



FEMTOSECOND LASER APPLICATIONS IN ANTERIOR SEGMENT SURGERY

Essay

Submitted for partial fulfillment of Master Degree in
Ophthalmology

By

Caroline Atef Georgeus Tawfik

M.B.,B.Ch.

Faculty of Medicine – Ain Shams University

Supervised by

PROF. DR. BAHAA EIDIN ABDALLAH ALY

Professor of Ophthalmology

Faculty of Medicine - Ain Shams University

DR. AHMED HOSNI ABD ELHAMID

Assistant Professor of Ophthalmology

Faculty of Medicine - Ain Shams University

Faculty of Medicine
Ain Shams University
Cairo 2011



تطبيقات ليزر الفيمتوثانية فى جراحات الجزء الأمامى من العين

رسالة
تمهيداً للحصول على درجة الماجستير فى
طب وجراحة العيون

مقدمة من
الطبيبة/ كارولين عاطف جرجس توفيق
بكالوريوس الطب والجراحة – جامعة عين شمس

تحت إشراف
أ.د/ بهاء الدين عبدالله علي
أستاذ طب وجراحة العيون
كلية الطب جامعة عين شمس

أ.م.د/ أحمد حسني عبدالحميد
أستاذ مساعد طب وجراحة العيون
كلية الطب جامعة عين شمس

كلية الطب
جامعة عين شمس
القاهرة ٢٠١١

The FSL is a new surgical tool, almost anything in corneal surgeries can be done using this computer controlled laser knife. With the rapid development of the programs running these machines; modification of old techniques, discovering new approaches and inventing new procedures will be an applicable dream to future ophthalmology surgeons.

The FSL is an infrared laser that gives ultra fast pulses with a spot size of about 1 μm , FSL uses a wavelength of 1053 nm that can pass through the outer layers of the cornea with no effect on the tissue until it reaches the pre-programmed target. With the energy and firing pattern controlled by computer, the laser is capable of cutting tissue at various depths and patterns.

The laser essentially vaporizes small volumes of tissue by photodisruption, producing plasma, shock wave, cavitation, and gas bubbles. The laser spots may be fired in a vertical pattern for trephination (side) cuts or in a spiral or raster (zigzag) pattern to achieve lamellar cuts.

FSL applications in corneal and refractive surgeries are increasing day after day, at present, corneal flap creation in LASIK surgery is the most common application. Some studies have shown equivalency between the FSL and the mechanical keratome whereas other studies have reported improved visual results.

Advantages of FSL over mechanical microkeratomes include: reduced incidence of flap complications such as buttonholes, epithelial abrasions, short flaps, and free caps (some

Acknowledgment

First and foremost, I'd like to thank God who had given me the power to follow my passion and patience to pursue my dreams.

It would not have been possible to write this essay without the help and support of the kind people around me, to only some of whom it is possible to give particular mention here.

Above all, I would like to thank my husband Adel for his personal support and great patience at all times. My parents, and brother have given me their unequivocal support throughout, as always, for which my mere expression of thanks likewise does not suffice.

This work would not have been possible without the help, support and patience of my principal supervisor, Prof. Bahaa Eldin Abdallah. The good advice and support of my second supervisor, Dr. Ahmed Hosni, has been invaluable on both an academic and a personal level, for which I am extremely grateful.

CONTENTS

	Page
Abbreviations	ii
List of tables	v
List of Figures	vi
INTRODUCTION	1
AIM OF THE WORK	5
Principles of FSL	6
FSL in Corneal Surgery	15
Currently Available FSL Systems	15
FSL assisted LASIK.....	21
FSL assisted Arcuate Keratotomy & Wedge Resection	51
FSL assisted Keratoplasty.....	55
FS Lenticule Extraction and Small Incision.....	71
FSL assisted ICRS Insertion	78
FSL in Cataract Surgery	83
FSL in Presbyopia	101
FSL in Glaucoma	114
Miscellaneous uses of FSL	120
FSL-created Pocket for Collagen Cross-linking.....	120
FAB.....	122
FALT	126
SUMMARY	129
REFERENCES	135
ARABIC SUMMARY	

