, similar results have been reported by Flanagan and Binder (Flanagan and Binder, 2003). They evaluated the ACS and SKBM microkeratomes in 4428 eyes and found a positive correlation between flap thickness and corneal thickness, and a negative correlation between flap thickness and patient age. Furthermore, they found that flap thickness correlated with flatter keratometry values in the ACS microkeratome, but with steeper keratometry values in the SKBM microkeratome. Ucakhan et al. also found a positive correlation between flap thickness and corneal thickness, but no correlation with the degree of myopia or corneal refractive power (Ucakhan, 2002).

Although in most clinical studies, mean flap thickness has been less than the attempted value, even overcutting occurs with microkeratomes. Some Nidek MK 2000 microkeratome models have been reported to cut thicker corneal flaps than attempted (Schumer and Bains, 2001; Naripthaphan and Vongthongsri, 2001). Amadeus microkeratome also tends to cut thicker flaps than intended (Jackson et al., 2003).

In Study II, in the bilateral comparison of the Moria reusable metallic head 130 and single-use head microkeratomes, thinner corneal flaps were obtained than the intended 160-µm flaps. In Study I evaluating 454 eyes with the Moria M2 metallic head 130, the same mean flap thickness was achieved as in Study II, but with a higher standard deviation. This improvement in SD was achieved, most likely, by the enhanced technique of the surgeon.

In Study II, flap thickness was dependent on corneal thickness with both head types. Flap thickness correlated with the keratometric power $K_1$ when the metallic head was used, but not in the case of a single-use head. With both head types, there were differences between the right and left eye operated. Right flaps were about 3 µm thinner than in the left ones. The difference between the right and left eye is presumably due to the technical difficulty to operate the microkeratome in a similar way for both eyes. Moreover, that the second cut is thinner most likely depends on the cutting edge of the blade. It is likely that the first cut affects the sharpness of the blade and even small changes in sharpness may cause variations between the first and the second cut.

In clinical practice, single-use heads were easier to use, because they do not need any assembly. The transparent plastic single-use head provided a better observation view for the surgeon on the operated eye than the metallic head. The plastic heads also worked more evenly than the metallic heads. In a larger-scale clinical practice, single-use heads may minimize the risk of infections related to the use of microkeratomes (Ambrosio, Jr. and Wilson, 2001; Jacobs and Taravella, 2002).

Thin flaps are liable to buttonholes and acquire more complicated handling of the flap during the surgery. In Study III, however, there were no incomplete flaps, buttonholes or other microkeratome-related complications.

In Study III, flap thickness was found to correlate positively with the corneal thickness as also shown in Studies I and II. Moreover, flap thickness correlated negatively with patient age as shown in Study I.

The Moria M2 single-use head 90 creating corneal flaps with a small variation is recommended for making thin flaps.

In Study IV, the Moria M2 metallic head 130, intended to create a 160-µm flap, was adjusted with either the Med-Logics single-use calibrated blade ML -20 or the ML -30 for the intended flap thickness of 140 µm or 130 µm, respectively. For both cohorts, the difference between the first and second cut was significant. The variation of flap thickness was also considerably wide. There was no clinically relevant difference in flap thickness between ML -20 and ML -30.

In the additional operations performed in a total of 40 eyes, the left eye was operated first before the right eye. Also in these cases, the first cut flap was thicker than the secondly cut flap.

Although there was considerable variation in the flap thickness, there were no buttonholes or other significant flap-related complications in Study IV.

Corneal flap thickness in ML -30-treated eyes correlated with corneal thickness, but not in ML -20-treated eyes. This may be due to fact that thicker corneas do not adapt in the same way to the suction head as thinner corneas. Flap thickness was found not to correlate significantly with age.

Flap thickness was associated with keratometric power $K_1$ in ML -30-treated eyes in both myopic and hyperopic eyes, but not in myopic ML -20-treated eyes. The correlation analysis showed large differences between myopic and hyperopic eyes in some correlations. Patient age affecting hyperopic regressions but not myopic regressions may be an artifact due to the large difference in the populations.

The ML -30 calibrated LASIK blade did not cut considerably thinner flaps than the ML -20 blade. As the Moria M2 single-use head 90 created corneal flaps with a smaller variation, its use for the creation of thin flaps is recommended.

### 6.2. Femtosecond laser –assisted LASIK

The FEMTO LDV cut thinner flaps than intended, such as most mechanical microkeratomes. In Study V, the 5.0-µm SD was very low compared to standard deviations achieved with most microkeratomes. Traditional microkeratome systems can produce variable flap thickness with standard deviations greater than ±25 µm to ±40 µm (see Table 2). In bilateral operations with traditional microkeratomes, the first cut flap will generally be thicker than the second one. However, the FEMTO LDV cut the eyes in a similar way.

The Intralase has been used in a number of clinical studies, and it has been reported to induce both thicker and thinner flaps than intended (see Table 3). Binder has measured for an intended flap thickness of 110 µm, 125.0±12.0 µm; for an intended flap thickness of 120 µm, 122.4±11.9 µm; for an intended flap thickness of 130 µm, 128.7±16.6 µm; and for an intended flap thickness 140 µm, 132.5±18.5 µm (Binder, 2004). Furthermore, with the Intralase for an intended flap thickness of 130 µm, Kezirian and Stonecipher have measured 114 µm±14 (Kezirian and Stonecipher, 2004). Binder (Binder, 2004) derived flap thickness from intraoperative ultrasonic pachymetry measurements, and Kezirian and Stonecipher (Kezirian and Stonecipher, 2004) derived flap thickness from preoperative and intraoperative ultrasonic pachymetry measurements. Later Binder has evaluated one thousand consecutive Intralase flaps with subtraction ultrasound and has found that the mean achieved flap thickness exceeded the attempted flap thickness by 9.4 to 34.3 µm with the standard deviations varying from ±10.2 to ±21.7 µm (Binder, 2006). Patel et al. have also used the Intralase technology but measured flap thickness by confocal microscopy one month later (Patel et al., 2007). In the study for an intended flap thickness of 120 µm, they measured 143±16 µm. Hu et al. have reported a mean difference between the actual flap thickness and intended thickness by confocal microscopy as 16.8±11.1 µm and 13.9±7.1 µm for the Intralase FS15 and FS30 femtosecond lasers, respectively (Hu et al., 2007).

The FEMTO LDV system was slightly dependent on corneal thickness and keratometric value $K_1$. Increasing flap thickness was associated with increasing corneal thickness and flatter keratometric value. It was found that increasing flap diameter was associated with thinner flaps in myopic eyes. Moreover, increasing flap diameter was correlated with steeper keratometric value $K_{1.}$ Mechanical microkeratomes have also been reported to be sensitive to preoperative corneal curvature creating larger diameter flaps with steeper corneas and smaller diameter flaps with flatter corneas (Flanagan and Binder, 2003). With the Intralase it has been reported that preoperative corneal thickness and keratometric power did not affect the achieved flap thickness (Binder, 2006).

In Study VI, the mean flap thickness was equal to the one obtained in the Study V. The other postoperative flap-related characteristics in Study VI were also within the same range as in Study V. There was no difference in flap characteristics between primary and secondary operation.

In LASIK enhancements of previously LASIK-treated eyes, flap thickness correlated positively with patient age in myopic patients.

The 85 reoperated eyes represent the very first cases of LASIK revisions with the FEMTO LDV using very thin flaps. Therefore, a learning curve was to be expected when the microkeratome-based LASIK was changed to the femtosecond laser-based LASIK, especially when more challenging reoperations were done. Bleeding from the limbal vessels was reported in 11 (12.9%) eyes. Other complications were reported in 12 eyes in a total of 85 recut eyes (14.1%). Adhesions/tight openings were the most common problem. Adhesions were most likely related to the scar tissue in the primary flap. However, most of the complications were mild and did not prevent further treatment with excimer laser.

The previous reoperation study of 85 previously PRK or LASIK-operated eyes reoperated with the Moria M2 and the single-use head 90 or 130 (with the intended flap thicknesses of 120 µm and 160 µm, respectively) showed lower complication rate (5.9%) (Pitkänen et al., 2010). All the complications in that study were related to iron particles obtained from the microkeratome blade, or to epithelial ingrowth or defects. The flaps obtained were thicker (mean values ranging from 115.1 μm to 141.9 μm) than in Study VI (90.2 μm).

In LASIK revisions, when the flap is still readily visible and is not too tightly adhered, flap relifting is the recommended choice. However, if the primary flap has a small diameter or the old flap is tightly adhered, flap recutting is the method of choice. In typical cases, it is recommended to make a new hinge in a different position than in the primary flap. In the case of a primary free flap, the recommendation is using a microkeratome instead of the FEMTO LDV. One potential complication in LASIK revision is the creation of free corneal tissue, so called slivers, that may produce irregular astigmatism (Peters et al., 2001; Domniz et al., 2001). Such a case was also seen in Study VI presented as the case report 1. In LASIK revision, surgical experience is essential and special attention should be paid to the technical details to avoid complications in the demanding cases.

### 6.3. Microkeratome-assisted LASIK vs femtosecond laser –assisted LASIK

In the presented studies, the most common problem of different Moria microkeratomes was undercutting. FEMTO LDV femtosecond laser cut more predictable thin flaps. SD was higher with the Moria microkeratomes. With the FEMTO LDV the second flap was equal to the first cut flap, while with the Moria microkeratomes the first flap was thicker than the second one.

With mechanical microkeratomes, many factors determine corneal flap thickness profiles, including the quality of the blade's cutting edge, speed of microkeratome pass, speed of blade oscillation, ease of pass on the cornea, and advancement of the microkeratome along the track of the suction ring (Stonecipher et al., 2006a). Clinical studies have shown variable flap thickness with different microkeratomes (see Table 2). Other problems with microkeratome technology include epithelial defects, epithelial sloughing, decentered flaps, free flaps, incomplete flaps, irregular flaps, and buttonholes (Binder, 2004; Stonecipher et al., 2006a; Binder, 2006).

Femtosecond lasers have been reported to have several advantages over classic microkeratomes, including improved predictability of flap thickness and diameter (Binder, 2004; Kezirian and Stonecipher, 2004; Binder, 2006), astigmatic neutrality (Kezirian and Stonecipher, 2004; Durrie and Kezirian, 2005; Tran et al., 2005), and reduced incidence of epithelial defects and buttonholes (Binder, 2004; Kezirian and Stonecipher, 2004; Binder, 2006). Complications reported with femtosecond lasers include transient light sensitivity (Stonecipher et al., 2006b; Munoz et al., 2006), corneal folds (Biser et al., 2003), and increased interface inflammation (Munoz et al., 2006; Sonigo et al., 2005).

In the present study, keratometric $K_1$ value influenced the Moria microkeratomes so that buttonholes and free caps were more common than in the FEMTO LDV. These problems were minimized with the FEMTO LDV. In the case of an incomplete flap with the Moria microkeratomes you have to wait for three months before a new flap can be made. In the case of an incomplete flap with the FEMTO LDV, a new flap can be made even within the same day, but on a deeper level. Epithelial defects are not a problem with the FEMTO LDV. Bleeding from the limbal vessels is also no big problem with the Moria microkeratomes or the FEMTO LDV, although the intention is to make as large flaps as possible. In the experienced hands, decentration is not a problem either with the Moria microkeratomes or the FEMTO LDV. Adhesions are more common with the FEMTO LDV than with the Moria microkeratomes. The suction times with the Moria microkeratome and the FEMTO LDV are equal. With the FEMTO LDV, IOP increases less.

The features of flap creation with different keratomes diverge. Furthermore, the flap-related complications are different according to the keratome type chosen. In order to get the best results, the surgeon should be aware of the characteristics that influence the surgical outcome.

# 7. SUMMARY

1. The most common feature of all the tested Moria microkeratomes, metallic, single-use, or Med-Logics calibrated LASIK blade microkeratomes was undercutting; the achieved corneal flap thickness was smaller than the attempted one. In bilateral operations with microkeratomes, the first-cut flap was thicker than the second one, not depending on which eye was operated first.
2. Flap thickness with femtosecond laser was more predictable than microkeratomes. There was no difference in flap thickness between the first and the second eye.
3. In tested microkeratomes and the femtosecond laser, precision in flap thickness in terms of SD was small compared to other studies published.
4. With the Moria M2 metallic head 130, an increase in flap thickness was related to thicker preoperative corneal thickness and younger age. Increasing flap thickness was also related to flatter preoperative keratometric $K_1$ power. With the Moria M2 metallic head 130, occasional iron particles were observed in 5.5% of the eyes. Epithelial ingrowth in the flap edge occurred in 7.7% of the eyes.
5. With the Moria M2 metallic head 130 or single-use head, flap thickness was dependent on corneal thickness. Flap thickness correlated with the keratometric power $K_1$ when the metallic head was used, but not in the case of a single-use head. Flap-related complications occurred in 2.0% of the eyes with both head types.
6. With the Moria M2 single-use head 90, flap thickness correlated positively with corneal thickness. The thicker the cornea, the thicker the flap. Flap thickness correlated negatively with patient age. The younger the patient, the thicker the flap. Occasional iron particles were observed in 1.0% of the eyes.
7. Increasing corneal thickness in eyes treated with Med-Logics calibrated LASIK blade ML -30 was associated with increasing corneal flap thickness, but not in ML -20-treated eyes. Increasing flap thickness was associated with flatter keratometric power $K_1$ in ML -30 -treated eyes in both myopic and hyperopic eyes, but not in myopic ML -20-treated eyes. Flap thickness did not correlate significantly with age. There were no buttonholes or other flap-related complications in this study.
8. The FEMTO LDV system was slightly dependent on corneal thickness and keratometric value $K_1$. Increasing flap thickness was associated with increasing corneal thickness and

flatter keratometric value. Increasing flap diameter was also found to be associated with thinner flaps in myopic eyes. Moreover, increasing flap diameter was correlated with steeper keratometric value $K_1$. The most common complication was bleeding from the limbal vessels (12.7%). Other complications were seen in 8.4% of the cases, but none prevented further laser ablation.

9. In LASIK enhancements with the FEMTO LDV of previously LASIK-treated eyes, flap thickness correlated with patient age and hinge length in myopic patients. Bleeding from the limbal vessels was reported in 12.9% of the eyes and other complications in 14.1% of the eyes, but none prevented further treatment with excimer laser.
10. In these studies, average horizontal flap diameter varied from 9.1 to 9.2 mm, and average hinge length varied from 4.0 to 4.6 mm. White-to-white distance of the eyes averaged from 11.4 to 11.8 mm.
11. In LASIK revisions, when the flap is still readily noticeable and not too tightly adhered, flap relifting is the recommended procedure. If the primary flap has a small diameter or the old flap is tightly adhered, flap recutting is the method of choice. In LASIK revision, making of the new flap in a different position than the primary flap is recommended. In the cases of primary free cap, the use of a microkeratome is recommended. In LASIK revision with femtosecond laser, surgical experience is required and special attention should be paid on the technical details to avoid complications in the difficult cases.
12. In flap creation, undercutting (thinner flap thickness than attempted) was the most common feature in all microkeratomes. Femtosecond laser created more predictable flaps, which made it possible to create thin flaps. The advantage of making thin flaps is that more corneal tissue is saved to avoid possible iatrogenic keratoectasia. Thin flaps also make reoperation more potential perform if needed.

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## ORIGINAL COMMUNICATIONS

# Corneal Flap Measurements in Laser in situ Keratomileusis Using the Moria M2 Automated Microkeratome

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## ABSTRACT

**PURPOSE:** To evaluate accuracy and predictability and factors that influence the dimensions of the laser in situ keratomileusis (LASIK) corneal flap created with the Moria M2 automated microkeratome (Moria SA, Antony, France).

**METHODS:** The flap thickness of 454 eyes of 243 consecutive patients was measured using subtraction ultrasonic pachymetry during LASIK with the Moria M2 microkeratome head 130 designed to create a 160-μm-thick flap. Flap dimensions were evaluated and measurements were correlated with preoperative parameters. A stepwise regression analysis was used to determine the factors that influenced actual flap thickness.

**RESULTS:** The preoperative spherical equivalent refraction of the 454 eyes ranged from −12.125 diopters (D) to +6.25 D. Patient age ranged from 18 to 57 years (mean age: 31.3±8.8 years). Mean preoperative keratometric power $K_1$ was 44.31±1.59 D and $K_2$ was 43.32±1.54 D. Mean preoperative central corneal thickness was 552.4±32.5 μm (range: 466 to 665 μm). With an attempted thickness of 160 μm, the Moria M2 flap thickness ranged from 77 to 209 μm (mean: 153.3±19.0 μm). Mean horizontal flap diameter was 9.2±0.2 mm and mean hinge length 4.6±0.3 mm. Increasing flap thickness was found to correlate with increasing preoperative corneal thickness, younger patient age, and flatter preoperative keratometric power $K_1$.

**CONCLUSIONS:** Although the standard deviation of the flap thickness was relatively small, remarkable individual variation was noted. Therefore, the intraoperative calculation of the remaining stromal bed is recommended. Furthermore, the consideration of central corneal thickness, patient age, and preoperative keratometry are helpful parameters to avoid too deep ablation. [*J Refract Surg.* 2005;21:377-385.]


Since its introduction in 1990,[1] laser in situ keratomileusis (LASIK) has become one of the most popular surgical procedures to correct refractive errors worldwide.[2-5] In the first step of LASIK, a hinged corneal flap is created with a microkeratome, followed by the ablation of the revealed stromal bed with a 193-nm argon-fluoride excimer laser. Laser in situ keratomileusis has many advantages compared to photorefractive keratectomy (PRK), but the creation of the corneal flap with the microkeratome is a critical step, as flap complications can potentially, although rarely, lead to complications and even to the significant loss of the quality of vision.[6,7] In clinical studies including >1000 eyes, the incidence of intraoperative flap complications during LASIK has been reported to range from 0.3% to 8.6%.[8-12]

A number of different microkeratomes are in clinical use, such as the Hansatome[13-17] (Bausch & Lomb Surgical, Salt Lake City, Utah), the Chiron Automated Corneal Shaper (ACS)[16-19] (Bausch & Lomb), the Moria LSK-1[20,21] and Moria Carriazo Barraquer[22-24] (Moria SA, Antony, France), the SCMD[25,26] (New United Development, Fountain Hills, Ariz), the Summit Krumeich-Barraquer (SKBM; Alcon Laboratories, Ft Worth, Tex),[19,27] the Nidek MK 2000[17,28-32] (Nidek, Gamagori, Japan), and the Amadeus[33] (Advanced Medical Optics, Santa Ana, Calif). Some studies with different microkeratomes report inaccuracies between the intended and achieved flap thickness.[13,14,16-19,26,34-36] In general, undercutting appears to be the most common problem.

The aim of this study was to measure the dimensions of the corneal flaps generated with the Moria M2 automated microkeratome and to determine the factors that were correlated with these dimensions.

