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A retrospective analysis of visual outcomes in laser vision correction of hyperopic patients using the VISX STAR S4 IR® and the WaveLight® EX500 excimer laser platforms

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Thesis

A RETROSPECTIVE ANALYSIS OF VISUAL OUTCOMES IN LASER VISION CORRECTION OF HYPEROPIC PATIENTS USING THE VISX STAR S4 IR® AND THE WAVELIGHT® EX500 EXCIMER LASER PLATFORMS

by

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DEDICATION

I dedicate this thesis to Ketti, my ever-supportive mother, without whom I could never have achieved my goals.

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I would like to thank Drs. Brenner, Melki, and Sood and the entire staff of the Boston Eye Group for their continuous support throughout this process. Additionally, I would like to thank my wonderful partner, Sean, for his assistance in decoding the numerous counting functions of spreadsheet softwares without which, I would likely still be counting. Finally, I would like to thank Dr. Jonathan Dobres whose statistical knowledge saved me many a headache.

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ABSTRACT

Background: Laser vision correction (LVC) developed as a more permanent alternative to other forms of refractive error correction. In the last several decades, visual outcomes of corneal refractive surgeries like LVC have improved dramatically with the discovery of new technologies and techniques designed to make the patient experience more comfortable and worthwhile. LVC has been shown to safely and effectively treat refractive errors in myopic and hyperopic eyes, with gradually improving outcomes and safety measures. However, it is important to note whether specific excimer lasers impart the same level of safe, effective treatments for patients as technology advances.

Objective: This study aims to identify whether any statistically significant difference exists in the visual and refractive outcomes of hyperopic laser vision correction using two excimer laser platforms, the VISX STAR S4 IR® and the WaveLight® EX500, and to determine whether either laser shows any statistically significant difference in the rate of repeat surgery within one year post-operatively.

Methods: Using EMR data collected from December 2008 through December 2016, distance and near visual acuity outcomes for hyperopic eyes treated with LASIK, LASEK, or PRK were compared at one month and up to one year post-operatively. Distance eyes were compared separately from monovision (near-targeted) eyes for visual acuity;

however, if manifest refraction post-operative data were available, they were used to identify whether any difference existed in the refractive outcomes in either category. The number of enhancements (repeat surgeries) was also tabulated. X^2 Tests of Independence were used to determine statistical significance.

Results: Visual acuity outcomes in distance eyes at one month post-operatively showed similar trends between the two lasers, with 54% of the 267 VISX- and 60% of the 119 EX500-treated eyes presenting with UCVA of 20/20 or better. Eyes available for follow-up within one year post-operatively kept with this trend; 98 (51%) VISX- and 58 (67%) EX500-treated, eyes had UCVA measured at 20/20 or better. For monovision (treated for reading vision) eyes, 29 (47%) eyes and 19 (54%) of VISX- and EX500-treated eyes, respectively, read J1+ by one month post-operatively. By one year, 16 (39%) and 3 (21%) of available eyes read J1+ after treatment with the VISX and EX500 respectively. The relative enhancement rate was 7.82% (28 eyes) on the VISX and 4.19% (7 eyes) on the EX 500.

Conclusion: Overall, visual outcomes of laser vision correction for hyperopic patients did not differ consistently between the two lasers. Only distance-treated eyes measured up to one year post-operatively showed a statistically significant difference between the two lasers. The visual and, more importantly, the refractive outcomes were statistically similar at both one month and up to one year post-operatively irrespective of treatment type. Enhancement rate between the two lasers also showed no differences. Both lasers are similarly safe and effective for treating hyperopia and hyperopic astigmatism.

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LIST OF ABBREVIATIONS

ASA ..... Advanced Surface Ablation

BCVA ..... Best Corrected Visual Acuity

BSS ..... Balanced Saline Solution

BU ..... Boston University

D ..... Diopter

DVA ..... Distance Visual Acuity

HOA ..... Higher Order Aberrations

LASIK ..... Laser-Assisted *In Situ* Keratomileusis

LASEK ..... Laser-Assisted Sub-Epithelial Keratectomy

LVC ..... Laser-Assisted Sub-Epithelial Keratectomy

NVA ..... Near Visual Acuity

PRK ..... Photorefractive Keratectomy

RSE ..... Refractive Spherical Equivalent

UDVA ..... Uncorrected Distance Visual Acuity

UNVA ..... Uncorrected Near Visual Acuity

VRR ..... Variable Repetition Rate

VSS ..... Variable Spot Scanning

INTRODUCTION

The human eye is an immensely powerful, complex organ, and diseases and dysfunctions of this structure can affect even the most basic aspects of life. Perhaps the most widely experienced disorders of the eye are refractive errors. The visual disturbances induced by these errors often require corrective lenses to allow the person to function normally during day-to-day activities. As such, the demand for a more permanent, affordable, and safe alternative to these lenses and their daily annoyances developed throughout the late 1900's and early 2000's in the form of refractive corneal surgery (Reinstein, Archer, & Gobbe, 2012).

The Anatomy of Vision

A knowledge of the anatomy of the eye is vital to understanding vision. From anterior to posterior, the major structures of the eye involved in transmitting and interpreting received light include the cornea, aqueous humor, lens, vitreous humor, and retina. Vision is the byproduct of neurological processing of reflected light entering the eye, passing through the first four components, and contacting photoreceptor cells at the back of the eye. The light energy received by these cells is converted into electrical energy, which is transmitted through the optic nerve to the brain ("How Your Eyes Work," 2017).