ABBREVIATIONS

AC	: Anterior Chamber
ACI	: Acufocus Corneal Inlay
AH	: Aqueous Humour
ALK	: Anterior Lamellar Keratoplasty
AMO	: Advanced Medical Optics
ASOCT	: Anterior Segment Optical Coherence Tomography
BCVA	: Best Corrected Visual Acuity
BSCVA	: Best Spectacle Corrected Visual Acuity
BSS	: Balanced Salt Solution
CCI	: Clear Corneal Incision
CCT	: Central Corneal Thickness
CDVA	: Corrected Distance Visual Acuity
CPD	: Cycle Per Degree
CQ	: Clinical Quality
CS	: Contrast Sensitivity
CXL	: Collagen Cross-Linking
D	: Dioptre
DALK	: Deep Anterior Lamellar Keratoplasty
DLEK	: Deep Lamellar Endothelial Keratoplasty
DLK	: Diffuse Lamellar Keratitis
DM	: Descemet's Membrane
DSAEK	: Descemet Stripping Automated Endothelial Keratoplasty
DSEK	: DESCOMET Stripping Endothelial Keratoplasty
ELP	: Effective Lens Position
FAB	: Femtosecond Assisted Diagnostic Corneal Biopsy
FALK	: Femtosecond-Assisted Anterior Lamellar Keratoplasty
FALT	: Femtosecond-Assisted Anterior Lamellar Corneal Staining–Tattooing

FDA	: Food and Drug Administration
FDALK	: Femtosecond-assisted Deep Anterior Lamellar Keratoplasty
FDOCT	: Frequency-Domain OCT
FLAK	: Femtosecond Laser Assisted Keratoplasty
FLEK	: Femtosecond-assisted Endothelial Keratoplasty
FLEx	: Femtosecond Lenticule Extraction
FS-AK	: Femtosecond Laser Assisted Astigmatic Keratotomy
FSL	: Femtosecond Laser
GUI	: Graphical User Interface
HOAs	: High Order Aberrations
ICRS	: Intrastromal Corneal Ring Segments
IOLs	: Intraocular Lenses
IOP	: Intraocular Pressure
IR	: Infra-Red
J	: Joule
KHz	: Kilo Hertz
KP	: Keratoplasty
LAR	: Laser Arcuate Wedge Shaped Resection
LASIK	: Laser in SITU Keratomileusis
LIOB	: Laser Induced Optical Breakdown
LOCS	: Lens Opacities Classification System
LRI	: Limbal Relaxing Incision
MHz	: Mega Hertz
mJ	: Milli Joule
MK	: Microkeratome
mm	: Millimeter
Nd	: Neodymium-Doped
YAG	: Yttrium Aluminium Garnet

nJ	: Nanojoule
nm	: Nanometer
NPDS	: Non-Penetrating Deep Sclerectomy
ns	: Nanosecond
OBL	: Opaque Bubble Layer
OCT	: Optical Coherence Tomography
ODM	: Ophthalmodynamometer
PK	: Penetrating Keratoplasty
PMMA	: Poly Methyl Methacrylate
PRK	: Photorefractive Keratectomy
ps	: Picoseconds
PTK	: Phototherapeutic Keratectomy
PVDF	: Polyvinylidene Fluoride
RI	: Refractive Index
SD	: Standard Deviation
SE	: Spherical Equivalent
SHIM	: Second Harmonic Imaging Microscope
SMILE	: Small-Incision Lenticule Extraction
TLSS	: Transient Light Sensitivity Syndrome
UDVA	: Unaided Distance Visual Acuity
UNVA	: Unaided Near Visual Acuity
UV	: Ultraviolet