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*The authors have no proprietary interest in the materials presented herein.*

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TABLE 1

**Characteristics of 454 Eyes That Received LASIK With the Moria M2 Microkeratome**

| Demographic | Mean±SD |
|---|---|
| Patient age (y) | 31.3±8.8 |
| Preoperative keratometric $K_1$ power (D) | 44.31±1.59 |
| Preoperative keratometric $K_2$ power (D) | 43.32±1.54 |
| Preoperative keratometric power (D) | 43.82±1.53 |
| Spherical equivalent refraction (D) | |
| Myopic eyes | −5.07±2.22 |
| Hyperopic eyes | +2.83±1.70 |
| Horizontal white-to-white distance of the eye (mm) | 11.6±0.4 |

## PATIENTS AND METHODS

### Patient Characteristics

Between August 2001 and November 2002, 454 eyes of 243 consecutive patients underwent LASIK at Kirurgipalvelu Eye Surgery Clinic, Tampere, Finland. All patients were operated on by a single surgeon (J.P.) with vast experience in refractive surgery. Inclusion criteria followed our regular criteria for LASIK operations: age ⩾18 years, stable refraction, no keratoconus, no pregnancy at the time of operation, and no cardiac pacemaker. We excluded two eyes from the study because corneal bed thickness could not be measured during the operation due to technical difficulties. Patient age ranged from 18 to 57 years (mean age: 31.3±8.8 years).

Preoperatively, all patients had a complete ophthalmologic examination, which included slit-lamp microscopy, corneal topography (TMS 2 upgraded; Computed Anatomy Inc, New York, NY), determination of refraction, uncorrected visual acuity (UCVA) and best spectacle-corrected visual acuity (BSCVA), measurement of intraocular pressure (Topcon Computerized Tonometer CT-60; Topcon Corp, Tokyo, Japan), and wavefront analysis (WASCA; Asclepion-Meditec AG, Jena, Germany).

Topical anesthetic oxybuprocain hydrochloride (Oftan Obucain; Santen Oy, Tampere, Finland) was instilled in the operated eyes preoperatively. Central corneal thickness was measured before the surgery with ultrasonic pachymetry (CILCO Inc, Huntington, WV). Two hours postoperatively, UCVA and BSCVA were measured. Uncorrected visual acuity and BSCVA and refraction were also determined 1 month postoperatively. All possible complications encountered intraoperatively or during the 1-month postoperative period were recorded.

### Microkeratome and Surgical Techniques

For corneal flaps, the Moria M2 microkeratome with the control unit ME-LSK evolution 2 and the Head 130 designed to create a 160-µm-thick flap was used for all eyes. Flap thickness was calculated by subtracting the remaining central stromal bed thickness, measured with ultrasonic pachymetry, from the preoperative central corneal thickness. The horizontal white-to-white distance of the eye, flap diameter, and hinge length were measured using a standard caliper. The measurement was read to the nearest 0.1 mm. The suction ring was chosen according to the manufacturer's recommendations (nomogram) based on the keratometric value $K_1$. When both eyes of a patient were operated simultaneously, the same blade was used for the first and second eye. In those cases, the right eye was always treated first. For laser ablation, the Meditec MEL70 G-scan excimer laser system (Aesculap-Meditec) was used. The MEL 70 G-scan is a third-generation laser of Meditec and it operates with a flying spot technique with the following parameters: beam diameter 1.8 mm, fluency rate 180 mJ/cm$^2$, maximum pulse frequency 50 Hz, and optical zone range from 4.0 to 7.0 mm.

### Statistical Analysis

The mean values and standard deviations of corneal thickness, flap thickness, flap horizontal diameter, and hinge length of 454 eyes were calculated. To determine the keratometric power K in hinge direction, the angle between hinge and $K_2$ was determined and the difference between $K_1$ and $K_2$ was calculated. Keratometric power value was assumed to change linearly from $K_1$ to $K_2$. Thus, the K value in hinge direction was determined with the following equation:

$$K_{hinge} = K_2 + (K_1 - K_2) \times (\text{Angle between } K_2 \text{ and hinge}/90) \qquad \text{(Eq 1)}$$

A stepwise regression analysis was used to determine preoperative continuous variables that were predictive of achieved corneal flap thickness.

## RESULTS

The demographic characteristics of the 454 eyes (243 patients) that received LASIK are presented in Table 1. Preoperative spherical equivalent refraction ranged from −12.125 to +6.25 diopters (D). The mean preoperative spherical equivalent refraction in myopic eyes was −5.07±2.22 D and in hyperopic eyes +2.83±1.70 D. Mean

TABLE 2

**Characteristics of 454 Eyes Operated with the Moria M2 Microkeratome***

| | |
|---|---|
| Preoperative corneal thickness (pachymetry, μm) | 552.4±32.5 |
| Flap thickness (μm) | 153.3±19.0 |
| Horizontal flap diameter (mm) | 9.2±0.2 |
| Hinge length (mm) | 4.6±0.3 |

*Values represented as mean±standard deviation.*

preoperative keratometric power $K_1$ was 44.31±1.59 D (range: 39.40 to 48.54 D). Mean keratometric power $K_2$ was 43.32±1.54 D (range: 38.55 to 47.08 D). Mean horizontal white-to-white distance was 11.6±0.4 mm (range: 10.7 to 13.0 mm).

The characteristics of the 454 eyes operated with the Moria M2 microkeratome are shown in Table 2. Preoperative corneal thickness ranged from 466 to 665 µm (mean: 552.4±32.5 µm). The frequency distribution of the preoperative corneal thickness is presented in Figure 1.

With the attempted thickness of 160 µm, the Moria M2 flap thickness averaged 153.3±19.0 µm (range: 77 to 209 µm). The frequency distribution of the flap thickness for 454 eyes is shown in Figure 2. In simultaneously treated cases, the mean flap thickness of the first operated right eyes was 155.8±18.1 µm and 152.0±18.3 µm of the left eyes. Mean horizontal flap diameter was 9.2±0.2 mm (range: 7.9 to 10.0 mm). Mean hinge length was 4.6±0.3 mm (range: 3.7 to 5.4 mm).

No intraoperative complications, such as flap perforation or laceration, occurred. Iron particles were observed in 25 (5.5%) eyes. Epithelial ingrowth in the flap edge occurred in 35 (7.7%) eyes. However, none of those eyes required flap lift and epithelium removal. The change in Snellen lines of the BSCVA 1 month after LASIK is presented in Figure 3. The BSCVA improved by 2 Snellen lines in 2 (0.4%) eyes. Four (0.9%) of the operated eyes lost ⩾2 lines. In 380 (83.7%) eyes, no changes were noted in the Snellen lines of BSCVA.

Figure 4 shows the relationship between preoperative spherical equivalent refraction and preoperative corneal thickness for all operated eyes. In myopic eyes, the greater myopia, the greater the preoperative corneal thickness. In hyperopic eyes, the variation of corneal thickness was larger and no correlation was found.

Table 3 shows the correlation coefficients of the main variables versus the flap thickness. A slight, statistically insignificant relationship was found between preoperative spherical equivalent refraction and corneal flap thickness in myopic and hyperopic eyes, respectively. In myopic eyes, the trend was, the greater myopia, the thinner the flap ($r$=0.057). Similarly, in hyperopic eyes, the greater hyperopia, the thinner the corneal flap ($r$=−0.116).

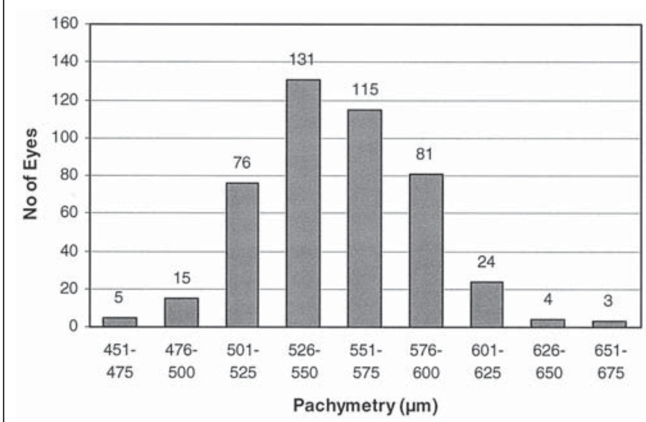


**Figure 1.** Frequency distribution of preoperative corneal thickness (pachymetry, μm) for 454 eyes operated with the Moria M2 microkeratome.

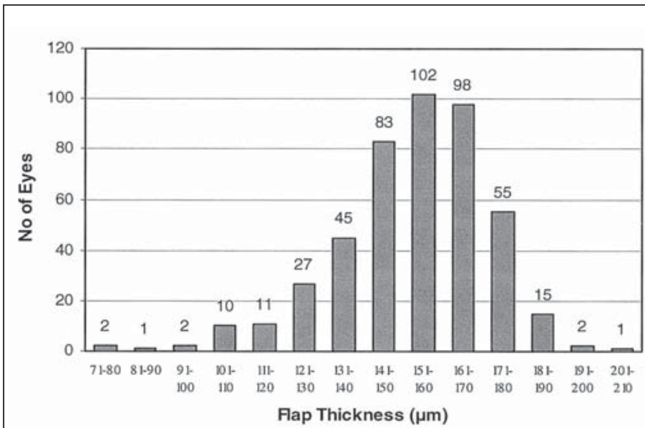


**Figure 2.** Frequency distribution of corneal flap thickness (μm) for 454 eyes operated with the Moria M2 microkeratome. An attempted thickness of 160 μm was intended.

Figure 5 shows the negative correlation of patient age and corneal flap thickness. The younger the patient, the thicker the flap. Figure 6 shows the relationship between preoperative corneal thickness and flap thickness in all operated eyes. It demonstrates that the thicker the cornea, the thicker the flap. Figure 7 shows the relationship between preoperative keratometric power $K_1$ and flap thickness. Increasing flap thickness was associated with flatter keratometric power. A similar relationship was noted between preoperative keratometric power K in hinge direction and corneal flap thickness ($r$=−0.110, $P$<.05).

In hyperopic eyes, the higher the preoperative refraction, the higher the flap diameter ($r$=0.517, $P$<.01). In my-

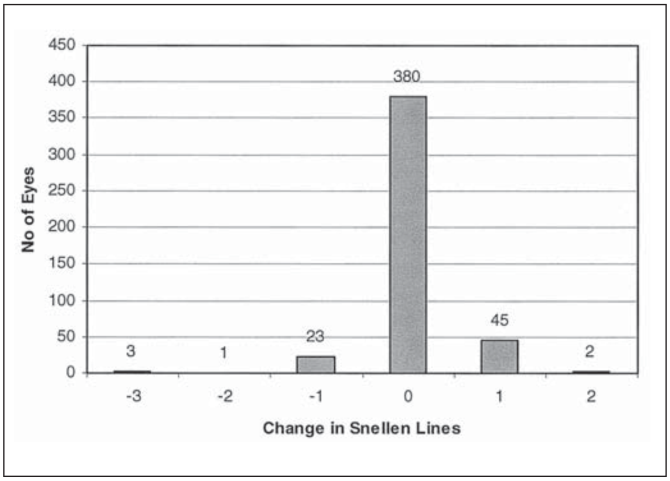


**Figure 3.** Change in Snellen lines of the BSCVA in 454 eyes 1 month after the LASIK surgery.

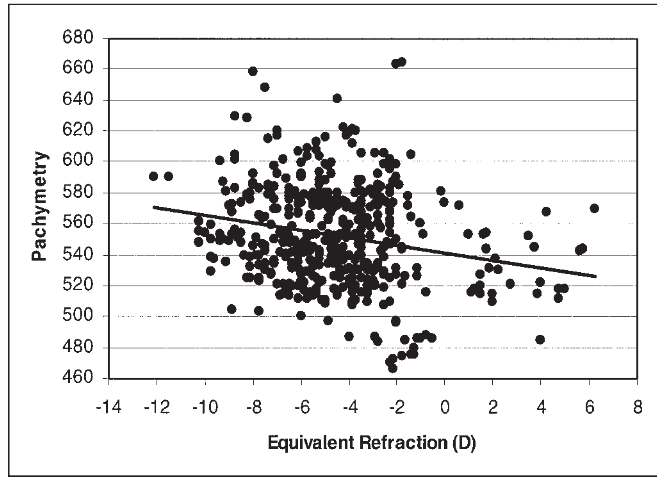


**Figure 4.** Preoperative spherical equivalent refraction (D) and preoperative corneal thickness (pachymetry, $\mu$m). $r=-0.218$ (all eyes). The greater myopia, the greater preoperative corneal thickness.

opic eyes, this correlation could not be found ($r=-0.016$). Increasing corneal flap diameter did not correlate significantly with preoperative corneal thickness ($r=0.068$), but correlated with thinner flaps ($r=-0.148$, $P<.01$). A slight correlation of increasing preoperative spherical equivalent refraction to hinge length was noted in hyperopic eyes ($r=0.475$, $P<.05$). In myopic eyes, no correlation was found between preoperative spherical equivalent refraction and hinge length ($r=-0.011$). Increasing hinge length was associated with thicker corneas ($r=0.206$, $P<.001$) and larger flaps ($r=-0.489$, $P<.001$).

Data of 454 eyes were used for a stepwise regression analysis to generate a model for the Moria M2 microkeratome. $R^2$ value for the model was 0.319 of which 0.282 (88.3%) was explained by preoperative corneal thickness (see Fig 6). The flap thickness can be predicted by the following formula:

$$\text{Corneal flap thickness (µm)} = 78.19 + 0.297 \times \text{mean preoperative corneal thickness} - 0.245 \times \text{patient age} - 1.837 \times \text{keratometric power } K_1 \quad \text{(Eq 2)}$$

## DISCUSSION

In this study, the Moria M2 automated microkeratome with the Head 130 designed for the corneal thickness of 160 µm was used for all 454 operated eyes. The Moria M2 flap thickness averaged 153.3 µm. The standard deviation was relatively small (19.0 µm) when compared to other keratomes (Table 4). However, both undercutting and overcutting occurred (range: 77 to 209 µm). In 5 (1.1%) eyes, the corneal flap was <100 µm. The handling of thin flaps may cause technical difficulties during the operation. However, no buttonholes or other significant flap complications occurred in this study. On the other hand, the corneal flap was >190 µm in 3 (0.7%) eyes.

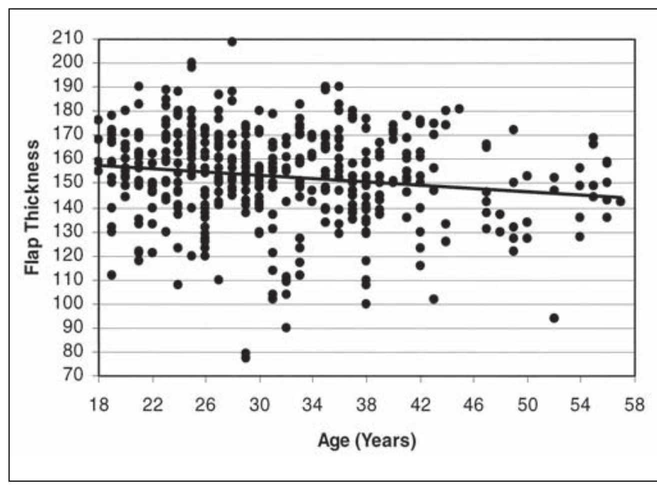


**Figure 5.** Patient age (years) and corneal flap thickness ($\mu$m). $r=-0.157$, $P<.001$. The younger the patient, the thicker the cornea.

We recommend adjusting the ablation zone accordingly when a thick flap is encountered. The standard deviation for flap diameter was very small (0.2 mm). No flaps had a diameter >10.0 mm. A flap diameter <8.5 mm occurred in 1 eye. In the study, increasing hyperopia was associated with increasing flap diameter. The flap diameter created with the Moria M2 microkeratome was large enough for the wider ablations used for hyperopic eyes.

It is valuable for a surgeon to know how preoperative parameters affect actual flap thickness. Therefore, a mathematical formula was generated for the Moria M2 microkeratome to evaluate which preoperative parameters predicted the actual flap thickness. Corneal thickness, patient age, and corneal curvature were found to predict the actual flap thickness best (see Figs 5-7). An increase in flap thickness correlated with thicker preoperative corneal thickness and younger age. Increas-

TABLE 3

**Correlation Coefficients of Variables vs Flap Thickness of 454 Eyes Operated With the Moria M2 Microkeratome**

| Variable | Mean (SD) | Correlation Coefficient | *P* Value |
|---|---|---|---|
| Equivalent refraction (D) | −4.56 (2.92) | −0.052 | NS |
| Myopic eyes | −5.07 (2.22) | 0.057 | NS |
| Hyperopic eyes | 2.83 (1.70) | −0.116 | NS |
| Corneal thickness (μm) | 552.36 (32.45) | 0.531 | <.0001 |
| Myopic eyes | 553.63 (32.68) | 0.523 | <.0001 |
| Hyperopic eyes | 533.79 (21.90) | 0.487 | <.01 |
| Age (y) | 31.26 (8.79) | −0.157 | <.001 |
| Myopic eyes | 30.22 (7.80) | −0.126 | <.01 |
| Hyperopic eyes | 46.41 (8.67) | 0.192 | NS |
| $K_1$ (D) | 44.31 (1.59) | −0.207 | <.001 |
| Myopic eyes | 44.32 (1.60) | −0.221 | <.001 |
| Hyperopic eyes | 44.11 (1.51) | −0.055 | NS |
| Flap diameter (mm) | 9.169 (0.22) | −0.148 | <.01 |
| Myopic eyes | 9.169 (0.22) | −0.141 | <.01 |
| Hyperopic eyes | 9.159 (0.23) | −0.324 | NS |
| Hinge length (mm) | 4.63 (0.32) | 0.180 | <.0001 |
| Myopic eyes | 4.63 (0.32) | 0.09 | NS |
| Hyperopic eyes | 4.58 (0.32) | −0.266 | NS |

*SD = standard deviation, NS = not significant*

ing flap thickness was also related to flatter preoperative keratometric $K_1$ power. This may be due to the fact that in the Moria automated microkeratome M2 system, the suction ring is chosen according to the manufacturer's recommendation, which is based on the $K_1$ value.

Over the past few years, a number of studies evaluating different microkeratomes have been published (Table 4). Variations in flap thickness occur with the attempted flap thickness using the same microkeratome. Undercutting appears to be the most common problem of microkeratomes. Some studies also report differences between the first and second eye operated with the same blade. When the same blade is used in simultaneously treated eyes, the second cut typically creates thinner flap. This was also found in our study. In clinical studies evaluating the flap dimensions with the Moria LSK-1 microkeratome, the achieved flap thicknesses 159 μm[20] and 161 μm[21] have been close to the 160-μm intended flap thickness. On the contrary to our studies, Jacobs et al[20] found no significant correlation between preoperative corneal thickness or mean keratometry and flap thickness when using the Moria LSK-1. Unlike other microkeratomes, Moria microkeratome systems rely on suction rings, which are chosen based on keratometric value $K_1$. In clinical practice, the suction ring is selected by using a nomogram provided by the manufacturer.

Yi and Joo[26] evaluated the SCMD microkeratome and found a significant correlation between corneal thickness and flap thickness, but no correlation between flap thickness and the steepening of the cornea. Gailitis and Lagzdins[14] evaluated the Hansatome microkeratome and found a correlation between flap thickness and corneal thickness, but no correlation between flap thickness and patient age or average keratometric power. Shemesh et al[17] found a statistically significant difference between the first and second eye operated with the same blade using the Hansatome and ACS microkeratomes, but no such difference when using the Nidek MK 2000 microkeratome.