This passage of light occurs primarily due to the natural refractive properties of ocular structures. Each of the major anterior components possesses its own refractive index, which relates to the extent to which light is bent or refracted when passing from one component to another. Light waves pass first through the cornea and refract such that they

pass through aqueous humor toward the pupil and lens. Further refraction by the lens assists in focusing the received light waves, ideally onto the retina. A deficiency in any of these components – though primarily the cornea, lens, or retina – may result in difficulties processing light information correctly, thus leading to blurry vision, incomplete images, or even permanent loss of vision (Ohno-Matsui, 2016; Saw, 2006).

Refractive Errors

A healthy eye, where light passes through the anterior refractive components and focuses properly onto retinal photoreceptors at the back of the eye, is referred to as an emmetropic eye. However, refractive errors can occur such that light entering the eye does not focus on the retina due to some deficiency in part of the ocular organ. The most common refractive errors are myopia (nearsightedness), hyperopia (farsightedness) and astigmatism. Astigmatism itself may compound with myopia or hyperopia, further disrupting visual acuity. These errors may develop from a specific defect in one of the components involved in the passage of light into the eye, like the opacification of the lens during cataract formation leading to myopic refractive errors (Brown, 1993). Although, more commonly, errors result as part of the anatomical development of the eye during childhood and early adulthood (Flitcroft, 2014).

In myopia, light rays entering the eye are refracted such that light is focused in the front of the retina. Unfortunately, this limits the ability of a myopic eye to see objects at a distance; however, objects closer to the eye appear more appropriately. This failure to focus light on the retina typically results from an increased axial length – anterior to posterior length of the eye itself – shifting the focus point forward. It may also result from a

steepening of corneal tissue during eye development (Flitcroft, 2014; Richdale, Bullimore, Sinnott, & Zadnik, 2016). Traditional treatment for myopia involves the usage of diverging lenses designed to refract light more appropriately for the converging cornea prior to it encountering other intraocular structures. Corrective lenses prescribed for this purpose are written with a negative spherical power in diopters; the magnitude of this number indicates the power of the lens. For higher spherical power myopes, contact lenses may better serve this purpose than traditional glasses (Stein, Stein, & Freeman, 2013).

Conversely, refractive errors can produce an image that focuses behind the retina, which is the case for hyperopic eyes. Thus, unlike in myopic eyes, images further away from the eye itself (> 20 ft.) produce light waves that may properly focus on the retina, while closer objects may be more difficult to see for these patients. Like myopia, the primary causes of hyperopia lie in the axial length and anterior corneal curvature. A shortening of the axial length of the eye (axial hyperopia) or a flattening of the anterior corneal curvature (curvature hyperopia) each induce hyperopic refractive errors (Stein et al., 2013). During ocular development, it has been suggested that early in life (birth through 6 years old) eyes tend to begin with relatively hyperopic refractions and progress toward emmetropia through anatomical and physiological changes within the eye. Failure of physiological changes to reduce this hyperopia for any reason may result in a permanent refractive error in adulthood (Flitcroft, 2014). Fortunately, accommodation provides a means for patients to overcome mild to moderate hyperopia.