LIST OF TABLES

Table No.	Title	Page
1	Typical laser parameters and tissue effects for photodisruption in the ns, ps and fs regimes.....	9
2	Comparison of the technical features of FSL systems.....	19
3	Incidence of minor flap complications and final VA	38
4	Comparison of complications of tunnel creation for ICRS via mechanical versus fs-assisted methods	81
5	Comparison between 3 FSL systems for use in cataract	100
6	Experimental ultrashort pulse laser sources for intralenticular photodisruption.....	108

LIST OF FIGURES

Fig. No.	Title	Page
1	Process of laser-matter interaction.....	7
2	Sequence of photodisruption process	8
3	Mechanism of corneal femtodissection	12
4	Decreasing tissue bridges by the "double pass" technique	12
5	Decreasing tissue bridges by overlapping laser pulse	13
6	Distance between laser pulses and laser pulse energy	14
7	High and Low pulse energy FSL machines	14
8	Inverted bevel-in side cut.....	16
9	Four commercially available FSL systems.....	20
10	Glass fixation cone docked into the suction fixation ring	23
11	Cone and ring applied on a patient	23
12	Top and Cross-sectional view of FSL created flap, showing side cut angle and hinge angle	24
13	Different FSL pulse patterns.....	24
14	Hinge Length and angle.....	25
15	Meniscus flap vs Planar flap.....	28
16	OCT of thin FSL LASIK	28
17	Smooth stromal bed by IntraLase	32
18	Changes in CS function under scotopic conditions for FSL vs MK	33
19	Flap-induced wavefront changes	35
20	Gas breakthrough.....	39
21	OBL during LASIK flap creation	40
22	DLK starts with haze & then sandy granular appearance.....	44
23	Flap folds after FSL created flap	46
24	OCT showing thinner than intended FSL flap.....	47

25	Epithelial ingrowth after FSL LASIK	48
26	Decentered Flap	49
27	FSL-assisted AK incisions.....	51
28	Intraoperative view during wedge tissue removal and 1 month following LAR.....	54
29	Preoperative view of corneal scar, postoperative following FALK and PTK for residual scarred stromal bed.....	58
30	FSL setting for mushroom configuration FDALK	62
31	Different wound configurations for FSL-assisted PK	66
32	Slit lamp examination of Postoperative decagonal cut PK with FSL	68
33	Top-hat incision pattern with varied suture depth	70
34	Slit lamp examination of Postoperative of 24-bit running suture PK	70
35	Schematic drawing of FLEx procedure	72
36	Schematic drawing of SMILE procedure	73
37	Surgeon's view of lenticule extraction	75
38	Operative steps of SMILE	77
39	Schematic presentation of laser photolysis.....	85
40	The optical and mechanical interface between the laser system and the eye	87
41	Images and cutting patterns produced by the FSL system	88
42	Images of the eye after cuts of capsulotomy and lens fragmentation are made	91
43	Details of the corneal incision	95
44	Ophthalmodynamometer applied to the globe.....	96
45	Intraoperative images showing capsule and lens removal.....	97
46	Intraoperative and postoperative view of Acufocus corneal inlay.....	104
47	INTRACOR; 1 hour post operative and 1 day post operative	106
48	Principle of the three-dimensional scanning unit	111
49	Schematic drawing of the combined, steering-wheel pattern	112

50	OCT images of a subsurface drainage channel created by the FSL in rabbit sclera.....	117
51	Pre- and post-operative IOP levels measured in treated live rabbit eyes.....	117
52	Limbal-based sclera flap created by FSL in cadaver eye	119
53	FSL assisted CXL	122
54	Slit lamp examination of cornea after FAB	124
55	FAB; corneal specimen lifting.....	125
56	Before and after FALT	128

In addition to the nanosecond (ns) and picoseconds (ps) lasers used in ophthalmology, a relatively new laser technology is becoming popular for use in refractive correction. The ultrashort laser pulses of the femtosecond (FS) laser, which focuses the laser beam to a spot size of several micrometers in diameter and does not exceed a pulse energy of 1 μ J, are in the range of 100–200 fs pulse duration. What is unique about the fs laser is its ability to produce a cut within the corneal stroma, rendering the need for a microkeratome unnecessary. **(Lubatschowski et al., 2000)**