Spadea et al[15] evaluated the Hansatome microkeratome and found statistically significant correlations between mean keratometric power and hinge length and flap diameter. They found a correlation between

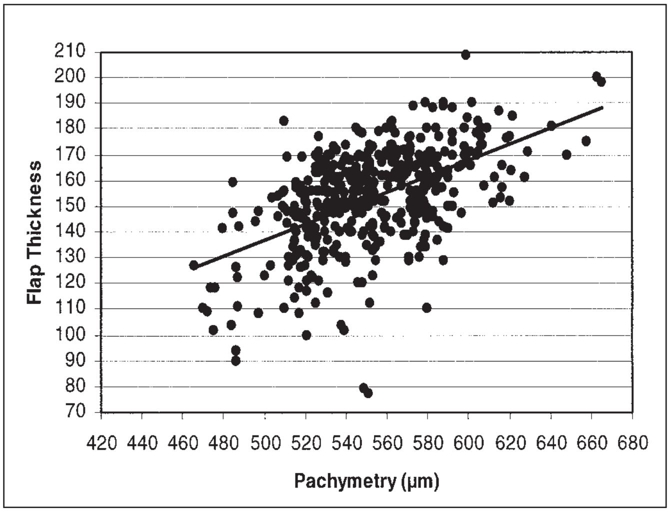


**Figure 6.** Preoperative corneal thickness (pachymetry, $\mu$m) and corneal flap thickness ($\mu$m). $r$=0.531, $P$<.0001. The thicker the cornea, the thicker the flap.

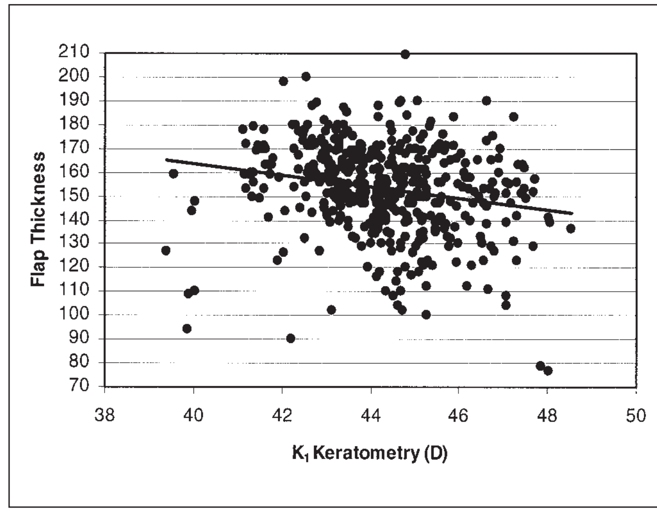


**Figure 7.** Preoperative keratometric power $K_1$ (D) and corneal flap thickness ($\mu$m). $r$=−0.207, $P$<.001. Increasing flap thickness was associated with the flatter keratometric value.

preoperative spherical equivalent refraction and flap diameter, and in accordance with our study, between corneal thickness and hinge length. However, they did not find a correlation between flap thickness and corneal steepening or corneal thickness.

Yildirim et al[13] found a correlation between flap thickness and corneal thickness with the Hansatome microkeratome, but no correlation with keratometry. Compared to our study, similar results have been reported by Flanagan and Binder.[19] They evaluated the ACS and SKBM microkeratomes in 4428 eyes and found a correlation between flap thickness and corneal thickness and flap thickness and patient age. Furthermore, they found that flap thickness correlated with flatter keratometry values in the ACS microkeratome but with steeper keratometry values in the SKBM microkeratome. Ucakhan[27] also found a correlation between flap thickness and corneal thickness, but no correlation with degree of myopia or corneal refractive power.

Although in most clinical studies mean flap thickness has been less than the attempted value, overcutting also occurs. Some Nidek MK 2000 microkeratome models have been reported to cut thicker corneal flaps than attempted.[30,31] In a study evaluating the manually guided microkeratome Moria M1 in pig eyes, some overcutting occurred.[37] With the intended 130-µm flap thickness, 135±37-µm flaps were created.

According to the standard practice, the remaining stromal bed thickness should be at least 250 µm or 50% of the preoperative corneal thickness after the flap thickness and stromal ablation have been subtracted.[38] Manufacturer's stated flap thickness often is used for these calculations. We recommend that the stromal bed thickness be measured intraoperatively to avoid too deep ablation. The most popular means to measure flap thickness is subtraction ultrasonic pachymetry.[39-41] Other methods to measure flap thickness include confocal microscopy, ultrasound biomicroscopy, very high-frequency ultrasound scanning, optical coherence tomography, and partial coherence interferometry. However, these methods can be used only pre- and postoperatively. With very high-frequency ultrasound scanning, the accuracy of the measurement of corneal thickness is 0.71 µm and flap thickness is 1.14 µm.[42] In vivo confocal microscopy through-focusing provides a sensitive method for corneal thickness measurements with a precision of 2.6 µm.[43] Optical coherence tomography and ultrasonic pachymetry have poorer axial resolution with the precision of 6 µm[44] and 12 µm,[45] respectively. Despite these drawbacks, ultrasonic pachymetry provides the most practical means in clinical use to measure corneal thickness intraoperatively.

The Moria M2 is a reliable and safe microkeratome for the wider laser ablation treatment used in hyperopic eyes. In general, refractive surgeons should, however, be aware of the variation in the flap thickness when any of the microkeratomes are used. Although the standard deviation of the flap thickness (19 µm) was relatively small with the Moria M2 microkeratome, in 5% of cases the flap is either 38 µm too thick or thin. Therefore, it is important to evaluate the factors affecting the accuracy of the available microkeratomes. In the present study, the main factors that predict an increase in corneal flap thickness were increasing corneal thickness, younger age, and flatter keratometric value $K_1$. Thus the recognition of these factors and an extra margin for the remaining stromal bed thickness are important to avoid too deep ablations and complications.

TABLE 4

## Comparison of Microkeratomes Used in Clinical Studies

| Study | Microkeratome | Intended Flap Thickness (μm) | No. of Eyes in Study | Mean Achieved Flap Thickness (μm) (SD) |
|---|---|---|---|---|
| Jacobs et al[20] (1990) | Moria LSK-1 | 160 | 93 | 159 (28) |
| Srivannaboon[21] (2001) | Moria LSK-1 | 160 | 151 | 161 (38) |
| Yi & Joo[26] (1999) | SCMD | 150 | 69 | 137.2 (33.7) |
| Maldona et al[34] (2000) | Hansatome | 160 | 63 | 124.8 (18.5) |
| Gailitis & Lagzdins[14] (2002) | Hansatome | 160 | 132 | 119 (20) |
| Shemesh et al[17] (2002) | Hansatome | 160 | 132 | 141.2 (20.1) right eye |
| | | | | 121.0 (27.0) left eye |
| Spadea et al[15] (2002) | Hansatome | 160 | 50 | 142.6 (20.8) |
| Yildirim et al[13] (2000) | Hansatome | 180 | 140 | 120.8 (26.3) |
| Gailitis & Lagzdins[14] (2002) | Hansatome | 180 | 132 | 143 (19) |
| Gokmen et al[16] (2002) | Hansatome | 180 | 15 | 167.4 (21.4) |
| Perez-Santonja et al[18] (1997) | ACS | 130 | 100 | 86.6 (12) |
| Wang et al[46] (1999) | ACS | 130 | 32 | 131 (3) |
| Perez-Santonja et al[18] (1997) | ACS | 160 | 43 | 114.1 (17) |
| Wang et al[46] (1999) | ACS | 160 | 32 | 159 (6) |
| Vesaluoma et al[35] (2000) | ACS | 160 | 62 | 112 (25) |
| Gokmen et al[16] (2002) | ACS | 160 | 12 | 132.7 (12.5) |
| Shemesh et al[17] (2002) | ACS | 160 | 132 | 128.3 (12.6) right eye |
| | | | | 123.0 (13.3) left eye |
| Flanagan & Binder[19] (2003) | ACS | 160 | 1776 | 119.8 (22.9) |
| Ucakhan[27] (2002) | SKBM | 160 | 78 | 154.9 (19.3) |
| Flanagan & Binder[19] (2003) | SKBM | 160 | 2652 | 160.9 (24.1) |
| Naripthaphan & Vongthongsri[31] (2001) | Nidek MK 2000 | 130 | 200 | 120.5 (16.5) 8.5-mm ring |
| | | | | 122.1 (18.5) 9.5-mm ring |
| Schumer & Bains[30] (2001) | Nidek MK 2000 | 130 | 370 | 129 (21.8) model 121 |
| | | | | 152 (25) model 65 |
| Arbelaez[32] (2002) | Nidek MK 2000 | 130 | 328 | 116.0 (19.3) |
| Shemesh et al[17] (2002) | Nidek MK 2000 | 130 | 132 | 127.3 (4.1) right eye |
| | | | | 127.5 (3.7) left eye |
| Schumer & Bains[30] (2001) | Nidek MK 2000 | 160 | 370 | 150 (29.6) model 121 |
| | | | | 173 (26.9) model 65 |
| Vongthongsri et al[28] (2000) | Nidek MK 2000 | 160 | 12 | 149.6 (25.6) |
| Naripthaphan & Vongthongsri[31] (2001) | Nidek MK 2000 | 160 | 200 | 172.7 (27.5) 8.5-mm ring |
| Arbelaez[32] (2002) | Nidek MK 2000 | 160 | 328 | 147.7 (21.7) |

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# Bilateral Comparison of Corneal Flap Dimensions With the Moria M2 Reusable Head and Single Use Head Microkeratomes

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## ABSTRACT

**PURPOSE:** To compare the Moria (Antony, France) M2 automated microkeratome with the head 130 to a new disposable single use head to evaluate complications, accuracy, and safety of the procedure.

**METHODS:** Ninety-eight eyes of 49 consecutive patients were operated with the Moria M2 microkeratome. One eye was operated with the metallic head 130 and the other with a plastic single use head, both designed to create a 160-µm flap. Intraoperative flap dimensions were correlated to preoperative parameters and evaluated 1 month postoperatively.

**RESULTS:** With the head 130, mean thickness was 153.3 µm (standard deviation [SD] 13.3, range: 102 to 179 µm). When using a single use head, mean thickness was 148.0 µm (SD 9.8, range: 120 to 170 µm). Occasional iron particles were observed in one eye with both head types. No true epithelial ingrowth was detected in any of the eyes, but epithelial dots at the wound edge occurred in one eye, when using the head 130, but not in the eyes operated with a single use head.

**CONCLUSIONS:** On average, both head types created thinner flaps than attempted. Single use heads produced thinner flaps than the head 130. Accuracy in flap thickness in terms of standard deviation was significantly better in single use heads than in the head 130. Single use heads also had fewer microkeratome-related complications. In clinical practice, the single use head was easier to use because no assembly was required. Plastic single use heads also worked more smoothly than the metallic head 130. [*J Refract Surg*. 2006;22:354-357.]


Laser in situ keratomileusis (LASIK) has gained popularity compared to photorefractive keratectomy (PRK) as a treatment of choice for correcting refractive errors.[1-3] Today, LASIK is the dominant procedure in refractive surgery.[4,5] The first step of LASIK, the creation of a hinged corneal flap with a microkeratome, is critical.[6-8] A wide variety of microkeratomes are in clinical use, such as the LSK-One, Carriazo-Barraquer (C-B), and M2 by Moria (Antony, France); Hansatome by Bausch & Lomb (Rochester, NY); Automated Corneal Shaper (ACS) by Chiron; Krumeich Barraquer microkeratome (SKBM) by Alcon (Ft Worth, Tex), NIDEK MK-2000 (Gamagori, Japan), and Amadeus by AMO (Santa Ana, Calif). In most studies, achieved flap thickness varies from the attempted flap thickness using the same microkeratome.[9-12] Undercutting appears to be the most common problem of microkeratomes, except for the Amadeus, which tends to cut thicker flaps than attempted.[13] Differences between the first and second eye operated with the same blade have also been reported.

In the present study, the automated Moria M2 microkeratome with the metallic head 130 designed to create a 160-µm flap was compared to a plastic disposable single use head designed for a similar flap thickness. The accuracy of corneal flap dimensions and possible complications encountered were evaluated and compared.

## PATIENTS AND METHODS

### PRE- AND POSTOPERATIVE EXAMINATIONS

Forty-nine consecutive patients (98 eyes) with no previous refractive operations underwent LASIK at Kirurgipalvelu Eye

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TABLE 1

**Preoperative Characteristics of 98 Eyes That Received LASIK With the Moria M2 Reusable Head 130 or a Single Use Head**

| | Reusable Head 130 | | Single Use Head | |
|---|---|---|---|---|
| **Characteristics** | **Right Eye** | **Left Eye** | **Right Eye** | **Left Eye** |
| No. of eyes (%) | 24 (24.5) | 25 (25.5) | 25 (25.5) | 24 (24.5) |
| Mean keratometric power (D, SD) | | | | |
| $K_1$ | 44.26 (1.68) | 44.16 (1.32) | 44.05 (1.44) | 44.41 (1.96) |
| $K_2$ | 43.23 (1.51) | 43.11 (1.61) | 42.94 (1.55) | 43.25 (1.40) |
| Mean spherical equivalent refraction (D, SD) | | | | |
| Myopic eyes | −4.44 (2.13) | −4.30 (2.37) | −4.16 (2.06) | −4.35 (2.13) |
| Hyperopic eyes | +2.44 (0.52) | +2.88 (1.94) | +3.08 (2.14) | +2.50 (0.44) |
| Mean horizontal white-to-white distance (mm, SD) | 11.7 (0.3) | 11.5 (0.3) | 11.5 (0.3) | 11.7 (0.3) |
| Mean corneal thickness (pachymetry, μm, SD) | 553.4 (25.9) | 552.7 (36.8) | 549.4 (34.5) | 554.0 (25.3) |

Surgery Clinic, Tampere, Finland between August and October 2003. Patient age ranged from 18 to 54 years (mean age: 31.7±9.5 years). All patients had a complete preoperative ophthalmologic examination including slit-lamp microscopy, measurement of corneal topography (TMS 2 upgraded; Computed Anatomy Inc, New York, NY), determination of refraction, measurement of uncorrected (UCVA) and best spectacle-corrected visual acuity (BSCVA), measurement of intraocular pressure (Topcon Computerized Tonometer CT-60; Topcon Corp, Tokyo, Japan), and wavefront analysis (WASCA; Asclepion-Meditec AG, Jena, Germany).

Preoperatively, topical anesthetic oxybuprocain hydrochloride (Oftan Obucain; Santen Oy, Tampere, Finland) was instilled in the operated eyes. Preoperative central corneal thickness was measured using ultrasonic pachymetry (CILCO Inc, Huntington, WV). The speed of the sound of the ultrasonic pachymetry was 1623 m/s. The pachymetry was calibrated before each new patient was operated. One month after surgery, UCVA, BSCVA, and refraction were measured. All complications encountered intraoperatively or during the 1-month postoperative period were noted.

### Surgical Technique

The Moria M2 microkeratome with the control unit ME-LSK evolution 2 was used for the creation of corneal flaps. The randomly selected patient's eye was operated with the metallic head 130 and the other eye with the plastic single use head, both designed to create a 160-μm flap. Prior to the operation, a notepaper representing either a single use or head 130 microkeratome was randomly picked by the surgeon's assistant. The right eye was then operated first with the microkeratome type thus chosen. The suction ring was chosen according to the manufacturer's recommendations (nomogram) based on the keratometric value $K_1$. After creation of a hinged flap, flap thickness was calculated by subtracting the remaining central stromal bed thickness from the preoperative central corneal thickness. Stromal thickness was measured immediately after cutting of the flap. No moistening drops were used to obtain pachymetry readings. The horizontal white-to-white distance of the eye, flap diameter, and hinge length were measured using a standard caliper. The stromal bed was ablated using the Meditec MEL70 G-scan excimer laser (Aesculap-Meditec).

## RESULTS

Preoperative spherical equivalent refraction of 98 eyes ranged from −11.4 to +5.4 diopters (D). Preoperative characteristics (by right and left eyes) of the eyes operated with either the Moria M2 head 130 or a single use head are presented in Table 1. Twenty-four right eyes and 25 left eyes were operated with the head 130, whereas 25 right eyes and 24 left eyes were operated with the single use head.

Mean preoperative keratometric powers $K_1$ and $K_2$ were 44.21 D (standard deviation [SD] 1.49) and 43.17 D (SD 1.54) for all eyes operated with the head 130 and 44.22 (SD 1.71) and 43.09 (SD 1.47) for all eyes operated with the single use head.

Mean preoperative central corneal thickness for all eyes operated with the head 130 was 553.0 μm (SD 31.6, range: 493 to 639 μm) and the corresponding

TABLE 2

**Postoperative Characteristics of 98 Eyes That Received LASIK With the Moria M2 Reusable Head 130 or a Single Use Head**

| | Reusable Head 130 | | Single Use Head | |
|---|---|---|---|---|
| **Characteristics** | **Right Eye** | **Left Eye** | **Right Eye** | **Left Eye** |
| Mean flap thickness (µm, SD) | 149.7 (14.6) | 156.8 (11.1) | 148.8 (10.1) | 147.2 (9.6) |
| Mean horizontal flap diameter (mm, SD) | 9.1 (0.2) | 9.1 (0.2) | 9.0 (0.2) | 9.0 (0.2) |
| Mean hinge length (mm, SD) | 4.2 (0.3) | 4.2 (0.3) | 4.2 (0.2) | 4.3 (0.2) |

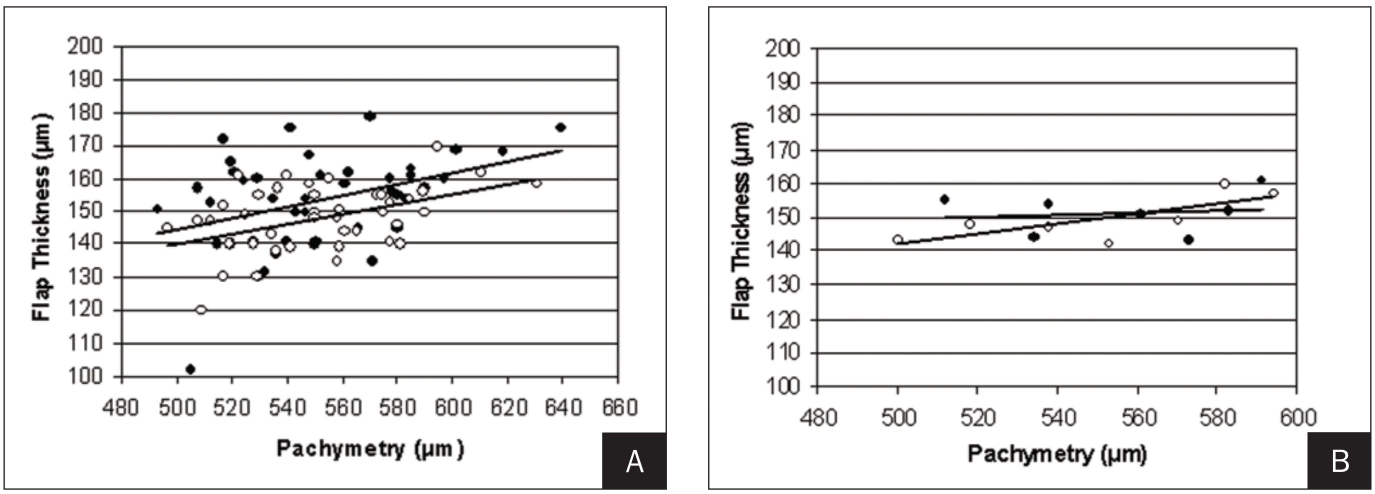


**Figure 1.** Preoperative corneal thickness (measured by ultrasonic pachymetry) and corneal flap thickness in **A)** myopic eyes and **B)** hyperopic eyes operated with the Moria M2 head 130 (●) or single use head microkeratome (○).

value for the single use head was 551.7 µm (SD 30.1, range: 497 to 630 µm).