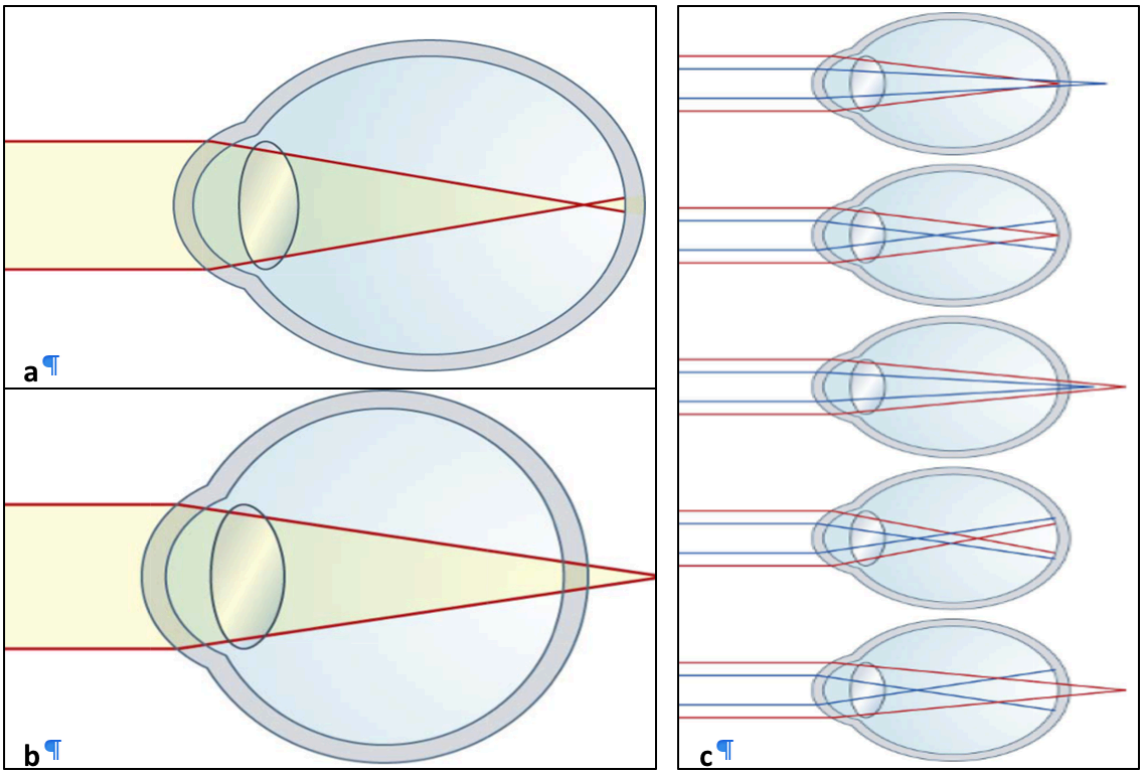

Figure 1. Artistic Representation of Refractive Errors. This figure depicts the various refractive errors treatable with laser vision correction. a) Myopia, wherein parallel light rays entering the eye focus in front of the retina. b) Hyperopia, parallel light rays focus behind the retina. c) Various astigmatism presentations where parallel light rays are focused at perpendicular angles to one another; astigmatism may present with hyperopia or myopia as well. (Adapted from Stein et al., 2013).

Accommodation refers to the ciliary body's ability to control the shape of the relatively malleable lens such that it can refocus light from objects closer than 20 feet onto the retina. In fact, working primarily on close-up tasks and objects has been suggested as one of the causes for progressive myopia, though support for this is limited (Sivak, 2012). In mild to moderate hyperopes, accommodation may sufficiently focus light such that both uncorrected distance and near visual acuities fall within functional norms; many patients who accommodate sufficiently do not think to see an eye doctor for any correction at all. The ability of the eye to accommodate to light reflected from nearer objects is most

powerful in childhood and declines with age; however, this does not typically result from a decrease in ciliary muscle tone (American Academy of Ophthalmology, 2016; Glasser & Campbell, 1998). This degradation often results in the need for corrective lenses to see close objects after the age of 40 years old even for previously uncorrected eyes in a condition known as presbyopia, which is discussed more in depth in the monovision section. For those patients who present with unaccommodated hyperopia, treatment typically involves prescribing a converging corrective lens, which is identified by a positive spherical power (Stein et al., 2013).

Finally, refractive errors may arise due to astigmatism. In eyes with astigmatism, light reflected from objects is refracted within the eye and projected such that two refracted light rays meet perpendicular to one another as opposed to at any specific point as with myopia or hyperopia. Both the cornea and lens may contribute to astigmatism; however, the anterior curvature of the cornea contributes the bulk of astigmatic refractive errors (Read, Vincent, & Collins, 2014). Treatment for astigmatism may also involve corrective lenses written for cylindrical power; lens prescriptions for these corrections may be written in either plus (converging) or minus (diverging) powers. Ophthalmologists tend to write prescriptions for lenses in positive cylinder, while optometrists tend to write prescriptions for lenses in negative cylinder. However, due to the nature of corrective converging lenses, overcorrecting myopic patients becomes a greater possibility when using positive cylinders; thus, refractive surgery specialists tend to work in negative cylinders. Negative cylinders were used in the refraction performed in this study.

Laser Vision Correction

As an alternative to corrective lenses, laser vision correction serves to reduce patients' need for glasses and other corrective interventions by inducing permanent changes to the anterior corneal stroma and altering the focal point of light refraction within the eye (Bower, Weichel, & Kim, 2001). A variety of techniques have been employed over the past fifty years to make changes to the cornea, including early radial keratectomy treatments in the 1970s; however, development of excimer and femtosecond laser technology alongside LASIK, LASEK, and PRK techniques have improved visual outcomes dramatically (Reinstein et al., 2012).

To determine a patients' candidacy for the procedure, several measurements are taken prior to the initial meeting with the surgeon. The details of how these measurements are conducted and what the results of these measurements entail for a patient's procedure are discussed more fully in the methods section. The power of laser vision correction stems from the cornea providing the majority of the refractive power to the eye (Mahendiran, Elie, Nebel, Ryan, & Pierscionek, 2014). It is important to note the limitations of laser vision correction and the contraindications for LVC, however. Anatomically, the cornea consists of the surface epithelium, Bowman's membrane, corneal stroma, Descemet's membrane, and corneal endothelium (Mescher, 2013). Given that the procedure is performed on the cornea, any malformations and dystrophies of these corneal components or other conditions that might affect long-term ocular health may disqualify patients from the procedure. These include keratoconus, Fuchs corneal dystrophy, thin central corneal

pachymetry, autoimmune disease, immunodeficiency, and other long-term ocular disorders like glaucoma (Bower et al., 2001).

This study focuses on three more modern, widely accepted treatment options for qualifying patients: LASIK, LASEK, and PRK (Duffey & Leaming, 2005). LASIK or Laser-Assisted *In Situ* Keratomeileusis involves the generation of a flap in the anterior cornea, allowing the surgeon to expose the corneal stroma for treatment by excimer laser with minimal damage to Bowman's membrane and the corneal epithelium. The creation of the flap may be performed using either a microkeratome, which is a small, circular device applied with significant pressure, or, more recently, a femtosecond laser. The development of the femtosecond laser has allowed for the rapid generation of the flap, saving time and potentially reducing post-operative dryness and visual disturbances (Xia, Yu, Chai, Wang, & Li, 2015). The femtosecond laser and its functionality are discussed in the section on laser platforms. Most importantly, LASIK has proven effective in correcting refractive errors in both myopia and hyperopia and their respective astigmatisms (Alió, El Aswad, Vega-Estrada, & Javaloy, 2013; Balazsi, Mullie, Lasswell, Lee, & Duh, 2001; Varley et al., 2004).