Femtosecond lasers have ultrashort laser pulses which means that the pulse energy is decreased and that there is a reduction in the amount of thermal and mechanical damage to the surrounding corneal and stromal tissue. **(Lubatschowski et al., 2000)**

The first commercially available fs laser model, the IntraLase FS laser (Abbott Medical Optics Inc., Santa Ana, CA, USA), was introduced in 2001. Since then other fs lasers, including the Femtec (Technolas Perfect Vision, Heidelberg, Germany), Femto LDV (Ziemer Ophthalmic Systems, Port, Switzerland), and the VisuMax (Carl Zeiss Meditec AG, Jena, Germany), have entered the market. **(Soong and Malta, 2009)**

The technology was marketed as a replacement for the mechanical microkeratome. **(Sugar, 2002)**

Although each system boasts its own unique features and offers various configurations, all fs lasers have the same interaction process based on nonlinear absorption and tissue disruption. **(Lubatschowski, 2008)**

They allow three-dimensional tissue processing and absorption beneath the corneal surface. This technology offers many advantages for refractive correction, including precise cuts and minimal complications. Once designed as a simple flap cutter for refractive surgery, the FS laser is being used in new and exciting applications, including preparing cuts for intrastromal corneal ring segments, lamellar keratoplasty, and presbyopia correction. **(Noack and Vogel, 1999) (Heisterkamp et al., 2002) (Vogel et al., 2005)**

Using the FS laser to create a flap prior to LASIK has become established as a standard procedure. Between 2006 and 2007, the number of FS-created flaps during LASIK was more than doubled, with 15–17% of surgeons changing over from the mechanical microkeratome to the FS laser. **(Optics.org)**

Its use eliminates most of the complications associated with microkeratome-created flaps including variable flap thickness and reduction of mechanical and thermal side effects. **(Behrens et al., 1999) (Gimbel et al., 2000) (Vongthongsri et al., 2000)**

One of the most recent developments in the ophthalmologic application of FS lasers is its use in the correction of presbyopia. Previously, the only successful methods for presbyopic correction included lens implants or monovision surgery. Ripken et al., studied the effects of using the FS laser to create gliding planes inside the crystalline lens. The investigators postulated that the procedure, lentotomy, would not only help to regain elasticity and increase accommodation, but would do so without harming the lens capsule. **(Ripken et al., 2008)**

Another proposed method of presbyopic correction is photophaco modulation. **(Krueger et al., 2005)**

Manual Penetrating keratoplasty requires a long learning curve and a lengthy procedure time. **(Steinert et al., 2007)**

The FS laser can be used to create a “top hat”-shaped PKP that boasts creation of penetrating corneal incisions in one step. It has been found that the “top hat”-PKP configuration causes less wound leakage and provides a platform for looser sutures, which theoretically may decrease suture-induced astigmatism and allow faster visual recovery. Additionally, using the fs laser during PKP provides a better match at the wound edge between donor and recipient. **(Busin, 2003)**

These new lasers have the means of not only removing the cataract, but of creating precise capsulorhexis and treating astigmatism via arcuate relaxing incisions. The three companies which are working on these lasers are: LenSx Lasers (Aliso Viejo, CA, USA), LensAR (Winter Park, FL, USA), and Optimedica (Santa Clara, CA, USA). **(Dick et al., 2010)**

The great potential of all three laser systems is the automation these lasers can provide in creating the capsulorhexis and in pre-chopping the nucleus, reducing the overall energy needed to remove the cataract. Using the fs laser for incisions makes them more precise and repeatable, and they have been proven to self-seal more reliably. Astigmatic incisions can be programmed to be precisely repeatable, which should lead to greater accuracy. The capsulorhexis can be placed exactly where the surgeon wants it to be, which is different to the current situation. **(Dick et al., 2010)**