Postoperative characteristics of 98 eyes by right and left eyes are shown in Table 2. With the attempted thickness of 160 µm with the head 130, the mean thickness for all eyes was 153.3 µm (SD 13.3, range: 102 to 179 µm). When using the single use head, mean thickness for all eyes was 148.0 µm (SD 9.8, range: 120 to 170 µm). Based on statistical analysis, standard deviations, 9.8 µm for the single use head and 13.3 µm for the head 130, were significantly different ($P<.025$).

With the head 130, mean horizontal flap diameter was 9.1 mm (SD 0.2, range: 8.3 to 9.5 mm). With the single use head, the corresponding value was 9.0 mm (SD 0.2, range: 8.3 to 9.4 mm). Mean hinge length was 4.2 mm (SD 0.3, range: 3.3 to 4.6 mm) for the head 130. With the single use head, mean hinge length was 4.2 mm (SD 0.2, range: 3.7 to 4.8 mm). No statistical difference was noted in the mean horizontal flap diameter or the mean hinge length between the head types.

Flap thickness correlated to preoperative corneal thickness in both head types (Fig 1), especially in myopic eyes (r=0.40 for the head 130, r=0.44 for the single use head). There was a tendency towards thinner flaps with higher keratometric $K_1$ values in myopic eyes (Fig 2), but this was not significant. The trend was more evident in the head 130 (r=−0.29) than in the single use head (r=−0.11). No free or incomplete flaps or flaps with buttonholes occurred in the study. Occasional iron particles were observed in one eye with both head types. No real epithelial ingrowth was detected in any of the eyes, but epithelial dots at the wound edge were observed in one eye when using the head 130, but not in the eyes operated with a single use head. However, flap wrinkles/striae occurred in one eye with a single use head.

## DISCUSSION

It has been shown in most clinical studies evaluating different microkeratomes that achieved flap thickness varies from the attempted value.[12] Undercutting appears to be the most common feature. In the present study, thinner corneal flaps were obtained with a single use head than with the head 130 (148.0 vs 153.3 µm). However, accuracy in flap thickness in terms of standard deviation was statistically better in

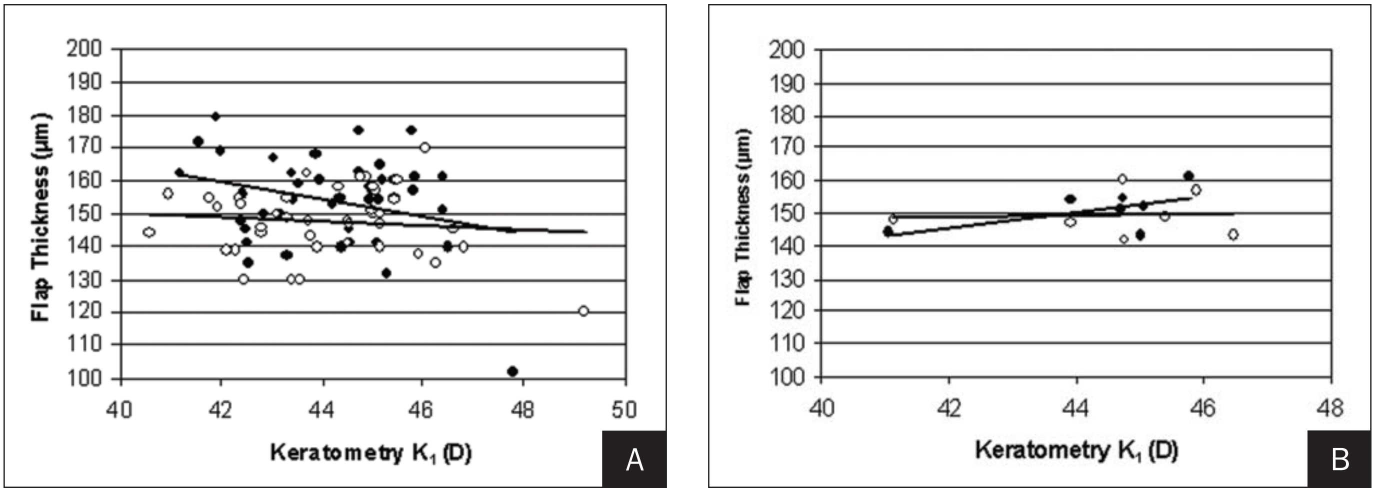


**Figure 2.** Keratometric power $K_1$ and corneal flap thickness in **A)** myopic eyes and **B)** hyperopic eyes operated with the Moria M2 head 130 (●) or single use head microkeratome (○).

a single use head than in the head 130 (9.8 vs 13.3 µm). The most commonly used microkeratomes have been reported to have standard deviations of approximately ⩾20 µm.[12] In our previous study, evaluating 454 eyes with the Moria M2 metallic head 130, we obtained the same mean flap thickness (153.3 µm) as in the current study, but a higher standard deviation (19 µm).[12] This improvement in standard deviation was obtained, in all probability, by the learning curve of the procedure.

In our earlier study, we found that increasing flap thickness was mostly dependent on increasing corneal thickness, younger patient age, and flatter keratometric power $K_1$.[12] In the present study, with both head types, flap thickness was mostly dependent on corneal thickness. Differences were also noted between the right and left eye operated. The slight variation between the right and left eye was most likely due to the technical difficulty in operating the microkeratome in a similar way for both eyes. Furthermore, the numbing drops applied may have caused variation in hydration and flap thickness. The numbing drops were applied in the eyes approximately 20 minutes, 5 minutes, and immediately before the operation. The left eye was covered during surgery on the right eye. This difference may also have some impact on flap thickness.

In clinical practice, the single use head was easier to use. No assembly was needed and the transparent plastic head provided a better observation view for the surgeon on the operated eye. The plastic single use head also worked more smoothly than the metallic head 130. Moreover, it should be noted that in a larger scale clinical practice, single use heads have the potential to minimize the risk of infection related to microkeratome use.[6-8]

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# Corneal flap thickness with the Moria M2 single-use head 90 microkeratome

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**ABSTRACT.**
***Purpose:*** **To analyse the accuracy of corneal flap thickness created in laser-assisted *in situ* keratomileusis (LASIK) using the Moria Model 2 (M2) single-use head 90 microkeratome.**
***Methods:*** **The corneal thickness of 300 (266 myopic and 34 hyperopic) eyes of 150 patients was measured by ultrasonic pachymetry preoperationally and intraoperationally after flap cut. The Moria M2 single-use head 90, intended to create a flap with a thickness of 120 μm, was used in all eyes. The right eye was always operated first and the left eye second, using the same blade.**
***Results:*** **Mean corneal flap thickness was 115.4 μm (standard deviation [SD] 12.5) in the two eyes, 115.7 μm (SD 12.4, range 73–147 μm) in right eyes and 115.1 μm (SD 12.6, range 74–144 μm) in left eyes. Mean horizontal flap diameter was 9.1 mm (SD 0.2) and mean hinge length 4.1 mm (SD 0.1). There were no free flaps, incomplete flaps or flaps with buttonholes in the study. Occasional iron particles were observed in three (1.0%) eyes.**
***Conclusions:*** **As with most microkeratomes, the single-use head 90 microkeratome cut thinner flaps than were intended. The range of the cuts was relatively wide. However, thin flaps did not increase the rate of flap-related complications. The difference between the first and second eyes was not significant.**

**Key words:** laser-assisted *in situ* keratomileusis – LASIK – microkeratome – single use – corneal flap thickness

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## Introduction

Laser-assisted *in situ* keratomileusis (LASIK) is the most popular procedure in refractive surgery (Duffey & Leaming 2003, 2005). The first step in LASIK, the creation of a hinged corneal flap with a microkeratome, is critical (Wilson 1998; Ambrosio & Wilson 2001). In some LASIK studies evaluating ≥1000 eyes, the incidence of microkeratome-related flap complications has been reported to range from 0.3% to 1.9% (Gimbel et al. 1998; Tham & Maloney 2000; Jacobs & Taravella 2002).

There are a wide variety of microkeratomes in clinical use. These include the LSK-1, the Carriazo-Barraquer (C-B), and the Model 2 (M2) (all by Moria SA, Antony, France), the Hansatome (Bausch & Lomb Surgical, Salt Lake City, UT, USA), the Chiron automated corneal shaper (ACS; Bausch & Lomb), the Summit Krumeich Barraquer microkeratome (SKBM; Alcon Laboratories, Forth Worth, TX, USA), the Nidek MK-2000 (Nidek, Gamagori, Japan) and the Amadeus (Advanced Medical Optics, Santa Ana, CA, USA). The most common feature of different microkeratomes is that the flap thickness achieved is thinner than that intended (Shemesh et al. 2002; Spadea et al. 2002; Flanagan & Binder 2003; Pietilä et al. 2005). An exception is the Amadeus, which tends to cut thicker flaps than intended (Jackson et al. 2003). Differences between the first (primary) and second (fellow) eye operated with the same blade have also been reported (Gailitis & Lagzdins 2002; Shemesh et al. 2002, 2004).

The recently developed single-use head microkeratomes have several advantages compared with the traditional metallic heads, such as lack of assembly requirements and transparency (Pietilä et al. 2006). In the present study, the accuracy of corneal flap dimensions created by the automated, plastic single-use head 90 Moria M2 microkeratome, designed to create a thin 120-$\mu$m flap, was evaluated in 300 operated eyes.

# Materials and Methods

### Pre- and postoperative examinations

A total of 150 consecutive patients with no earlier refractive operations underwent LASIK at Mehiläinen Eye Surgery Clinic (Tampere, Finland) between September 2004 and February 2005. Mean patient age was 34.7 years (SD 10.7, range 18–63 years. All patients underwent a complete preoperative ophthalmological examination including biomicroscopy, measurement of corneal topography (TMS 2 upgraded; Computed Anatomy Inc., New York, NY, USA), determination of refraction, measurement of uncorrected (UCVA) and best spectacle-corrected visual acuity (BSCVA), measurement of intraocular pressure (Topcon computerized tonometer CT-60; Topcon Corp., Tokyo, Japan), and wavefront analysis (WASCA; Asclepion-Meditec AG, Jena, Germany). Preoperative central corneal thickness was measured with ultrasonic pachymetry (CILCO Inc., Huntington, WV, USA) operating at a speed of sound of 1623 m/second. The pachymetry was calibrated before each new patient.

Prior to the surgery, topical anaesthetic oxybuprocain hydrochloride (Oftan Obucain; Santen Oy, Tampere, Finland) was instilled into the operated eyes. After the operation, 3% ofloxacin solution (Exocin; Allergan, Eastport, Co. Mayo, Ireland) and 1% diclofenac solution (Voltaren Ophtha; Novartis, Copenhagen, Denmark) were applied. Over the following 7 days, 1% dexamethason-2% chloramphenicol solution (Oftan Dexa-chlora; Santen Oy) was tapered from five times to twice daily. One month after surgery, UCVA, BSCVA and refraction were measured.

### Microkeratome and surgical techniques

The Moria M2 microkeratome with the ME-LSK evolution 2 control unit (Moria SA) was used to create corneal flaps in all eyes. This is a plastic single-use head 90 microkeratome, designed to create a 120-$\mu$m flap. The right eye was always operated first and the left eye second, using the same blade. The suction ring was chosen according to the manufacturer's recommendations (nomogram) based on the keratometric value $K_1$. After creation of a hinged flap, flap thickness was calculated by subtracting the remaining central stromal bed thickness from the preoperative total central corneal thickness. Stromal thickness was measured immediately after flap cut. No moistening drops were used to obtain pachymetry readings. The horizontal white-to-white distance of the eye, flap diameter and hinge length were measured using a standard calliper. The stromal bed was ablated using the Meditec MEL80 G-scan excimer laser (Carl Zeiss-Meditec, Jena, Germany).

### Statistical analysis

The mean values and standard deviations of corneal thickness, flap thickness, flap horizontal diameter and hinge length in 300 eyes were calculated. To determine the keratometric power K in the hinge direction, the angle between the hinge and $K_2$ was determined and the difference between $K_1$ and $K_2$ calculated. Keratometric power value was assumed to change linearly from $K_1$ to $K_2$. Thus, the K-value in hinge direction was determined with the following equation:

$$K_{hinge} = K_2 + (K_1 - K_2) \times (\text{angle between} K_2 \text{and hinge}/90) \quad (1)$$

# Results

The demographic characteristics of the 300 eyes (150 patients) that underwent LASIK are presented in Table 1. Preoperative spherical equivalent refraction varied from −14.00 D to +5.75 D. The study included 266 myopic and 34 hyperopic eyes. Mean spherical equivalent refraction in myopic eyes was −5.04 D (SD 2.26); that in hyperopic eyes was +2.67 D (SD 1.49). Mean preoperative keratometric $K_1$ value was 44.42 D (SD 1.54, range 40.98–48.31 D). Mean preoperative keratometric $K_2$ was 43.46 D (SD 1.48, range 40.11–47.41 D). Mean horizontal white-to-white distance of the eyes was 11.6 mm (SD 0.4, range 10.5–12.6 mm). Mean preoperative corneal thickness was 548.9 $\mu$m (SD 32.0, range 458–653 $\mu$m). The frequency distribution of preoperative corneal thickness is presented in Fig. 1.

The postoperative characteristics of the 300 eyes operated with the Moria M2 single-use head 90 microkeratome are shown in Table 2. Attempted corneal flap thickness was 120 $\mu$m; actual flap thickness averaged 115.4 $\mu$m (SD 12.5, range 73–147 $\mu$m). The frequency distribution of flap thickness for 300 eyes is shown in Fig. 2. The mean value in right eyes (operated first) was 115.7 $\mu$m (SD 12.4); that in left eyes was 115.1 $\mu$m (SD 12.6). The difference between right and left eyes was not statistically significant ($p > 0.05$). Horizontal flap diameter ranged from 8.6 mm to 9.6 mm. The mean flap diameter for both right and left eyes was 9.1 mm (SD 0.2). Hinge length ranged from 3.4 mm to 4.5 mm. The mean hinge length in right eyes was 4.1 mm (SD 0.1); that in left eyes was 4.1 mm (SD 0.2).

**Table 1.** Characteristics of 300 eyes operated with the Moria M2 single-use head 90 microkeratome.

| Demographic | Mean | (SD) |
|---|---|---|
| Patient age (years) | 34.7 | (10.7) |
| Spherical equivalent refraction (D) | | |
| Myopic eyes ($n$ = 266) | − 5.04 | (2.26) |
| Hyperopic eyes ($n$ = 34) | + 2.67 | (1.49) |
| Preoperative keratometric $K_1$ power (D) | 44.42 | (1.54) |
| Preoperative keratometric $K_2$ power (D) | 43.46 | (1.48) |
| Mean preoperative keratometric power (D) | 43.94 | (1.47) |
| Horizontal white-to-white distance of the eye (mm) | 11.6 | (0.4) |

SD = standard deviation.

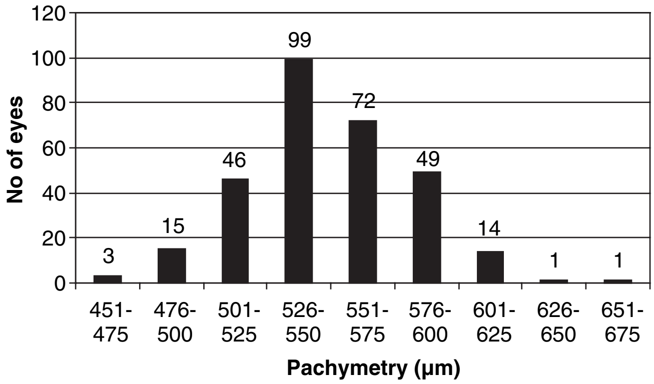


**Fig. 1.** Frequency distribution of preoperative corneal thickness (pachymetry, $\mu$m) for 300 eyes operated with the Moria M2 single-use head 90 microkeratome.

**Table 2.** Characteristics of 300 eyes operated with the Moria M2 single-use head 90 microkeratome.

| Demographic | Mean | (SD) |
|---|---|---|
| Preoperative corneal thickness (pachymetry, $\mu$m) | 548.9 | (32.0) |
| Flap thickness both eyes ($\mu$m) | 115.4 | (12.5) |
| Flap thickness right eyes ($\mu$m) | 115.7 | (12.4) |
| Flap thickness left eyes ($\mu$m) | 115.1 | (12.6) |
| Horizontal flap diameter (mm) | 9.1 | (0.2) |
| Hinge length (mm) | 4.1 | (0.1) |

SD = standard deviation.

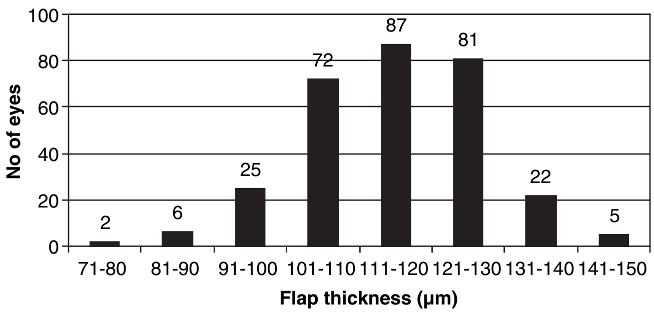


**Fig. 2.** Frequency distribution of corneal flap thickness ($\mu$m) for 300 eyes operated with the Moria M2 single-use head 90 microkeratome. Intended thickness was 120 $\mu$m.

**Table 3.** Uncorrected visual acuity preoperatively and 1 month after LASIK.

| | Myopic eyes | | | | Hyperopic eyes | | | |
|---|---|---|---|---|---|---|---|---|
| | Baseline | | 1 month | | Baseline | | 1 month | |
| Visual acuity | *n* | (%) | *n* | (%) | *n* | (%) | *n* | (%) |
| 20/20 | 0 | | 210 | (79.5) | 0 | | 18 | (52.9) |
| < 20/20 but ≥ 20/40 | 2 | (0.8) | 47 | (17.8) | 7 | (20.6) | 12 | (35.3) |
| < 20/40 but ≥ 20/100 | 21 | (7.9) | 7 | (2.7) | 22 | (64.7) | 4 | (11.8) |
| < 20/100 but ≥ 20/200 | 14 | (5.3) | 0 | | 3 | (8.8) | 0 | |
| < 20/200 | 229 | (86.1) | 0 | | 2 | (5.9) | 0 | |

There were no free or incomplete flaps, or flaps with buttonholes in the study. Occasional iron particles were observed in three (1.0%) eyes.