Laser-Assisted Sub-Epithelial Keratectomy or LASEK involves a flap creation similar to LASIK; however, the flap is much thinner and is not generated by a femtosecond laser. Instead, a 20% alcohol solution is instilled into a ringwell for 40 seconds to loosen only the surface epithelium, after which the loosened epithelium can be lifted as a flap. This flap is very thin, approximately 50 micrometers thick, making it particularly friable; thus, for some LASEK procedures, the surface epithelium is completely removed, making

it effectively a photorefractive keratectomy (PRK) procedure. PRK is similar in technique (described in methods) to the LASEK procedure, with the exception being that the surface epithelium is completely removed and must regenerate more completely before visual stabilization. Both procedures have proven effective and safe in treating both myopic, hyperopic, and astigmatic refractive errors (Autrata & Rehurek, 2003; Habibollahi et al., 2015; Hashemi, Aghazadeh Amiri, Tabatabaee, & Ayatollahi, 2016; O'Brart, Patsoura, Jaycock, Rajan, & Marshall, 2005; Shah et al., 2012). Given their similarities, for the purposes of this study, both procedures will be referred to as advanced surface ablation (ASA) for the remainder of this thesis. Additionally, particular attention will be paid to hyperopic treatments and outcomes; while no randomized comparisons have been made between treatment options (LASIK or ASA), non-randomized studies have shown equal efficacy between these options for treating hyperopic refractive errors (Settas, Settas, Minos, & Yeung, 2012).

Monovision

As was mentioned previously, the accommodative ability of intraocular muscles declines with age, resulting in difficulties clearly seeing nearby objects and text after 40 years of age. This condition is called presbyopia (American Academy of Ophthalmology, 2016). Fortunately, by treating separate eyes for reading and distance vision (i.e. monovision), it is possible to minimize patients' need for reading and distance glasses (Charman, 2014; Mantry & Shah, 2004). In terms of laser vision correction, undercorrecting myopia (i.e. leaving one eye nearsighted) or overcorrecting hyperopia (creating nearsightedness) both impart the effects of monovision.

Laser Platforms

Femtosecond laser technology allows for safe LASIK flap generation using lamellar, short wavelength beams to create micro air pockets within the corneal tissue (Kohnen, Schwarz, Remy, & Shajari, 2016); these micro air pockets create consistent, efficient flaps reducing intraoperative time and post-operative complications as compared to mechanical microkeratomes (J.-H. Kim, Lee, & Rhee, 2008; Knorz & Vossmerbaeumer, 2008; Kohnen et al., 2016; Xia et al., 2015). The IntraLase® iFS 60-kHz laser (Abbott Medical Optics) used in this study is comparable to the Alcon WaveLight® FS200 (Alcon equivalent fifth generation femtosecond laser) in producing quality, reproducible flaps for predictable, safe LASIK outcomes (Liu et al., 2016).

In addition to the femtosecond flap-generation laser, the excimer laser induces the permanent corneal changes that aim to improve uncorrected visual acuities. For treating myopia, excimer laser ablation flattens the relatively steep cornea, while for. Thus, confirming that individual, commercially available excimer lasers produce effective, safe, reproducible results in terms of those visual outcomes is important when applying these treatments to patients' eyes. This study focuses on the comparability of two excimer lasers – the Abbott VISX STAR S4 IR® (Abbott Medical Optics, Inc.) and the Alcon WaveLight® EX500 (Alcon Laboratories, Inc.) lasers. The inherent differences between the two lasers lies not only in their manufacturers but also in their functionality.

The VISX laser boasts a variable spot scanning (VSS) treatment profile; this means that each beam emitted by the laser for treatment may vary in size (0.65 to 6.5mm) and rate of fire (variable repetition rate, VRR), providing a controlled ablation zone up to 8mm in

diameter ("STAR S4 IR® Excimer Laser | Abbott Vision," n.d.). The CustomVue® option for treatment with this platform combines this VSS and VRR with images from their WaveScan scanners to target higher order aberrations (HOA's). Higher order aberrations are measured by the WaveScan, which shines light into the eye and measures how that light is refracted and reflected back to the system, creating a customized treatment profile for individual eyes. Using this wavefront-guided approach, post-operative higher order aberrations may be reduced as compared to other methods of treatment (Padmanabhan, Mrochen, Basuthkar, Viswanathan, & Joseph, 2008). However, this study focuses primarily on the standard ("traditional") treatment functionality of the laser, rather than the CustomVue® option. The VISX platform has proven effective in treating both myopia, hyperopia, and astigmatism irrespective of treatment type (LASIK and surface ablation) in previous studies (Jackson, Tuan, & Mintsioulis, 2011; Kulkarni et al., 2013; Schallhorn et al., 2016).

The EX500 laser shines due to the speed at which it provides treatment. Operating at 500 Hz, this laser is able to treat refractive errors significantly faster than its VISX counterpart, which Alcon suggests may decrease the risk of corneal dehydration and fixation losses intraoperatively thereby improving visual outcomes ("Wavelight® Ex500 Excimer Laser | myalcon.com," n.d.). This laser evolved from its 400 Hz counterpart, the Allegretto WaveLight® Eye-Q laser, which has positive, effective outcomes when treating myopia, hyperopia and astigmatism using LASIK and ASA treatment procedures (Costa et al., 2014; George, Shah, Hood, & Krueger, 2010; Kezirian, Moore, Stonecipher, & SurgiVision Consultants Inc WaveLight Investigator Group, 2008; Ziaei, Mearza, &

Allamby, 2015). Comparison studies conducted between the 400-Hz laser and the newer 500-Hz laser indicate better centration and eye-tracking capabilities (and therefore better visual outcomes) on the newer laser (J. Kanellopoulos & Asimellis, 2015). Although no ASA-specific studies could be identified using only the EX500 laser, it has been shown to produce appropriate results for LASIK treatments (A. J. Kanellopoulos & Asimellis, 2013; J. Kanellopoulos & Asimellis, 2013).

Fewer studies have been performed on the individual treatment outcomes of the EX500 laser; however, several comparison studies have been conducted between the VISX STAR S4 IR® and both the Allegretto and EX500 lasers. For myopic treatments, no significant difference has been identified between the visual, refractive, and safety outcomes between either the VISX or Allegretto lasers, though the evidence of how wavefront-guided (VISX CustomVue®) versus wavefront-optimized (modern Alcon lasers) treat HOA's is inconclusive (He & Manche, 2015; Khalifa, Mossallam, Massoud, & Shaheen, 2015; Kung & Manche, 2016; Moshirfar et al., 2011; Padmanabhan et al., 2008). Also, no identifiable difference between either the EX500 or VISX lasers could be identified from literature review of myopic treatments (Meidani & Tzavara, 2016); however, one presentation noted fewer post-operative spherical aberrations on the EX500 laser (S. I. Kim et al., 2014).

Despite the extensive research into myopic LVC, limited comparisons have been made for hyperopic treatments on these lasers. One study analyzing outcomes for hyperopic treatments between the VISX and Allegretto lasers showed no statistically significant difference between the CustomVue® and wavefront-optimized (Allegretto)

groups (Sáles & Manche, 2014). However, to the best of our knowledge, no study comparing the efficacy and safety of the WaveLight® EX500 to the standard option on the VISX STAR S4 IR® in treating hyperopic eyes has been published. This thesis aims to approach that topic and provide evidence in line with previous studies that no significant difference exists in the visual or refractive outcomes of either laser in treating hyperopes.

SPECIFIC AIMS

Laser vision correction technology has advanced considerably in the past several decades. With these advancements, several studies have been completed comparing the visual outcomes of LVC using a variety of excimer lasers, including the VISX CustomVue® STAR S4 IR® and Alcon WaveLight® EX500 excimer lasers. These studies have compared treatment outcomes for myopic patients separately on each laser and comparatively between the two lasers. The VISX CustomVue® treatments and the Alcon WaveLight® treatments have each been proven effective and safe for treating hyperopia separately, and the CustomVue® treatments have been compared to the Allegretto Eye-Q excimer laser. However, no study has been conducted comparing the visual outcomes of the traditional function of the VISX to the EX500 for hyperopic treatments.

This study aims to accomplish just that. Hyperopic eyes treated either with the traditional function of the VISX STAR S4 IR® or the WaveLight® EX500 excimer laser were compared to identify any statistically significant differences in the visual outcomes, refractive outcomes, and enhancement rates between each laser to verify that safe and effective treatments may be carried out on either laser.

METHODS

Laser Vision Correction Consultation

Patients evaluated for laser vision correction underwent Boston Laser's standard examination prior to scheduling treatment. Additionally, the surgical techniques and post-operative care described herein were conducted as standard practices performed at Boston Laser. The preliminary examination included checking corrected and uncorrected near and distance visual acuities, manifest refraction, keratometry, pachymetry, corneal topography, Zone-Quick dry eye test, and pupilometry. Patients were then dilated to perform a cycloplegic refraction and a retinal health exam. All distance visual acuities both for the preliminary examination and post-operative examinations were tested using a Snellen chart projection calibrated for a distance of twenty feet; near visual acuities were tested at fourteen inches using a Rosenbaum Pocket Vision Screener card and recorded on the Jaeger scale. Keratometry values were measured using an autorefractor. Corneal topography was conducted using either the Oculus Pentacam (Oculus, Inc.) or Galilei G4 (Zeimer Ophthalmic Systems) topography platforms, which also provided central, thinnest corneal pachymetry values. In order to rule out keratoconus and other corneal dystrophies, special attention is paid to the inferior-superior ratio of cornea thickness (I-S ratio). An I-S ratio greater than 1.5 indicates an increased risk for a condition known as keratoconus or post-operative ectasia; thus, LASIK, which affects more of the corneal stroma due to flap creation, is contraindicated typically in these patients. A Colvard pupilometer was used to assess mesopic pupil size, which was used to determine the appropriate optical zone for

use during the procedure. Using this information, the surgeon then determined the treatment appropriate for the patient between LASIK, LASEK, and PRK (Figure 2).