Refractive, UCVA and BSCVA outcomes 1 month after LASIK with the Meditec MEL80 G-scan excimer laser were available for 298 eyes (149 patients). The number of eyes within ± 0.50 D of target refraction 4 weeks after LASIK was 244 (92.4%) in the myopia group and 33 (97.1%) in the hyperopia group. After 1 month, 97.3% of myopic eyes achieved UCVA ≥ 20/40 (Table 3). The corresponding percentage for hyperopic eyes was 88.2%. Mean BSCVA improved slightly compared with baseline values. The change in BSCVA at 1 month is presented in Fig. 3. None of the eyes lost ≥ 2 Snellen lines. One (0.4%) myopic eye gained 2 lines and 68 (25.8%) myopic eyes gained 1 line. Two (5.9%) hyperopic eyes gained 1 line. In 205 eyes (68.3% of all eyes), no changes were noted in Snellen lines for BSCVA.

Preoperative spherical equivalent refraction did not correlate with preoperative corneal thickness ($r = -0.040$, all operated eyes) (Fig. 4). Table 4 shows the correlation coefficients of the main variables versus flap thickness. Figure 5 shows the negative correlation of patient age and corneal flap thickness ($r = -0.194$, $p < 0.001$). The younger the patient, the thicker the flap. Figure 6 shows the relationship between preoperative corneal thickness and flap thickness in the right (operated first) and left (operated second) eyes. It demonstrates that the thicker the cornea, the thicker the flap. There were no differences between right eyes ($r = 0.576$, $p < 0.0001$) and left eyes ($r = 0.536$, $p < 0.0001$). Figure 7 (A, B) shows the relationship between preoperative keratometric power $K_1$ and corneal flap thickness. In myopic eyes, flap thickness was not correlated with keratometric power $K_1$ ($r = -0.039$), but in hyperopic eyes increasing flap thickness was associated with flatter keratometric power $K_1$ ($r = -0.530$; $p < 0.01$). A similar relationship was noted between preoperative keratometric power $K_2$ and corneal flap thickness (myopic eyes $r = -0.015$, hyperopic eyes $r = -0.449$; $p < 0.01$), mean preoperative keratometric power K and corneal flap thickness (myopic eyes $r = -0.028$, hyperopic eyes $r = -0.499$; $p < 0.01$) and preoperative keratometric power K in hinge direction and corneal flap thickness (myopic eyes $r = -0.029$, hyperopic eyes $r = -0.393$; $p < 0.05$).

Increasing corneal flap diameter correlated significantly with preoperative

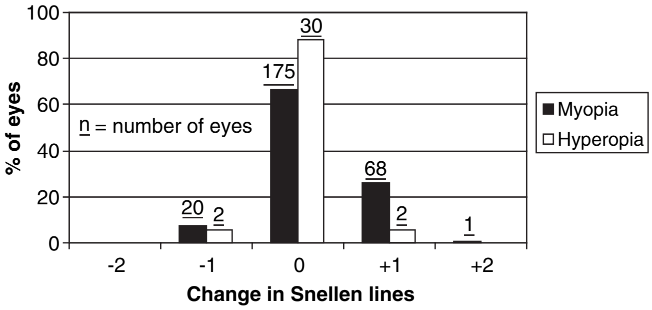


**Fig. 3.** Change in best spectacle-corrected visual acuity 1 month after LASIK, in myopic and hyperopic eyes.

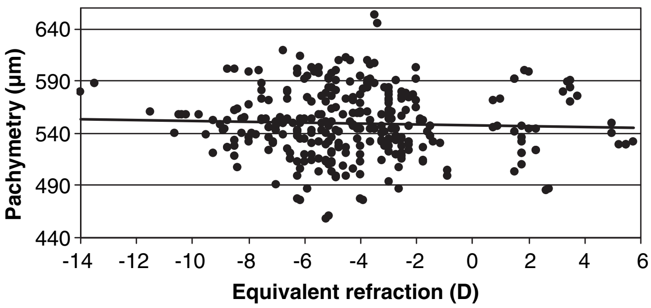


**Fig. 4.** Preoperative spherical equivalent refraction (D) and preoperative corneal thickness (pachymetry, $\mu$m), $r = -0.040$.

**Table 4.** Correlation coefficients of variables versus flap thickness in 300 eyes operated with the Moria M2 single-use head 90.

| Variable | Mean | (SD) | Correlation coefficient | p-value |
|---|---|---|---|---|
| Equivalent refraction (D) | − 4.16 | (3.28) | − 0.076 | NS |
| Myopic eyes | − 5.04 | (2.26) | − 0.052 | NS |
| Hyperopic eyes | + 2.67 | (1.49) | − 0.067 | NS |
| Corneal thickness ($\mu$m) | 548.94 | (32.02) | 0.555 | < 0.0001 |
| Myopic eyes | 549.07 | (32.13) | 0.567 | < 0.0001 |
| Hyperopic eyes | 547.91 | (31.54) | 0.470 | < 0.01 |
| Age (years) | 34.69 | (10.68) | − 0.194 | < 0.001 |
| Myopic eyes | 33.06 | (9.45) | − 0.211 | < 0.001 |
| Hyperopic eyes | 47.47 | (11.23) | − 0.054 | NS |
| $K_1$ keratometry (D) | 44.42 | (1.54) | − 0.083 | NS |
| Myopic eyes | 44.55 | (1.50) | − 0.039 | NS |
| Hyperopic eyes | 43.44 | (1.51) | − 0.530 | < 0.01 |
| Flap diameter (mm) | 9.09 | (0.17) | 0.040 | NS |
| Myopic eyes | 9.09 | (0.17) | 0.062 | NS |
| Hyperopic eyes | 9.04 | (0.12) | − 0.256 | NS |
| Hinge length (mm) | 4.06 | (0.15) | 0.091 | NS |
| Myopic eyes | 4.06 | (0.15) | 0.113 | NS |
| Hyperopic eyes | 4.07 | (0.10) | − 0.129 | NS |

SD = standard deviation, NS = not significant.

corneal thickness in myopic eyes ($r = 0.229$, $p < 0.001$), but not in hyperopic eyes ($r = -0.111$, $p > 0.05$). Similarly, increasing hinge length was associated with thicker corneas in myopic eyes ($r = 0.216$, $p < 0.001$), but not in hyperopic eyes ($r = 0.273$, $p > 0.05$).

# Discussion

One of the possible longterm complications in corneal surgery is postoperative keratectasia. Therefore, keeping the thickness of the corneal flap as thin as possible and thus the thickness of the corneal bed as thick as possible is important in LASIK surgery. Thus, establishing corneal flap thickness and predicting its variations both play significant roles in LASIK surgery. The flap thickness created with different microkeratomes has been shown to vary from intended values (Pietilä et al. 2005). Undercutting (i.e. cutting corneal flaps that are thinner than intended) appears to be the most common problem with most microkeratomes (Flanagan & Binder 2003; Pietilä et al. 2005, 2006) other than the Amadeus (Jackson et al. 2003), which tends to cut thicker flaps than intended. In this study, the Moria M2 automated single-use head 90 microkeratome, designed to achieve a corneal thickness of 120 $\mu$m, was used in all 300 operated eyes. The results with the M2 microkeratome averaged 115.4 $\mu$m (SD 12.5). Flap thickness ranged from 73 $\mu$m to 147 $\mu$m. Thin flaps are prone to buttonholes and necessitate more complicated handling during surgery. However, in this study, incomplete flaps, buttonholes and other microkeratome-related complications were not observed. The standard deviation was relatively small. Thick flaps can prevent appropriate laser ablation. In the present study, extraordinarily thick flaps, which may significantly reduce the thickness of the stromal tissue available for laser ablation, were not created. Only in a few cases was the thickness of the remaining untouched stromal bed < 300 $\mu$m. Usually, in the case of an unexpectedly thick flap, the size of the ablation is adjusted accordingly to a smaller depth. In the case of an exceptionally thick flap, which occurs very rarely, the procedure is aborted.

In the present study, thinner flaps (up to 73 $\mu$m) were created. It should be noted that surgeons must be as cautious of creating ultra-thin flaps, which may cause problems in the lifting and repositioning of the flap, as they are of thicker flaps. Flap thickness correlated positively with corneal thickness, as has been shown in our earlier studies with the Moria M2 metallic reusable head 130 microkeratome (Pietilä et al. 2005, 2006) and the plastic single-use head 130 microkeratome (Pietilä et al. 2006).

Another common feature of microkeratomes concerns the difference that emerges between the first and second

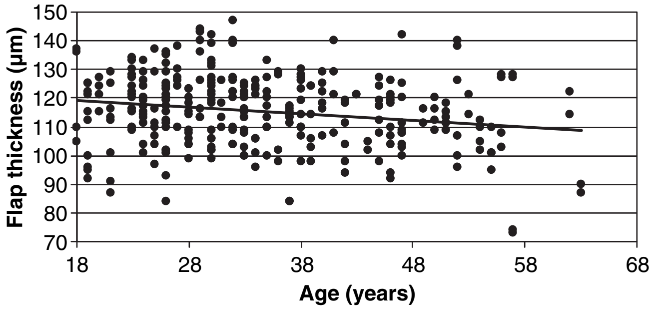


**Fig. 5.** Patient age (years) and corneal flap thickness ($\mu$m), $r = -0.194$, $p < 0.001$ (all eyes). The younger the patient, the thicker the flap.

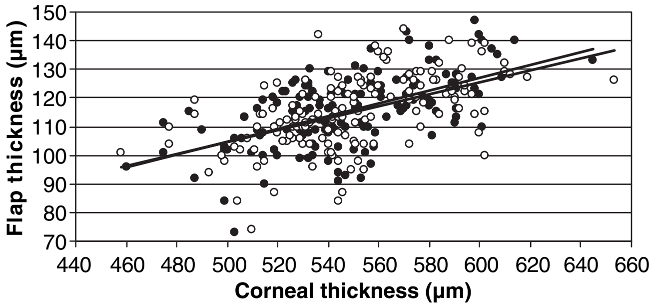


**Fig. 6.** Preoperative corneal thickness (measured by ultrasonic pachymetry, $\mu$m) and corneal flap thickness ($\mu$m) right eyes (•) $r = 0.576$, $p < 0.0001$; left eyes (○): $r = 0.536$, $p < 0.0001$.

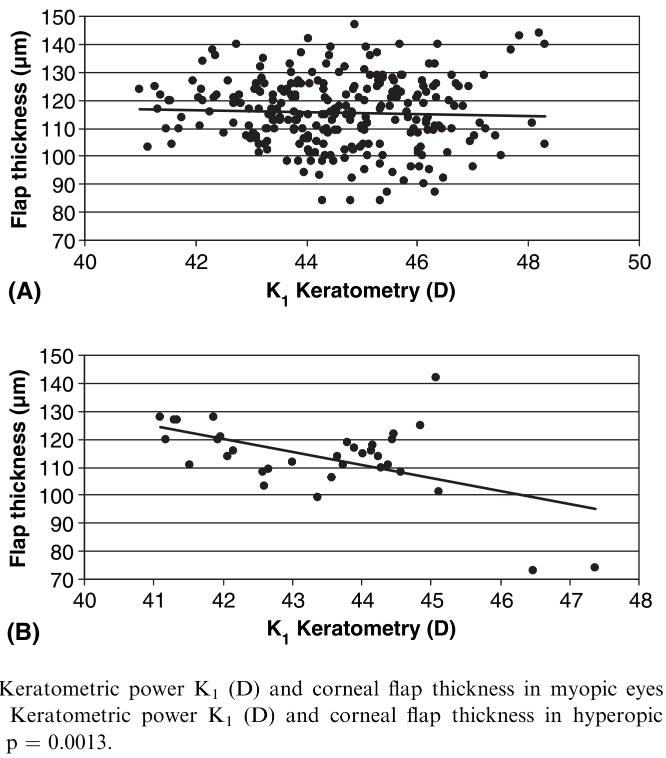


**Fig. 7.** (A) Keratometric power $K_1$ (D) and corneal flap thickness in myopic eyes ($\mu$m), $r = -0.039$. (B) Keratometric power $K_1$ (D) and corneal flap thickness in hyperopic eyes ($\mu$m), $r = -0.530$, $p = 0.0013$.

eyes when the same blade is used for both eyes (Arbelaez 2002; Shemesh et al. 2002, 2004). However, in this study of the Moria M2 single-use head 90, this difference was insignificant: mean corneal flap thickness was 115.7 $\mu$m (SD 12.4) in right eyes and 115.1 $\mu$m (SD 12.6) in left eyes.

A common source of serious complications is use of the microkeratome after improper assembly, which pertains to the use of reusable metallic microkeratomes (Ambrosio & Wilson 2001). The single-use microkeratome eliminates this problem because it does not need any assembly. Due to its transparency, the plastic head provides the surgeon with a better view of the operated eye than a metallic head does. In larger scale clinical practice, single-use heads have the potential to minimize the risk of infection related to reusable microkeratomes (Wilson 1998; Ambrosio & Wilson 2001; Jacobs & Taravella 2002).

The benefits of a thicker stromal bed and the potential technical problems with ultra-thin flaps should be taken into consideration when selecting a microkeratome. In the hands of an experienced surgeon, treatment with the Moria M2 single-use head 90 microkeratome is a safe procedure, as shown in this study, in which no incomplete flaps, buttonholes or other microkeratome-related complications were found.

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# Corneal flap thickness with the Moria M2™ microkeratome and Med-Logics calibrated LASIK blades

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**ABSTRACT.**
***Purpose:*** **This study aimed to compare and study potential factors that affect the accuracy of corneal flap thickness created in laser-assisted *in situ* keratomileusis (LASIK) using the Moria model 2 (M2™) head 130 microkeratome with the Med-Logics calibrated LASIK blades Minus 20 (ML –20) and Minus 30 (ML –30).**
***Methods:*** **Corneal thickness in 200 (164 myopic and 36 hyperopic) eyes (100 patients) was measured by ultrasonic pachymetry preoperatively and intraoperatively after flap cutting. A total of 100 eyes were treated with the ML –20 and 100 with the ML –30. The right eye was operated before the left eye in each patient, using the same blade. In an additional group of 40 eyes, the left eye was operated first.**
***Results:*** **Mean corneal flap thickness using the ML –20 blade for an intended flap thickness of 140 $\mu$m was 129.1 $\mu$m (standard deviation [SD] 15.6, range 104–165 $\mu$m) in right eyes and 111.5 $\mu$m (SD 14.5, range 78–144 $\mu$m) in left eyes. Mean corneal flap thickness using the ML –30 blade for an intended flap thickness of 130 $\mu$m was 127.1 $\mu$m (SD 16.6, range 90–168 $\mu$m) in right eyes and 109.9 $\mu$m (SD 16.8, range 72–149 $\mu$m) in left eyes.**
***Conclusions:*** **Both microkeratome blade types cut thinner flaps than were intended. There was substantial variation in flap thickness. The first flap to be cut with a particular blade was considerably thicker than the second flap cut with the same blade. Based on these data, we recommend the use of disposable single-use microkeratomes rather than these ML blades.**

**Key words:** calibrated blade – laser-assisted *in situ* keratomileusis – LASIK – microkeratome – single use

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## Introduction

Laser-assisted *in situ* keratomileusis (LASIK) remains the most popular procedure in refractive surgery (Duffey & Leaming 2003, 2005a, 2005b). Today, a wide variety of microkeratomes is in clinical use (Pietilä et al. 2006). Most studies evaluating different microkeratomes have shown that the flap thickness achieved varies from the intended value (for review, see Pietilä et al. 2005). Undercutting (i.e. achieving a thinner flap than expected) appears to be the most common problem with most microkeratomes (Flanagan & Binder 2003; Pietilä et al. 2005, 2006), except for the Amadeus™ (Jackson et al. 2003), which tends to cut thicker flaps than intended. Differences between first and second eyes operated with the same blade have also been reported (Arbelaez 2002; Gailitis & Lagzdins 2002; Shemesh et al. 2002, 2004). The incidence of actual microkeratome-related flap complications has been reported to range from 0.3% to 1.9% (Gimbel et al. 1998; Tham & Maloney 2000; Jacobs & Taravella 2002).

The recently developed, single-use head microkeratomes have advantages compared with the traditional metallic heads, such as lack of assembly requirements and transparency (Pietilä et al. 2006; Huhtala et al. 2007). Another new type of microkeratome is represented by the metallic head Moria model 2 (M2™) microkeratome (Moria SA, Antony, France), which is adjusted to a thinner corneal flap thickness with a calibrated single-use blade. The current study was performed to evaluate the accuracy of the adjustable M2™ microkeratome with single-use adjustable Med-Logics blades (Med-Logics, Inc., Laguna Hills, CA, USA) and to evaluate potential factors that may influence flap morphology, such as preoperative corneal thickness, patient age and keratometry readings.

# Materials and Methods

### Study design

This study presents a non-controlled, non-randomized retrospective analysis of 200 eyes in 100 patients undergoing LASIK at the Mehiläinen Eye Surgery Clinic (Tampere, Finland) between November 2005 and January 2006. All eyes were operated at one centre by one surgeon using one microkeratome. Enrolment criteria included no history of prior refractive surgery, corneal thickness ≥ 500 $\mu$m and no signs of keratoconus or other corneal pathology. The M2™ head 130 microkeratome, intended to create a 160-$\mu$m corneal flap, was adjusted with a single-use Med-Logics calibrated blade designated the Minus 20 (ML –20) to create an intended 140-$\mu$m flap (used in the 140-$\mu$m cohort). Correspondingly, the M2™ head 130 was adjusted with a Med-Logics calibrated blade designated the Minus 30 (ML –30) to create a 130-$\mu$m flap (used in the 130-$\mu$m cohort). A sample of 100 eyes were treated with the ML –20 and another 100 eyes were treated with the ML –30 and the results of the procedures compared. In these eyes, the right eye was always operated before the left eye. Results from an additional 40 eyes (20 eyes with each blade type), in which the left eye was operated first, were used to evaluate whether the measurements were affected by the sequence of operation.

### Preoperative examinations

To exclude any severe pathology which might contraindicate LASIK surgery or have an affect on flap creation, all patients underwent a complete preoperative ophthalmological examination. It included biomicroscopy, measurement of corneal topography (Allegro Topolyzer; Wavelight AG, Erlangen, Germany), determination of refraction, measurement of uncorrected and best spectacle-corrected visual acuity (VA), measurement of intraocular pressure (Topcon Computerized Tonometer CT-60; Topcon Corp., Tokyo, Japan), and wavefront analysis (Allegro Analyzer; Wavelight AG). Preoperative central corneal thickness (CCT) was measured with ultrasonic pachymetry (SP–3000; Tomey Corp., Nagoya, Japan). The median of three measurements before and after the cut was recorded as preoperative pachymetry. The stroma was not moistened prior to the measurements.

### Surgical technique

Prior to the surgery, topical anaesthetic oxybuprocain hydrochloride (Oftan Obucain; Santen Oy, Tampere, Finland) was instilled into the operated eyes, after which preoperative pachymetry was recorded. The M2™ microkeratome with the control unit ME-LSK Evolution 2 was used for the creation of corneal flaps. The suction ring was chosen according to the manufacturer's recommendations, a nomogram based on the keratometric value $K_1$. After creation of a hinged flap, flap thickness was calculated by subtracting the thickness of the remaining central stromal bed from preoperative total CCT. Stromal thickness was measured immediately after the flap was cut. The horizontal white-to-white distance of the eye, flap diameter and hinge length were measured using a standard calliper. The stromal bed was ablated using the Allegretto Wave Eye-Q excimer laser (Wavelight AG).