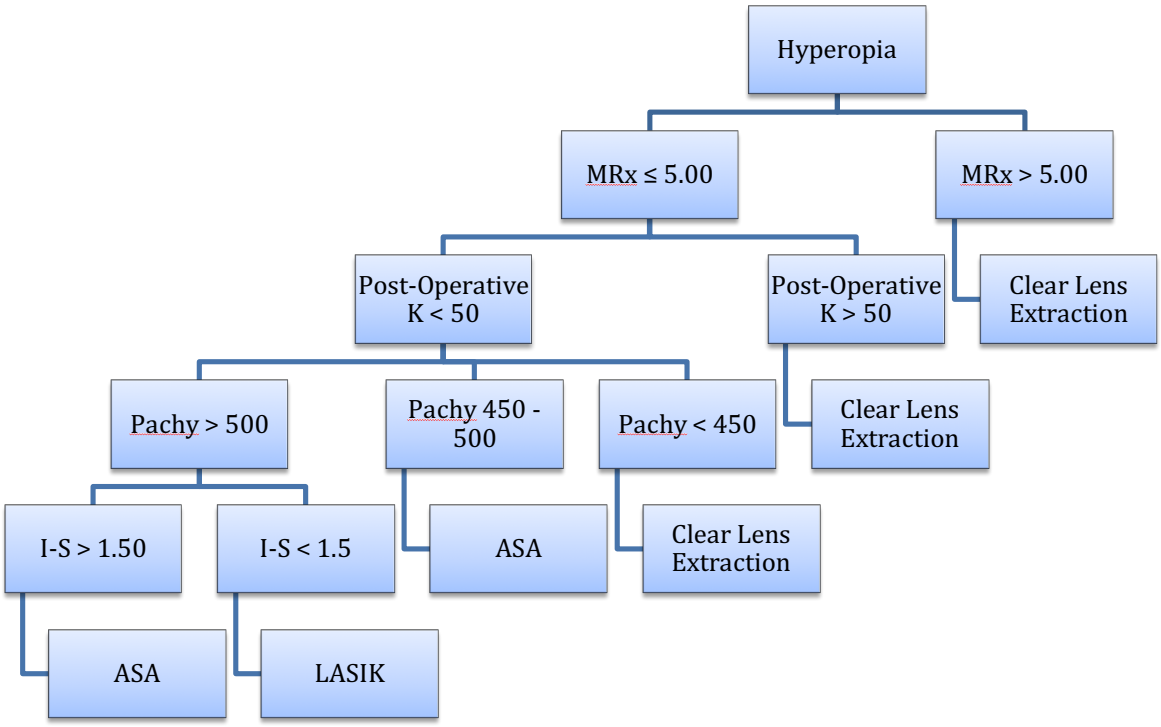

Figure 2. Boston Laser Hyperopic Refractive Surgery Algorithm. This figure illustrates the Boston Eye Group's basic decision-making process for identifying potential candidates for hyperopic LVC. These treatment parameters are evaluated with the limitations of the excimer lasers and FDA-approved treatment options in mind.

Pre-Operative Meeting

On the day of surgery, patients confirmed their understanding of the benefits, alternatives, and risks of their laser vision correction. Manifest refractions were repeated if the patient had previously not been out of contact lenses for at least one week prior to their initial evaluation, if significant (>0.5D) discrepancies between previous cycloplegic and manifest refractions, or if their most recent manifest refraction was conducted greater than three months prior to their surgery date. Corneal topographies were repeated for patients

whose most recent topography was taken more than twelve months prior to their day of surgery. Patients met with their respective surgeon for any final questions before being advised of the post-operative restrictions and medication instructions. A pre-operative drop of nepafenac 0.3% ophthalmic suspension and ciprofloxacin hydrochloride 0.3% was instilled into each operative eye prior to treatment. Additionally, patients were offered 5mg of diazepam (Valium) prior to treatment to reduce any possible anxieties associated with the procedure.

Surgical Technique

Irrespective of treatment type, each patient was prepared in the operating room initially with a topical betadine scrub over each operative eye. Additionally, one drop of topical anesthetic 1% proparacaine hydrochloride was instilled into each operative eye prior to beginning surgery. Each operative eye underwent LASIK, LASEK, or PRK procedures as described below. The excimer laser treatment itself depended on which excimer laser was used for the treatment, either the VISX STAR S4 IR® traditional treatment or WaveLight® EX500 wavefront-optimized treatment. Upon completion of the treatment, two drops of a 1:1 1% prednisolone acetate-0.3% ciprofloxacin cocktail were instilled in the affected eye(s).

LASIK

Following aseptic preparation, LASIK flap generation took place using the IntraLase Femtosecond Laser. Ideal flap thicknesses were verified in the laser system prior to treatment, with a target depth of between 100 and 110 microns. Suction was applied using the appropriate patient interface prior to docking the laser with attached optical cone.

A pupil-centered position was verified by the surgeon using minor adjustments as appropriate before instructing the patient to remain still while the laser generated the flap. After completion of the flap cut, the docking cone and suction interface were removed from the eye and discarded; the patient bed was then mechanically rotated to the excimer laser (either the VISX STAR S4 IR® or WaveLight® EX500). A tegaderm transparent film dressing was applied to the patient's superior eyelid to clear the surgical field of eyelashes. A speculum was used to hold the patient's eyes open for the duration of the treatment procedure. A corneal marking pen was then used to mark the boundary between the flap and remaining corneal surface for appropriate repositioning after excimer treatment. Pre-operative pachymetry values were verified using a portable pachymeter or laser system pachymetry functions and compared to the patient's Pentacam or Galilei G4 pachymetry values prior to proceeding with treatment. The flap was then lifted using a LASIK Flap Lifter; a flap-lifted pachymetry value was then measured to verify a safe, calculated flap thickness and remaining corneal stroma thickness prior to excimer laser treatment. After the completion of the laser treatment, the corneal flap was repositioned using an irrigating cannula and balanced saline solution (BSS).

LASEK and PRK

During both the LASEK and PRK preparations, a tegaderm transparent film was used to clear eyelashes from the surgical field prior to the application of a speculum to keep the patient's eye open. Topical 1% proparacaine hydrochloride was reapplied as anesthetic. An 8mm ring well was then placed firmly over the treatment area, and a 20% dehydrated alcohol solution instilled into this well for forty seconds. The treated corneal

epithelium was then rinsed thoroughly with 5mL of 0.9% saline solution (Addipak). For LASEK treated eyes, the loosened epithelium was lifted as a flap prior to excimer laser treatment. For PRK treated eyes, this epithelium was removed completely prior to excimer laser treatment using a dry Weck-Cel®. Upon completion of excimer treatment, a sponge soaked mitomycin-C (MMC) was applied to the exposed cornea to reduced corneal scarring during the healing process. The MMC was allowed to soak the cornea for a period of time dependent upon the treatment ablation (Habibollahi et al., 2015; Teus, de Benito-Llopis, & Alió, 2009) (Table 2). Upon completion of MMC soak, 10 mL of cold 0.9% saline solution was used to rinse and hydrate the cornea. Afterward, a bandage contact lens and 1 drop of 1% cyclogyl were placed in the eye to reduce patient discomfort during the healing process.

Post-Operative Care and Instructions

Printed post-operative instructions were provided to patients, which included no squinting, squeezing, or rubbing operative eye(s) during the healing process (at least two weeks). Additionally, patients were instructed to refrain from swimming, saunas, hot tubs, contact sports, and heavy exercise during first few weeks post-operatively. Patients were instructed to sleep with provided clear, plastic eye shields over each operative eye for one week following their procedure. After returning home from the procedure, patients were instructed to rest with eyes closed for four hours after the procedure before starting post-operative drops. All patients were seen in the clinic for 1 day, 1 week, and 1 month post-operative appointments.

Patients having undergone LASIK waited with their eyes closed in the clinic for thirty minutes before having their flap position checked by the surgeon. After this verification, a clear plastic eye shield was taped over the treated eye(s), and the patients were instructed to keep these shields in place for the remainder of the day of their surgery in addition to the standard instructions to wear them while sleeping. LASIK patients are instructed to use one drop of 1% prednisolone acetate ophthalmic solution into each surgical eye hourly while awake beginning four hours after the procedure for post-operative days 1-3 (including the day of surgery). On post-operative days 4 and 5, patients were instructed to decrease their usage of these drops to four times daily while awake. Patients were also told to instill an antibiotic drop four times per day while awake into each operative eye on days 1-5 post-operatively. Patients were instructed to discontinue both the prednisolone and antibiotic drops starting on day 6.

Patients receiving LASEK and PRK treatments were prescribed 1% prednisolone acetate eye drops. The steroid regimen for these patients involved using the drops four times per day into each operative eye during the first week post-operatively, three times per day during the second week, twice per day during the third week, and once per day during the fourth week. Patients were instructed to discontinue the prednisolone drops after the fourth week. Additionally, these patients were instructed to use an antibiotic eye drop in each operative eye four times per day until the bandage contact lens was removed by a physician, typically at the patient's one week post-operative appointment. As optional medications for managing patient discomfort post-operatively, a prescription for Nevanac (nepafenac 0.1%) to instill twice daily into operative eye(s) and 15 tablets of

acetaminophen/codeine (300-30mg) to take once (1 tablet) every 6 hours with food were provided. Patients were also asked to take 1000mg of Vitamin C daily for three months post-operatively to facilitate appropriate healing of surface epithelium.

Inclusion and Exclusion Criteria

A report was generated collecting EMR data for eyes treated with laser vision correction (either LASIK, LASEK, or PRK) between December 2008 and December 2016 whose manifest refractive spherical power was greater than 0.00. Eyes with a refractive spherical equivalent less than 0.00 were excluded from this analysis; however, eyes with mixed astigmatism were included and discussed. Refractive spherical equivalent was identified by adding the full power of the spherical refraction to half the power of the cylinder refraction. Eyes were included irrespective of treatment type – either LASIK, LASEK, or PRK. Particular attention was paid to LASIK treated eyes as significantly more treatments fell into that category. Due to this discrepancy between the number of eyes treated with LASIK and the number of eyes treated with LASEK and PRK, LASEK and PRK were collectively analyzed as advanced surface ablation (ASA). Only eyes available as part of a patient's electronic medical record were included in the study. Patients whose surgery was performed at the Boston Eye Group but whose post-operative care was provided by a co-managing physician were not included as their follow-up data was not available for analysis. Patients unavailable for follow-up through up to one year post-operatively were included if data existed for at least one month post-operatively; however, patients who did not have at least 1 month of follow-up data were excluded entirely. The total number of eyes treated using the VISX STAR S4 IR® excimer laser was 358 (267

distance, 91 monovision), and the total number of eyes treated using the Alcon WaveLight® EX500 eximer laser was 167 (119 distance, 48 monovision). A more detailed depiction of included eyes separated by treatment type and target correction can be found in Table 1.

Table 1. Number of Eyes Treated with LASIK, LASEK, and PRK on Each Excimer Laser. The total number of eyes treated using each excimer laser identified by treatment type and refractive aim. Near vision aims were determined based on age and patient preference for monovision.