### Statistical analysis

The mean values and SDs of corneal thickness, flap thickness, flap horizontal diameter and hinge length of 240 eyes were calculated. Unpaired Student's $t$-test was used to analyse differences between the two cohorts. Single-variable correlation of flap thickness and preoperative refraction, corneal thickness, age, $K_1$ keratometry, flap diameter or hinge length was performed using GraphPad Prism software (GraphPad Software, Inc., San Diego, CA, USA). Myopic and hyperopic subgroups were analysed separately.

# Results

The preoperative characteristics of 200 eyes treated with the M2™ head 130 and the Med-Logics calibrated blades ML –20 (the 140-$\mu$m cohort) and ML –30 (the 130-$\mu$m cohort) are presented in Table 1. These two cohorts included 164 myopic and 36 hyperopic eyes. Mean patient age was 36.5 years (SD 11.4, range 19–67 years). The frequency distribution of preoperative corneal thickness in eyes treated with

**Table 1.** Preoperative characteristics of 200 eyes that underwent LASIK with the Moria M2™ head 130 microkeratome and the Med-Logics blades ML –20 or ML –30.

| Characteristics | ML –20 | ML –30 | p-value |
|---|---|---|---|
| Eyes, $n$ (%) | 100 (50) | 100 (50) | NS |
| Mean spherical equivalent refraction in myopic eyes ($n$ = 82), D (SD) | − 4.15 (1.85) | − 4.63 (2.16) | NS |
| Mean spherical equivalent refraction in hyperopic eyes ($n$ = 18), D (SD) | 2.29 (1.31) | 2.98 (2.00) | NS |
| Mean preoperative keratometric $K_1$ power, D (SD) | 43.8 (1.6) | 43.5 (1.7) | NS |
| Mean preoperative keratometric $K_2$ power, D (SD) | 42.9 (1.5) | 42.7 (1.6) | NS |
| Mean horizontal white-to-white distance in the eye, mm (SD) | 11.7 (0.5) | 11.8 (0.5) | < 0.05 |
| Mean preoperative corneal thickness (pachymetry), $\mu$m (SD) | 565.1 (22.6) | 546.0 (21.7) | < 0.0001 |

D = dioptre; SD = standard deviation; NS = not significant.

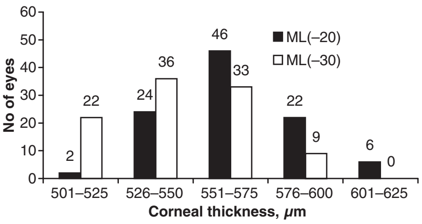


**Fig. 1.** Frequency distribution of preoperative corneal thickness (pachymetry, $\mu$m) in 200 eyes operated with the Moria M2™ head 130 microkeratome adjusted with the Med-Logics ML –20 or ML –30 calibrated blades.

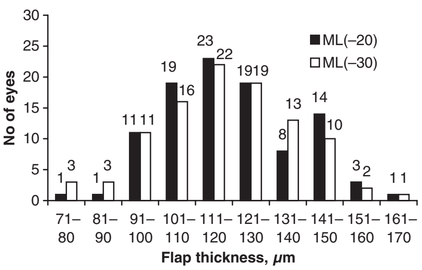


**Fig. 2.** Frequency distribution of corneal flap thickness ($\mu$m) in 200 eyes operated with the Moria M2™ head 130 microkeratome adjusted with the Med-Logics ML –20 or ML –30 calibrated blades. Intended flap thicknesses were 140 $\mu$m with the ML –20 and 130 $\mu$m with the ML –30.

the ML –20 and ML –30 is presented in Fig. 1.

The frequency distribution of the corneal flap thickness in eyes treated with the ML –20 and ML –30 is presented in Fig. 2. In ML –20-treated right eyes, in which the intended corneal flap thickness was 140 $\mu$m, mean flap thickness was 129.1 $\mu$m (SD 15.6) (Table 2). In ML –20-treated left eyes, mean flap thickness was 111.5 $\mu$m (SD 14.5). The difference between right and left eyes was statistically significant ($p < 0.0001$, Student's $t$-test). In ML –20-treated eyes, mean horizontal flap diameter was 9.1 mm (SD 0.3) and mean hinge length 4.2 mm (SD 0.2–0.3). In ML –30-treated right eyes, in which the intended corneal flap thickness was 130 $\mu$m, mean flap thickness was 127.1 $\mu$m (SD 16.6) (Table 2). In ML –30-treated left eyes, mean flap thickness was 109.9 $\mu$m (SD 16.8). The difference between right and left eyes was statistically significant also in this cohort ($p < 0.0001$, Student's $t$-test). In ML –30-treated eyes, mean horizontal flap diameter was 9.1 mm (SD 0.3) and mean hinge length 4.2 mm (SD 0.2).

Postoperative characteristics for the operations in the additional 40 eyes, when the left eye was operated before the right eye, are presented in Table 3. Mean flap thickness in ML –20-operated eyes was 145.8 $\mu$m (SD 14.5) in the 10 left eyes and 125.8 $\mu$m (SD 18.9) in the 10 right eyes. Correspondingly, mean flap thickness in ML –30-treated eyes was 135.4 $\mu$m (SD 21.7) in the 10 left eyes and 111.0 $\mu$m (SD 21.9) in the 10 right eyes. The difference between the first and second eyes was statistically significant ($p < 0.05$, Student's $t$-test) in both cohorts.

There were no free or incomplete flaps, or flaps with buttonholes in the study. Clinical outcomes for uncorrected and best corrected VA and refractive predictability did not differ significantly between the two cohorts.

Table 4 shows the correlation coefficients of the main variables versus flap thickness for eyes treated with the ML –20 and ML –30, respectively. Similar correlations were found when eyes treated first and second were analysed separately. In the hyperopic eyes treated with the ML –20, flap thickness was negatively correlated with the keratometric value $K_1$. In eyes treated with the ML –30, increasing flap thickness was associated with the flatter keratometric value in both myopic and hyperopic eyes. Moreover, in myopic eyes operated with the ML –30, increased flap thickness was associated with increased corneal thickness. Fig. 3 (A, B) presents the relationship between preoperative corneal thickness and flap thickness for right and left eyes treated with the

**Table 2.** Postoperative characteristics of 200 eyes that underwent LASIK with the Moria M2™ head 130 microkeratome and the Med-Logics blades ML –20 or ML –30. Right eyes were cut before left eyes, using the same blade in both eyes.

| | ML –20 | | | ML –30 | | |
|---|---|---|---|---|---|---|
| Characteristics | Right eyes | Left eyes | p-value | Right eyes | Left eyes | p-value |
| Range of flap thickness, $\mu$m | 104–165 | 78–144 | | 90–168 | 72–149 | |
| Mean flap thickness, $\mu$m (SD) | 129.1 (15.6) | 111.5 (14.5) | < 0.0001 | 127.1 (16.6) | 109.9 (16.8) | < 0.0001 |
| Range of difference from planned thickness, $\mu$m | −25 to 36 | −4 to 62 | | −38 to 40 | −19 to 58 | |
| Mean difference from planned thickness, $\mu$m (SD) | 10.9 (15.6) | 28.5 (14.5) | < 0.0001 | 2.9 (16.6) | 20.1 (16.8) | < 0.0001 |
| Range of horizontal flap diameter, mm | 8.7–9.8 | 8.7–9.8 | | 8.5–9.7 | 8.5–9.8 | |
| Mean horizontal flap diameter, mm (SD) | 9.1 (0.3) | 9.1 (0.3) | NS | 9.1 (0.3) | 9.1 (0.3) | NS |
| Range of hinge length, mm | 3.5–4.9 | 3.0–4.8 | | 3.9–4.7 | 3.9–5.0 | |
| Mean hinge length, mm (SD) | 4.2 (0.2) | 4.2 (0.3) | NS | 4.2 (0.2) | 4.2 (0.2) | NS |

SD = standard deviation; NS = not significant.

**Table 3.** Postoperative characteristics of the additional 40 eyes that underwent LASIK with the Moria M2™ head 130 microkeratome and the Med-Logics blades ML –20 or ML –30. Left eyes were cut before right eyes, using the same blade in both eyes.

| | ML –20 | | | ML –30 | | |
|---|---|---|---|---|---|---|
| Characteristics | Left eyes | Right eyes | p-value | Left eyes | Right eyes | p-value |
| Eyes, $n$ | 10 | 10 | NS | 10 | 10 | NS |
| Mean flap thickness, $\mu$m (SD) | 145.8 (14.5) | 125.8 (18.9) | < 0.05 | 135.4 (21.7) | 111.0 (21.9) | < 0.05 |
| Mean difference from planned thickness, $\mu$m (SD) | −5.8 (14.5) | 14.2 (18.9) | < 0.05 | −5.4 (21.7) | 19.0 (21.9) | < 0.05 |
| Mean horizontal flap diameter, mm (SD) | 9.0 (0.3) | 9.0 (0.3) | NS | 9.0 (0.1) | 9.0 (0.1) | NS |
| Mean hinge length, mm (SD) | 4.3 (0.3) | 4.3 (0.2) | NS | 4.1 (0.1) | 4.1 (0.1) | NS |

SD = standard deviation; NS = not significant.

**Table 4.** Correlation coefficients of variables versus flap thickness in 100 eyes operated with the Moria M2™ head 130 microkeratome and the Med-Logics blades ML –20 and ML –30.

| Variable for eyes cut with the ML –20 | Mean (SD) | Correlation coefficient | p-value |
|---|---|---|---|
| Equivalent refraction, D | − 2.99 (3.05) | 0.074 | NS |
| Myopic eyes | − 4.15 (1.85) | 0.017 | NS |
| Hyperopic eyes | + 2.29 (1.31) | 0.398 | NS |
| Corneal thickness, $\mu$m | 565.05 (22.57) | 0.105 | NS |
| Myopic eyes | 563.99 (22.90) | 0.096 | NS |
| Hyperopic eyes | 569.89 (20.91) | 0.126 | NS |
| Age, years | 34.84 (10.67) | 0.050 | NS |
| Myopic eyes | 31.42 (8.43) | 0.001 | NS |
| Hyperopic eyes | 50.44 (3.26) | 0.373 | NS |
| $K_1$ keratometry, D | 43.75 (1.58) | − 0.180 | NS |
| Myopic eyes | 43.89 (1.54) | − 0.055 | NS |
| Hyperopic eyes | 43.08 (1.65) | − 0.643 | < 0.01 |
| Flap diameter, mm | 9.13 (0.27) | − 0.013 | NS |
| Myopic eyes | 9.15 (0.26) | 0.023 | NS |
| Hyperopic eyes | 9.04 (0.30) | − 0.120 | NS |
| Hinge length, mm | 4.18 (0.27) | 0.163 | NS |
| Myopic eyes | 4.18 (0.24) | 0.541 | NS |
| Hyperopic eyes | 4.15 (0.39) | 0.292 | NS |
| **Variable for eyes cut with the ML –30** | | | |
| Equivalent refraction, D | − 3.26 (3.63) | − 0.101 | NS |
| Myopic eyes | − 4.63 (2.16) | − 0.140 | NS |
| Hyperopic eyes | + 2.98 (2.01) | − 0.018 | NS |
| Corneal thickness, $\mu$m | 546.04 (21.65) | 0.385 | < 0.0001 |
| Myopic eyes | 547.31 (22.73) | 0.399 | < 0.001 |
| Hyperopic eyes | 540.28 (14.98) | 0.280 | NS |
| Age, years | 38.16 (11.85) | 0.067 | NS |
| Myopic eyes | 35.29 (9.92) | 0.062 | NS |
| Hyperopic eyes | 51.22 (11.32) | 0.290 | NS |
| $K_1$ keratometry, D | 43.53 (1.69) | − 0.301 | < 0.01 |
| Myopic eyes | 43.76 (1.64) | − 0.300 | < 0.01 |
| Hyperopic eyes | 42.48 (1.56) | − 0.475 | < 0.05 |
| Flap diameter, mm | 9.11 (0.26) | − 0.132 | NS |
| Myopic eyes | 9.10 (0.25) | − 0.212 | NS |
| Hyperopic eyes | 9.17 (0.30) | 0.231 | NS |
| Hinge length, mm | 4.21 (0.20) | − 0.098 | NS |
| Myopic eyes | 4.18 (0.17) | − 0.194 | NS |
| Hyperopic eyes | 4.31 (0.30) | 0.201 | NS |

SD = standard deviation; NS = not significant.

ML –20 and ML –30, respectively. In ML –30-treated eyes, the thicker the cornea, the thicker was the flap. Fig. 4 (A, B) shows the relationship between keratometric power $K_1$ and flap thickness. Increasing flap thickness was associated with a flatter keratometric value, especially in ML –30-treated eyes. Flap thickness did not correlate with patient age with either blade type.

# Discussion

The most common feature of different microkeratomes is that the flap thickness achieved tends to be thinner than intended. In the present study, we obtained thinner corneal flaps (up to 72 $\mu$m) than intended. Another common feature of microkeratomes appears to be the difference in results between the first and second eyes when the same blade is used in both eyes (Arbelaez 2002; Gailitis & Lagzdins 2002; Shemesh et al. 2002, 2004). In the present study, the M2™ metallic head 130, intended to create a 160-$\mu$m flap, was adjusted with either the Med-Logics single-use ML –20 or the ML –30 for intended flap thicknesses of 140 $\mu$m and 130 $\mu$m, respectively. The mean corneal thickness obtained in the study reflected the surgeon's selection of the ML –20 for thicker corneas. There was no clinically relevant difference between flap thicknesses cut with the ML –20 and the

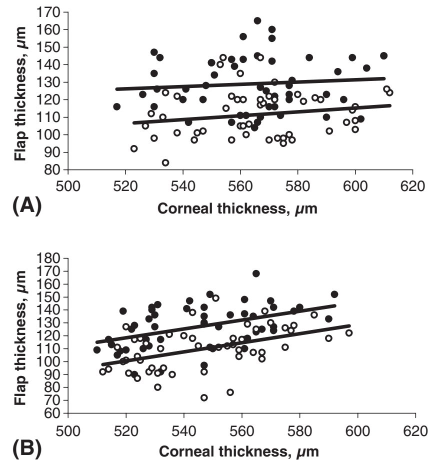


**Fig. 3.** (A) Preoperative corneal thickness (measured by pachymetry, $\mu$m) and corneal flap thickness ($\mu$m) in (A) 100 eyes treated with the Moria M2™ head 130 microkeratome adjusted with the ML –20 calibrated blade (all eyes: $r$ = 0.105, non-significant), and (B) 100 eyes treated with the M2™ head 130 adjusted with the ML –30 calibrated blade (all eyes: $r$ = 0.385, $p < 0.0001$). Increasing cornea thickness was associated with increasing flap thickness. ● = right eyes; ○ = left eyes.

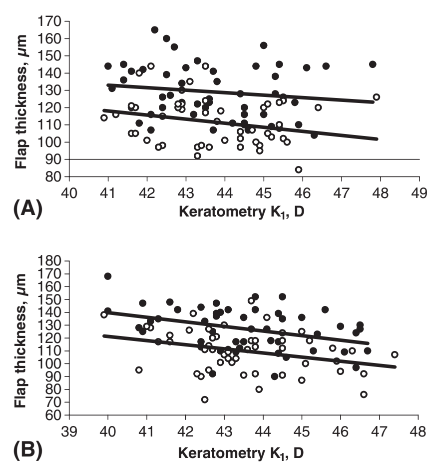


**Fig. 4.** Keratometric power $K_1$ (D) and corneal flap thickness ($\mu$m) in (A) 100 eyes treated with the Moria M2™ head 130 microkeratome adjusted with the ML –20 calibrated blade (all eyes: $r$ = −0.0180, non-significant), and (B) 100 eyes treated with the M2™ head 130 adjusted with the ML –30 calibrated blade (all eyes: $r$ = −0.301, $p < 0.01$). Increasing flap thickness was associated with flatter keratometric value. ● = right eyes; ○ = left eyes.

ML –30. The mean thickness of the first flap cut was 129.1 $\mu$m (SD 15.6) in ML –20-treated eyes and 127.1 $\mu$m (SD 16.6) in ML –30-treated eyes. The mean thicknesses of the second flap cut were 111.5 $\mu$m (SD 14.5) and

109.9 μm (SD 16.8), respectively. The difference between the first and second cuts was significant ($p < 0.0001$) for both the ML –20 and ML –30 blades. The variation in flap thickness was also fairly wide. In the operations performed in the additional 40 eyes, the left eye was operated before the right eye in each subject. In these cases, the flap cut first was also thicker than the second flap. However, although there was substantial variation in flap thickness, we found no buttonholes or other significant flap-related complications in this study.

That the second flap is cut thinner probably depends on the cutting edge of the blade. It is likely that the first cut affects the sharpness of the blade and even minor changes in sharpness may cause variations between the first and second cuts. Further study which includes scanning electron microscopy of the blades before and after the cuts are made might elucidate this issue.

In our previous study with the M2™ microkeratome head 130, we found that flap thickness correlated with increasing preoperative corneal thickness, younger patient age and flatter preoperative keratometric power $K_1$ (Pietilä et al. 2005). In the present study, flap thickness in eyes cut with the ML –30 correlated with corneal thickness, but did not in eyes cut with the ML –20. This may reflect the fact that thicker corneas do not conform equally to the suction head. Flap thickness did not correlate significantly with age with either blade. Flap thickness was associated with keratometric power $K_1$ in both myopic and hyperopic eyes treated with the ML –30, but not in myopic ML –20-treated eyes. The correlation analysis showed large differences between myopic and hyperopic eyes for some correlations. That patient age affected hyperopic regressions but not myopic regressions may be an artefact attributable to the large difference in the populations. These partially contradictory correlations may reflect the large variations in flap thickness obtained with the ML –20 and ML –30 blades and should be defined with a larger sample, especially if a formula or a nomogram for flap thickness is to be developed.

In the present study, flap thickness was based on ultrasound pachymetry measurements. It should be noted that the limited accuracy of ultrasound measurements and subtraction pachymetry precludes the determination of flap accuracy beyond certain limits.

An alternative method of cutting thin flaps involves using the M2™ single-use head 90 microkeratome for 120-μm flaps. We have previously shown that there are no significant differences between the first and second cuts with the single-use head 90 microkeratome (Huhtala et al. 2007). In our earlier study, mean flap thickness was 115.7 μm (SD 12.4) in right eyes (cut first) and 115.1 μm (SD 12.4) in left eyes (cut second). The SD was considerably smaller than in the present study. In addition, the ML –30 calibrated blade did not cut considerably thinner flaps than the ML –20. As the M2™ single-use head 90 creates corneal flaps with less variation, we would recommend its use for the creation of thin flaps. Another alternative to mechanical microkeratomes for creating thin flaps is femtosecond lasers, which have been shown to cut flaps that are more uniform in thickness than those cut with traditional microkeratomes (Kurtz et al. 1997; Stonecipher et al. 2006a, 2006b).

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# LASIK Flap Creation With the Ziemer Femtosecond Laser in 787 Consecutive Eyes

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**ABSTRACT**

**PURPOSE:** To present the flap characteristics and short-term efficacy and safety of 787 consecutive LASIK procedures with the FEMTO LDV femtosecond laser (Ziemer Ophthalmic Systems) for the treatment of refractive errors.

**METHODS:** Seven hundred eighty-seven consecutive eyes of 405 previously non-operated patients were treated with the FEMTO LDV. Intended flap thickness was 110 $\mu$m and intended flap diameter varied from 8.5 to 9.5 mm. Refractive treatment was performed with the WaveLight ALLEGRETTO WAVE Concerto 500 Hz excimer laser. All eyes were wavefront-optimized.

**RESULTS:** The mean flap thickness, measured by ultrasound pachymetry, was 90.0±5.5 $\mu$m (range: 67 to 107 $\mu$m) in right eyes and 90.1±4.6 $\mu$m (range: 77 to 106 $\mu$m) in left eyes. Mean flap diameter was 9.1±0.2 mm (range: 8.4 to 9.9 mm) in right eyes and 9.1±0.2 mm (range: 8.0 to 10.0 mm) in left eyes. Increasing flap thickness was correlated with increasing corneal thickness in right eyes and flatter keratometric value $K_1$ in left eyes. The most common complication was minor bleeding during the procedure (12.7%). All other complications were rare (8.4%), and none prevented further laser ablation.

**CONCLUSIONS:** The Ziemer FEMTO LDV laser created thinner LASIK flaps than intended but with a low standard deviation and minimal intraoperative complications. [*J Refract Surg*. 2010;26:7-16.]
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Laser in situ keratomileusis (LASIK) remains the most popular procedure in refractive surgery.[1] Traditionally, several types of mechanical microkeratomes are used for the creation of a corneal flap in the initial step of LASIK. One cause of flap-related complications is the variation of flap thickness. Most microkeratomes achieve thinner flaps than expected, and differences between the first and second eye operated with the same blade have been reported.[2] Actual microkeratome-related complications include decentered flaps, free flaps, irregular flap edges and stromal bed surfaces, epithelial abrasions, buttonholes, and flap lacerations, and their incidence has been reported to occur in 0.3% to 1.9% of cases, and incidences as high as 5% have been reported.[3-7]

Recently, femtosecond laser technology has emerged as an alternative to mechanical microkeratomes to offer patients all-laser LASIK procedures. Femtosecond lasers are produced and marketed by IntraLase (IntraLase FS; Abbott Medical Optics [AMO], Santa Clara, Calif), 20/10 Perfect Vision (FEMTEC, Heidelberg, Germany), Carl Zeiss Meditec (VisuMax, Jena, Germany), and Ziemer Ophthalmic Systems (FEMTO LDV, Port, Switzerland). This study was undertaken to present the flap characteristics and short-term efficacy and safety of our first 787 consecutive, previously nonoperated eyes treated with the Ziemer Femto Leonardo Da Vinci (FEMTO LDV) femtosecond laser by one surgeon (J.P.). To the best of our knowledge, no earlier clinical studies have reported LASIK flap creation with the FEMTO LDV. In enucleated porcine eyes, the laser cuts of the 60-kHz IntraLase FS

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*The authors have no proprietary interest in the materials presented herein.*

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and FEMTO LDV femtosecond lasers were reported to be equally smooth and of excellent quality with small and equal standard deviations.[8]

## PATIENTS AND METHODS

### Study Design

This study presents the outcomes of 787 consecutive eyes of 405 patients that underwent LASIK flap creation with the FEMTO LDV femtosecond laser at Mehiläinen Hospital, Tampere, Finland from August 2007 to June 2008. All eyes were operated for the first time by one surgeon (J.P.). In bilateral operations of 382 patients, the right eye was operated before the left eye. In all eyes, the intended thickness was 110 µm. The size of the suction ring was 8.5 mm in 1 eye, 9.0 mm in 766 eyes, and 9.5 mm in 20 eyes. To evaluate the surgeon's learning curve, the first 62 eyes operated during the first month (August 2007) were analyzed as a separate group. The eyes were divided in two groups based on spherical equivalent refraction (SE)—698 eyes with SE $<$0.00 diopters (D) were classified as myopic and 89 eyes with SE $\geqslant$+0.00 D were classified as hyperopic.

### Preoperative Examinations

All patients had a complete preoperative ophthalmologic examination to exclude any severe pathology known to be a contraindication for LASIK surgery or to have an effect on flap creation. Ophthalmologic examination included slit-lamp microscopy, measurement of three-dimensional corneal topography (Allegro Oculyzer; WaveLight AG, Erlangen, Germany), determination of refraction, measurement of uncorrected (UCVA) and best spectacle-corrected visual acuity (BSCVA), measurement of intraocular pressure (Tonoref RKT-7700; NIDEK Co Ltd, Gamagori, Japan), and wavefront analysis (Allegro Analyzer, WaveLight AG).

### Surgical Technique

Prior to surgery, topical anesthetic oxybuprocain hydrochloride (Oftan Obucain; Santen Oy, Tampere, Finland) was instilled in the operated eyes. In most eyes, an aspirating speculum (no 15961; Geuder, Heidelberg, Germany) was used for eyelid opening. In small eyes in which the cone of the FEMTO LDV did not fit, a Barraquer wired speculum was used (49 eyes [6.2%]). In very small eyes, canthotomy was also performed (6 eyes [0.8%]).

Preoperative corneal thickness was measured with ultrasonic pachymetry (SP-3000; Tomey Corp, Nagoya, Japan). Before flap cutting, the surgical assistant prepared the FEMTO LDV by assembling the sterile parts of the hand piece (hand piece cover, intershield determining flap thickness, suction ring determining flap diameter, and suction tubing) and input the patient's data. Flap thickness was determined by the InterShield spacer (Ziemer), a plastic foil interpositioned between the laser and cornea. The individual preset vacuum levels ranged between 700 and 800 mbar (mostly 750 mbar), depending on the curvature of the cornea. The articulated hand piece, including the precisely guided cutting laser head, was connected to the laser main unit by the counterbalanced mirror arm and was positioned on the operated eye. Using the microscope of the excimer laser, the surgeon centered the hand piece on the patient's eye so that the pupil was in the center of the planned ablation area.

The cutting speed was set between 27 and 30 seconds. The time to create a flap from suction-on to suction-off was approximately 40 seconds. For flap creation, the FEMTO LDV delivers 100 nJ pulse energy and $>$2 MHz repetition rate. The attempted flap thickness was 110 µm and the flap diameter varied from 8.5 to 9.5 mm; however, in most cases, it was 9.0 mm. In bilateral operations, the same distance foil was used for both eyes. After the cut, the flap was opened with a spatula and stromal thickness was measured immediately without any moisturizing. The mean of three measurements before and after the flap cut was recorded. Flap thickness was calculated as the difference between central corneal thickness before flap cutting and residual stromal bed thickness after flap lifting. The horizontal white-to-white distance of the eye, flap diameter, and hinge length were measured using a standard caliper.

Because no opaque bubble layer occurred after flap creation, treatment with the excimer laser was started immediately using the ALLEGRETTO WAVE Concerto 500 Hz excimer laser (WaveLight AG). All eyes were wavefront-optimized.

### Statistical Analysis

The mean values and standard deviations of flap thickness, horizontal flap diameter, and hinge length of the operated eyes were calculated. The Student *t* test was used to analyze differences between right and left eyes. Single variable correlation of flap thickness and preoperative refraction, corneal thickness, patient age, keratometric value $K_1$, flap diameter, or hinge length was evaluated using GraphPad Prism software (GraphPad, San Diego, Calif). Similarly, single variable correlation of flap diameter and preoperative refraction, corneal thickness, patient age, keratometric value $K_1$, or hinge length was evaluated. Myopic and hyperopic subgroups were analyzed separately. When flap diameter and hinge length were analyzed, only those eyes operated with the 9.0-mm suction ring were included

TABLE 1

**Preoperative Characteristics of Eyes That Received LASIK With the FEMTO LDV**

| Characteristics | First 62 Eyes | All 787 Operated Eyes |
|---|---|---|
| No. of eyes (%) | 62 (7.8) | 787 (100) |
| Mean age (range) (y) | 36.4±12.8 (20 to 61) | 36.4±10.4 (18 to 65) |
| Mean spherical equivalent refraction (D) | | |
| Myopic eyes (n) | −5.76±2.21 (52) | −4.92±2.67 (698) |
| Hyperopic eyes (n) | +1.69±0.43 (10) | +2.14±1.54 (89) |
| Mean preoperative keratometric power (D) | | |
| $K_1$ | 43.20±1.40 | 43.20±1.40 |
| $K_2$ | 44.20±1.30 | 44.10±1.50 |
| Mean horizontal white-to-white distance (mm) | 11.6±0.4 | 11.4±0.6 |
| Mean preoperative corneal thickness (μm) | 545.5±35.8 | 540.3±33.0 |

TABLE 2

**Postoperative Characteristics of Eyes That Received LASIK With the FEMTO LDV**

| | First 62 Eyes | | | All 787 Operated Eyes | | |
|---|---|---|---|---|---|---|
| Characteristics | Right Eye | Left Eye | *P* Value | Right Eye | Left Eye | *P* Value |
| No. of eyes | 31 | 31 | | 396 | 391 | |
| Mean flap thickness (range) (μm) | 86.9±7.7 (74 to 103) | 90.5±5.1 (81 to 101) | NS | 90.0±5.5 (67 to 107) | 90.1±4.6 (77 to 106) | NS |
| Mean horizontal flap diameter (range) (mm) (no. eyes) | | | | | | |
| 8.5-mm suction ring | | | | | 9.0 (1) | |
| 9.0-mm suction ring | 9.3±0.3 (9.0 to 9.9) (20) | 9.3±0.3 (9.0 to 9.9) (22) | NS | 9.1±0.2 (8.4 to 9.9) (385) | 9.1±0.2 (8.0 to 10.0) (381) | NS |
| 9.5-mm suction ring | 9.7±0.3 (9.2 to 10.0) (11) | 9.5±0.6 (8.0 to 9.9) (9) | NS | 9.7±0.3 (9.2 to 10.0) (11) | 9.5±0.6 (8.0 to 9.9) (9) | |
| Mean hinge length (range) (mm) | 4.6±0.5 (3.0 to 5.2) | 4.5±0.4 (3.9 to 5.2) | NS | 4.0±0.4 (2.0 to 5.2) | 3.9±0.4 (2.0 to 5.2) | NS |

*NS = not significant*
*Note. In bilateral cases, the right eye was operated before the left eye.*

due to the low number of eyes operated with the 8.5- and 9.5-mm suction rings.

## RESULTS

The preoperative characteristics of the 787 eyes that underwent LASIK with the FEMTO LDV are presented in Table 1. To evaluate the surgeon's learning curve, the first 62 eyes operated during the first month are presented as a separate group. The entire study included 787 previously unoperated myopic, hyperopic, and astigmatic eyes of which 698 (myopic group) had SE ranging from −0.13 to −17.38 D (mean: −4.92±2.67 D) and 89 eyes (hyperopic group) had SE ranging from +0.00 to +7.63 D (mean: +2.14±1.54 D). The postoperative characteristics of the 787 eyes are shown in Table 2. The first 62 eyes are presented as a separate group. In all eyes, corneal flap thickness ranged from 67 to 107 µm. The frequency distribution of the corneal flap thickness in these eyes is presented in Figure 1. The mean flap thickness of all 787 eyes was 90.0±5.0 µm; in 396 right eyes, it was 90.0±5.5 µm (range: 67 to 107 µm), and in 391 left eyes it was 90.1±4.6 µm (range: 77 to 106 µm). The difference between right and left eye was not statistically significant ($P$>.05, unpaired Student

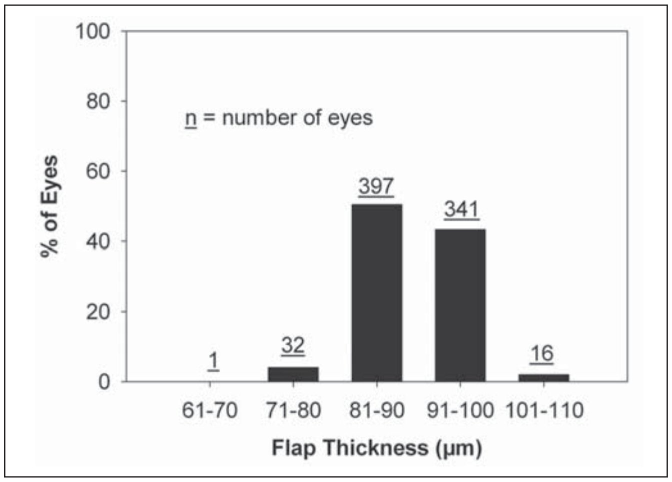


**Figure 1.** Frequency distribution of corneal flap thickness ($\mu$m) for 787 eyes treated with the FEMTO LDV. The intended flap thickness was 110 $\mu$m.

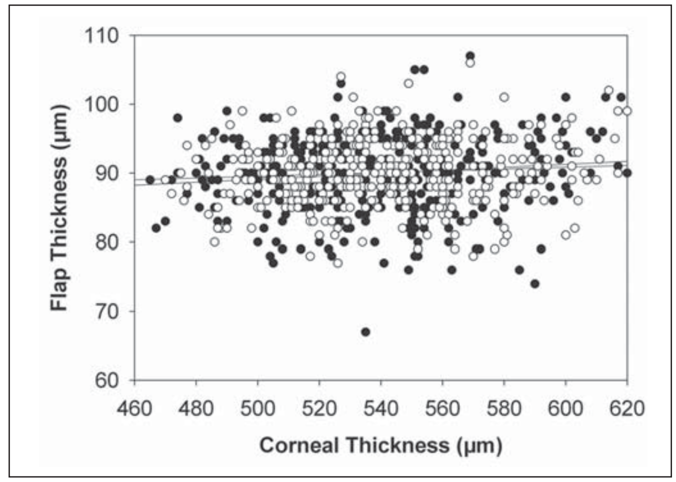


**Figure 2.** Preoperative corneal thickness (measured by pachymetry, $\mu$m) and corneal flap thickness ($\mu$m) in 787 eyes treated with the FEMTO LDV. Right eyes (r=0.131, $P$=.009), left eyes (r=0.094, $P$=.064). In right eyes, increasing flap thickness was associated with increasing corneal thickness. A similar, but not statistically significant, tendency was found in left eyes.

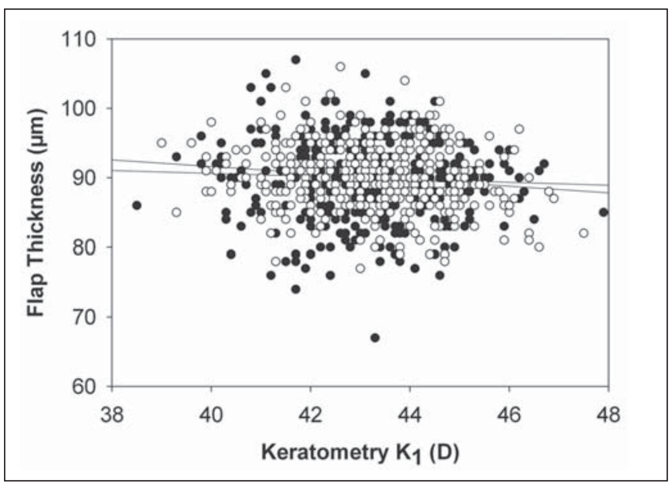


**Figure 3.** Keratometric power $K_1$ (D) and corneal flap thickness ($\mu$m) in 787 eyes treated with the FEMTO LDV. Right eyes (r=−0.055, $P$=.273), left eyes (r=−0.149, $P$=.003). Increasing flap thickness was associated with flatter keratometric value $K_1$ in left eyes.

*t* test). In the first 62 eyes, the mean flap thickness in right eyes was 86.9±7.7 µm (range: 74 to 103 µm) and 90.5±5.1 µm (range: 81 to 101 µm) in left eyes. This difference was also not statistically significant ($P$>.05, unpaired Student *t* test). In all eyes that were treated using the 9.0-mm suction ring, the mean flap diameter in right eyes was 9.1±0.2 mm (range: 8.4 to 9.9 mm) and 9.1±0.2 mm (range: 8.0 to 10.0 mm) in left eyes.

Corneal flap thickness was dependent on corneal thickness (Fig 2) in right eyes (r=0.131, $P$=.009). A similar tendency, although not statistically significant, was found in left eyes (r=0.094, $P$=.064). Corneal flap thickness was not dependent on keratometric power $K_1$ (Fig 3) in right eyes (r=0.055, $P$=.273), but in left eyes increasing flap thickness was associated with flatter keratometric value (r=0.149, $P$=.003). Table 3 shows the correlation coefficients of the main variables versus flap thickness in myopic and hyperopic eyes. Corneal flap thickness was negatively correlated with flap diameter in myopic eyes (r=−0.163, $P$<.0001). The greater the flap diameter, the thinner the flap thickness. Corneal flap thickness was not correlated with preoperative spherical equivalent refraction, patient age, or hinge length.

Table 4 shows the correlation coefficients of the main variables versus flap diameter in myopic and hyperopic eyes treated with the 9.0-mm suction ring. In myopic eyes, increasing flap diameter was associated with increasing preoperative spherical equivalent refraction both in right eyes (r=0.219, $P$<.0001) and left eyes (r=0.223, $P$<.0001). In all eyes treated with the 9.0-mm suction ring, increasing flap diameter was associated with steeper keratometric value $K_1$ both in right eyes (r=0.389, $P$<.0001) and left eyes (r=0.363, $P$<.0001) (Fig 4). In hyperopic eyes, increasing flap diameter was also associated with increasing hinge length both in right eyes (r=0.588, $P$<.0001) and left eyes (r=0.559, $P$<.0001) (Fig 5).

In this series of 787 eyes, we were able to analyze the visual functions and changes in Snellen lines of BSCVA 1 month after surgery in a total of 635 eyes, 570 myopic eyes (Fig 6A) and 65 hyperopic eyes (Fig 6B). In myopic eyes, 2 (0.4%) eyes gained 2 Snellen lines, 150 (26.3%) eyes gained 1 line, and 1 (0.2%) eye lost 1 line. In hyperopic eyes, 6 (9.2%) eyes gained 1 line and 2 (3.1%) eyes gained 2 lines. No change in Snellen lines occurred in 417 (73.2%) myopic eyes and 57 (87.7%) hyperopic eyes.

TABLE 3

**Correlation Coefficients of Variables vs Flap Thickness of 787 Eyes (698 Myopic and 89 Hyperopic) Operated With the FEMTO LDV**

| Variable | Mean±SD | Correlation Coefficient | *P* Value |
|---|---|---|---|
| Spherical equivalent refraction (D) | −4.12±3.41 | 0.023 | NS |
| Myopic eyes | −4.92±2.67 | 0.031 | NS |
| Hyperopic eyes | +2.14±1.54 | 0.101 | NS |
| Corneal thickness (μm) | 540.31±33.00 | 0.114 | <.01 |
| Myopic eyes | 540.15±32.62 | 0.107 | <.01 |
| Hyperopic eyes | 541.55±36.07 | 0.164 | NS |
| Age (y) | 36.39±10.42 | −0.165 | NS |
| Myopic eyes | 34.85±9.42 | −0.009 | NS |
| Hyperopic eyes | 48.42±10.01 | −0.116 | NS |
| $K_1$ keratometry (D) | 43.20±1.43 | −0.097 | <.01 |
| Myopic eyes | 43.28±1.42 | −0.084 | <.05 |
| Hyperopic eyes | 42.54±1.33 | −0.196 | NS |
| Flap diameter (mm) with a 9.0-mm suction ring (766 eyes) | 9.12±0.20 | −0.161 | <.0001 |
| Myopic eyes (n=681) | 9.12±0.20 | −0.163 | <.0001 |
| Hyperopic eyes (n=85) | 9.10±0.19 | −0.138 | NS |
| Hinge length (mm) with a 9.0-mm suction ring (763 eyes) | 3.98±0.34 | −0.025 | NS |
| Myopic eyes (n=678) | 3.97±0.34 | −0.024 | NS |
| Hyperopic eyes (n=85) | 4.07±0.36 | −0.045 | NS |

*SD = standard deviation, NS = not significant*

Complications of the all-laser procedure are presented in Table 5. In the first 62 eyes, 1 free flap, 2 decentered flaps, and bleeding in 13 eyes occurred. Bleeding was mainly associated with the larger 9.5-mm suction ring that was used in the first series of eyes. In all 787 eyes, there were 4 free caps, 17 preserved free caps, 10 pseudo buttonholes, 2 split flaps, 16 decentered flaps, 8 adhesions, and 5 epithelial defects. Bleeding occurred in a total of 100 eyes. In the preserved free caps, the FEMTO LDV cut a complete flap without a hinge, but the surgeon preserved a hinge of 3 to 4 mm when opening the flap. Flap decentration was defined by >0.5 mm. None of the decentrations prevented further treatment with excimer laser.

## DISCUSSION

Traditionally, corneal flaps in LASIK have been created with mechanical microkeratomes, but in recent years femtosecond laser technology has emerged as an alternative for flap creation.

With the classic mechanical microkeratome, multiple factors determine the corneal flap thickness profiles, such as the quality of the blade's cutting edge, speed of microkeratome pass, speed of blade oscillation, ease of pass on the cornea, and advancement of the microkeratome along the track of the suction ring.[9] Clinical studies have shown variable flap thickness with different microkeratomes.[2] Other problems with microkeratome technology include epithelial defects, epithelial sloughing, decentered flaps, free flaps, incomplete flaps, irregular flaps, and buttonholes.[9-11] Femtosecond lasers have been reported to have several advantages over classic microkeratomes including improved predictability of flap thickness and diameter,[10-12] astigmatic neutrality,[12-14] and reduced incidence of epithelial defects and buttonholes.[10-12] Complications reported with femtosecond lasers include light sensitivity,[15,16] corneal folds,[17] and inflammatory reactions in the interface.[16,18]

In the present study, the FEMTO LDV cut thinner flaps than intended, as do most mechanical microkeratomes. The mean flap thickness for all 787 eyes was 90.0 μm versus the intended flap thickness of 110 μm. When both eyes are operated with a traditional micro-

TABLE 4

**Correlation Coefficients of Variables vs Flap Diameter of 766 Eyes (681 Myopic and 85 Hyperopic) Operated With the FEMTO LDV Using the 9.0-mm Suction Ring**

| Variable | Mean±SD | Correlation Coefficient | *P* Value |
|---|---|---|---|
| Spherical equivalent refraction (D) | −4.13±3.41 | −0.186 | <.0001 |
| Myopic eyes | −4.91±2.68 | −0.220 | <.0001 |
| Hyperopic eyes | 2.17±1.56 | −0.191 | NS |
| Corneal thickness (μm) | 539.99±33.05 | 0.008 | NS |
| Myopic eyes | 539.73±32.57 | 0.007 | NS |
| Hyperopic eyes | 542.07±36.76 | 0.119 | NS |
| Age (y) | 36.32±10.40 | −0.013 | NS |
| Myopic eyes | 34.80±9.38 | −0.023 | NS |
| Hyperopic eyes | 48.48±10.24 | 0.193 | NS |
| $K_1$ keratometry (D) | 43.19±1.43 | 0.373 | <.0001 |
| Myopic eyes | 43.28±1.42 | 0.367 | <.0001 |
| Hyperopic eyes | 42.49±1.34 | 0.426 | <.0001 |
| Hinge length (mm) (n=763) | 3.98±0.34 | 0.030 | NS |
| Myopic eyes (n=678) | 3.97±0.34 | 0.029 | NS |
| Hyperopic eyes (n=85) | 4.07±0.36 | 0.573 | <.0001 |

*SD = standard deviation, NS = not significant*

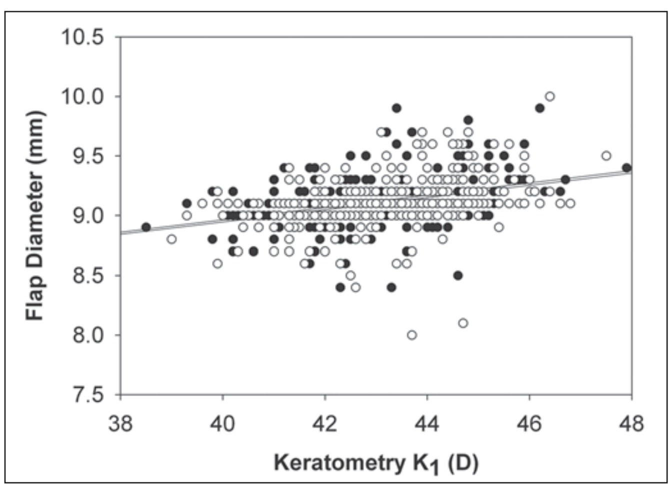


**Figure 4.** Keratometric power $K_1$ (D) and corneal flap diameter (mm) in 766 eyes treated with the FEMTO LDV using the 9.0-mm suction ring. Right eyes (r=0.389, *P*<.0001), left eyes (r=0.363, *P*<.0001). Increasing flap diameter was associated with steeper keratometric value $K_1$.

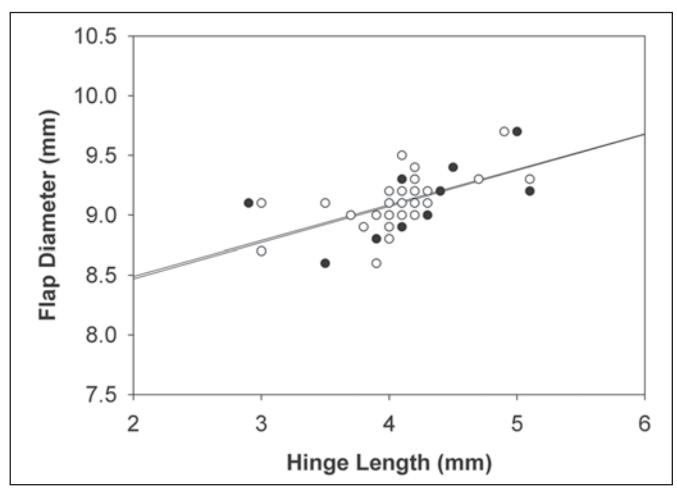


**Figure 5.** Hinge length and corneal flap diameter (mm) in 85 hyperopic eyes treated with the FEMTO LDV using the 9.0-mm suction ring. Right eyes (r=0.588, *P*<.0001), left eyes (r=0.559, *P*=.0001). Increasing flap diameter was associated with increasing hinge length.

keratome, the first cut flap is, in most cases, thicker than the second one. However, in our series of eyes, the FEMTO LDV cut the eyes in a similar way (right eye 90.0±5.5 μm, left eye 90.1±4.6 μm). In our study, the standard deviation of the flap thickness was very low—5.0 μm for all eyes. One additional cause of variability is the accuracy of ultrasound pachymetry. With very-high ultrasound scanning, the accuracy of the measurement of corneal thickness has been shown to be within 0.71 μm and flap thickness within 1.14 μm[19] and axial resolution with the precision of 12 μm.[20] Therefore, the accuracy of the ultrasonic measurement device sets certain limitations to these evaluations. Traditional microkeratomes produce variable flap thicknesses

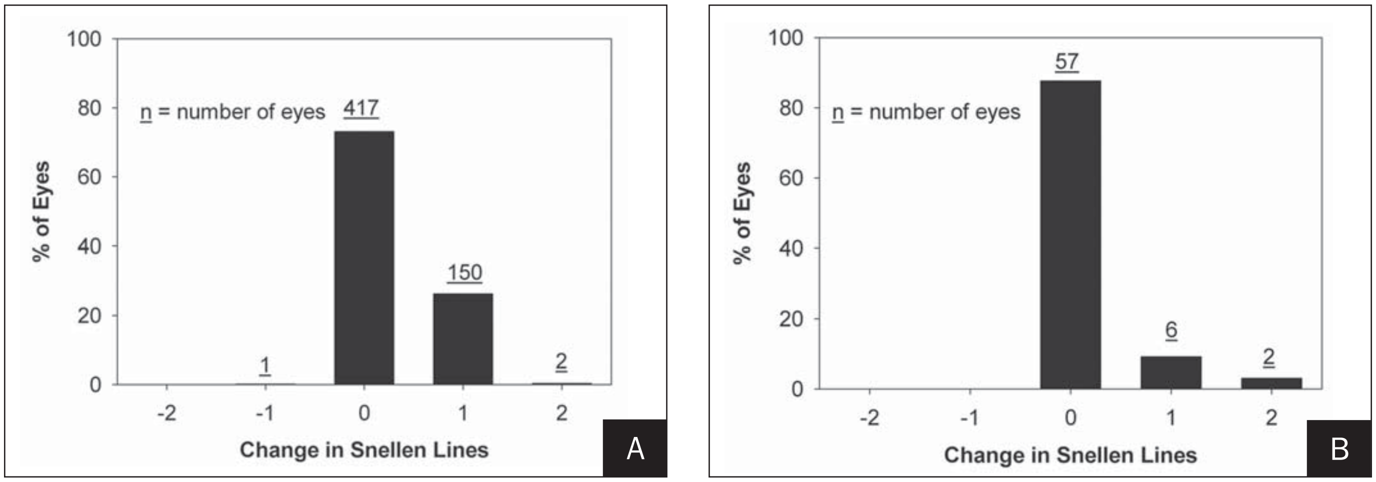


**Figure 6.** Change in Snellen lines of best spectacle-corrected visual acuity 1 month after surgery in **A)** 570 myopic eyes and **B)** 65 hyperopic eyes treated with the FEMTO LDV.

with standard deviations varying in most cases from ±25 to ±40 µm.[21-23] The achieved low standard deviation in this study was due to the good repeatability of the FEMTO LDV and the fact that all operations were conducted by a single surgeon experienced in LASIK procedures.

The IntraLase FS was the first femtosecond laser keratome to be introduced in the United States in 2001.[24] Shortly after, the FEMTEC (20/10 Perfect Vision) was introduced, followed by the FEMTO LDV in late 2005 and the VisuMax (Carl Zeiss Meditec) in fall 2006.[25] To the best of our knowledge, there are no earlier clinical reports on LASIK flap creation with the FEMTO LDV. Furthermore, no clinical studies on LASIK flap creation with the FEMTEC or the VisuMax have been reported to date. The IntraLase has been used in a number of clinical studies and it has been reported to induce both thicker and thinner flaps than intended (Table 6). Binder[10] reported the following measurements—for an intended flap thickness of 110 µm, he achieved 125.0±12.0 µm; for an intended flap thickness of 120 µm, 122.4±11.9 µm; for an intended flap thickness of 130 µm, 128.7±16.6 µm; and for an intended flap thickness of 140 µm, 132.5±18.5 µm. Furthermore, with the IntraLase for an intended flap thickness of 130 µm, Kezirian and Stonecipher[12] measured 114±14 µm. Binder[10] derived flap thickness from intraoperative ultrasonic pachymetry measurements whereas Kezirian and Stonecipher[12] derived flap thickness from pre- and intraoperative ultrasonic pachymetry measurements. Subsequently, Binder evaluated 1000 consecutive IntraLase flaps with subtraction ultrasound and found that the mean achieved flap thickness exceeded the attempted flap thickness by 9.4 to 34.3 µm with the standard deviations varying from ±10.2 to ±21.7 µm.[11] Patel et al[26] also used the IntraLase but measured flap thickness by confocal microscopy at 1 month. In their study, for an intended flap thickness of 120 µm, they measured 143±16 µm. Hu et al[27] reported the mean difference between the actual flap thickness and intended thickness by confocal microscopy as 16.8±11.1 µm and 13.9±7.1 µm for the IntraLase FS15 and FS30 femtosecond lasers, respectively.

TABLE 5

**Complications in Eyes That Received LASIK With the FEMTO LDV**

| | No. Eyes (%) | |
|---|---|---|
| **Complication** | **First 62 Eyes** | **All 787 Eyes** |
| Bleeding | 13 (21.0) | 100 (12.7) |
| Decentered flap | 2 (3.2) | 16 (2.0) |
| True free cap | 1 (1.6) | 4 (0.5) |
| Preserved free cap | — | 17 (2.2) |
| Pseudo buttonhole | — | 10 (1.3) |
| Split flap | — | 2 (0.3) |
| Epithelial defect | — | 5 (0.6) |
| Adhesion | — | 8 (1.0) |
| Bubbles under epithelium | — | 1 (0.1) |
| Flap displacement* | — | 3 (0.4) |
| Sum | 16 (25.8) | 166 (21.1) |

**Occurred 1 to 2 hours after flap creation and was easily replaced.*

Using the femtosecond laser technology in 1000 consecutive IntraLase flaps, Binder[11] found that preoperative corneal thickness or keratometric power did not affect achieved flap thickness. However, in the present study with the FEMTO LDV, we found that

TABLE 6

**Flap Thickness With the IntraLase in Clinical Studies**

| Study (y) | No. of Eyes | Femtosecond Laser | Intended or Set Flap Thickness (μm) | Achieved Flap Thickness (Mean±SD, μm) |
|---|---|---|---|---|
| Binder[10] (2004) | 34 | IntraLase 10 kHz | 110 | 125.0±12.0 |
| | 22 | | 120 | 122.4±11.9 |
| | 21 | | 130 | 128.7±16.6 |
| | 26 | | 140 | 132.5±18.5 |
| Kezirian & Stonecipher[12] (2004) | 106 | IntraLase 10 kHz | 130 | 114.0±14 |
| Binder[11] (2006) | 13 | IntraLase 10 kHz | 80 | 115.8±10.2 |
| | 320 | | 90 | 119.2±12.4 |
| | 140 | | 100 | 129.7±14.3 |
| | 49 | | 110 | 127.4±15.2 |
| | 31 | | 120 | 133.4±22.1 |
| | 25 | | 130 | 129.6±17.1 |
| | 38 | | 140 | 130.6±19.0 |
| Talamo et al[31] (2006) | 99 | IntraLase 10 kHz | 110 | 119.0±12 |
| Li et al[32] (2007) | 7 | IntraLase 10 kHz | 110 | 140±11 ultrasound<br>145±9 OCT 1 week postop |
| | 8 | | 120 | 160±19 ultrasound<br>156±11 OCT 1 week postop |
| Binder[11] (2006) | 249 | IntraLase 15 kHz | 90 | 115.8±10.8 |
| | 82 | | 100 | 120.1±11.8 |
| | 21 | | 110 | 131.1±10.2 |
| Javaloy et al[33] (2007) | 10 | IntraLase 15 kHz | 120 | 129.4±3.4 CM 1 month postop,<br>130.1±1.7 CM 3 months postop |
| Patel et al[26] (2007) | 21 | IntraLase 15 kHz | 120 | 143±16 CM 1 month postop |
| Hu et al[27] (2007) | 15 | IntraLase 15 kHz | 115-125 | DIFF 16.8±11.1 CM 3 months postop |
| | 15 | IntraLase 30 kHz | 115-120 | DIFF 13.9±7.1 CM 3 months postop |
| Alió & Piñero[34] (2008) | 22 | IntraLase 30 kHz | 110 | 115.95±6.2 |
| Neuhann et al[35] (2008) | 470 | IntraLase 30 kHz | 110 | 121.7±14.7 OCP |
| Kim et al[36] (2008) | 36 | IntraLase 60 kHz | 100 | 106.2±12.8 OCT 1 week postop |
| | 23 | | 110 | 117.8±7.8 OCT 1 week postop |

*OCT = optical coherence tomography, CM = confocal microscopy, DIFF = difference between actual flap thickness and intended flap thickness, OCP = online optical coherence pachymetry*
*Note. Flap thickness was measured with subtraction ultrasound pachymetry apart from a few exceptions.*

achieved flap thickness was slightly dependent on corneal thickness and keratometric value $K_1$. Increasing flap thickness was associated with increasing corneal thickness and flatter keratometric value. Furthermore, we found that increasing flap diameter was associated with thinner flap thickness in myopic eyes. In our previous studies with the Moria M2 (Moria, Antony, France) mechanical microkeratome, we also found that increasing flap thickness correlated with increasing corneal thickness and flatter keratometric value $K_1$.[2,28,29] With the IntraLase, Binder[11] found that flap diameter was not correlated with preoperative corneal curvature. In the present study, we found that in the FEMTO LDV system, increasing flap diameter was correlated with steeper keratometric value $K_1$. Mechanical microkeratomes have also been reported to be sensitive to preoperative corneal curvature, creating larger diameter flaps with steeper corneas and smaller diameter flaps with flatter corneas.[30]

In the 787 eyes presented herein, 10 pseudo buttonholes, 4 free caps, 17 preserved free flaps, 16 slight decentrations, and 5 epithelial defects were reported.

None of these complications prevented further refractive procedures. In 1000 consecutive eyes operated with the IntraLase, Binder[11] reported no free, irregular, buttonhole, or decentered flaps. However, Binder did not define his criteria for decentration nor did he report bleeding as a complication. In 1000 IntraLase eyes, no epithelial defects were encountered, but in 3 eyes, the peripheral host epithelium had focal defects at the end of the procedure.[11] Of the 635 eyes for which we had 1-month data available, only 1 eye lost 1 Snellen line of BSCVA whereas 156 eyes gained 1 and 4 eyes gained 2 Snellen lines.

In the hands of an experienced surgeon, LASIK with the FEMTO LDV appears to be a predictable and safe procedure for the creation of thin flaps. However, there was a steep learning curve. The transition from the microkeratome to the femtosecond laser seems to be relatively quick and easy for experienced refractive surgeons. Careful preoperative measurement of the corneal and refractive characteristics is a prerequisite for successful refractive surgery with femtosecond laser technology.

#### AUTHOR CONTRIBUTIONS

*Study concept and design (J.P., A.H., H.U.); data collection (J.P., M.J., J.J.); analysis and interpretation of data (J.P., A.H., P.M.); drafting of the manuscript (J.P., A.H.); critical revision of the manuscript (M.J., J.J., P.M., H.U.); statistical expertise (J.P., A.H.); obtained funding (J.P., A.H., H.U.); administrative, technical, or material support (J.P., A.H., M.J., J.J., P.M.)*

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