EXCIMER LASER	TARGET	TREATMENT TYPE	NUMBER OF EYES
VISX STAR S4 IR®	Distance	LASIK	238
		LASEK	23
		PRK	6
	Near	LASIK	76
		LASEK	10
		PRK	5
Alcon WaveLight® EX500	Distance	LASIK	93
		LASEK	18
		PRK	8
	Near	LASIK	36
		LASEK	10
		PRK	2

Data Collection and Grouping

Patient eyes were initially grouped according to treatment aim - either for distance or monovision - and additionally separated according to treatment type, LASIK, LASEK, or PRK. At the patient's standard one month post-operative

appointment, visual acuities were recorded and these visual acuity measures were used to analyze visual outcomes. For monovision eyes whose near visual acuity was not measured, no statistical or otherwise comparison was drawn between near visual acuities and distance visual acuities; however, monovision eyes with post-operative manifest refractions were included in refractive analyses with respect to their target refraction. If the patients returned to the clinic for follow-up within one year post-operatively, their latest visual acuity measurements were analyzed for long-term stability and efficacy of each excimer laser's treatment.

Patient's whose visual outcomes achieved target visual acuity, the refractive outcome was identified as that patient's target. For example, distance eyes were targeted for a plano spherical equivalent (0.00 RSE); eyes measuring 20/20 uncorrected were considered plano post-operatively. For a number of patients, manifest refractions were performed on eyes whose visual acuity was less than expected (either less than 20/20 for distance eyes or less than J1+ for monovision eyes). These manifest refractions were used to determine the refractive spherical equivalent post-operatively, and that RSE was used to determine the distance from the target refractive power. These distances were separated by those within 0.5 D of the target, 1.0 D of the target, and > 1.0 D of the target.

If a patient required or requested an enhancement, their visual acuity prior to the enhancement was used as their latest visual acuity up to one year. The number of eyes enhanced was recorded both for distance and near vision eyes. Enhancement eyes were excluded from statistical analysis if the enhancement was performed due

to patient dissatisfaction with monovision, distance vision (when they later wanted monovision), or if the initial refractive target was achieved.

Statistical Analysis

The statistical tools used were X^2 Tests of Independence to determine whether any significant difference existed between the excimer lasers in any of the measured values. The independent categorical variable was treatment laser, and the dependent categorical variable was visual acuity or post-operative refractive group. In order to impart the most power to the statistical calculations, treated eyes were grouped according to optimal, adequate, and suboptimal outcomes. For example, eyes whose UDVA was 20/20 or better by their post-operative visit were compared to eyes whose UDVA was between 20/25 and 20/40 and to eyes whose UDVA was worse than 20/40. This method reduced the likelihood of not identifying a statistically significant difference between the outcomes on either laser or of having too few eyes in any individual category. Table 2 depicts the possible categories into which treated eyes could have been included; however, not every visual level contained any treated eyes. For refractive outcomes, chi square analyses were conducted using eyes within 0.5 D, 1.00 D, or greater than 1.00 D of the target refractive outcome for both the one month and one year groups.

Table 2. Possible Categories for Distance and Near Visual Acuities. The distance visual acuity possibilities measured at 20 feet from the projected Snellen chart and the near visual acuity possibilities measured at 14 inches from the patient using the Jaeger scale, written adjacent to their DVA equivalents.

Distance Visual Acuity	Near Visual Acuity
20/15	-

20/20	J1+
20/25	J1
20/30	J2
20/40	J3
20/50	J4
20/60	J5
20/70	J7
20/80	-
20/90	-
20/100	J10
20/150	-
20/200	J16
20/400	-

RESULTS

Distance Vision Correction

For eyes targeted for distance vision, or plano spherical power (0.00 RSE), 267 included eyes were treated using the traditional setting on the VISX STAR S4 IR®, and 119 included eyes were treated using the Alcon WaveLight® EX500 excimer lasers. These all had distance visual acuity measurements for at least one month post-operatively. When all treatment types were compared, the UDVA's for both lasers exhibited primarily one month post-operative visual acuities around 20/20 (Figure 3a). More specifically, 54% of eyes treated on the VISX and 60% of eyes treated with the Alcon laser showed an uncorrected visual acuity of 20/20 or better at one month post-operatively (Figure 3b) ($X^2(2, N = 386) = 1.299$, $p = 0.5223$). This trend held for the LASIK group, which was comprised of 238 VISX eyes and 93 Alcon eyes. On the VISX, 55% of LASIK eyes treated for distance vision achieved an uncorrected distance visual acuity of 20/20 or better; on the Alcon laser, 63% of LASIK eyes treated for distance vision achieved the same uncorrected visual acuity (Figure 3c) ($X^2(2, N = 331) = 1.187$, $p = 0.5525$). For eyes treated with ASA, the one month post-operative trend was less clear. Using the VISX laser, 29 eyes were identified as having undergone ASA, and 26 eyes were treated using the EX500. Neither laser produced uncorrected visual acuity measures better than 20/20 by one month; the VISX produced 17% while 46% of Alcon eyes were 20/20 by one month post-operatively ($X^2(2, N = 55) = 5.401$, $p = 0.0672$). No ASA-treated distance eyes showed an uncorrected DVA less than 20/50 in the VISX group or less than 20/60 in the Alcon group (Figure 3d).

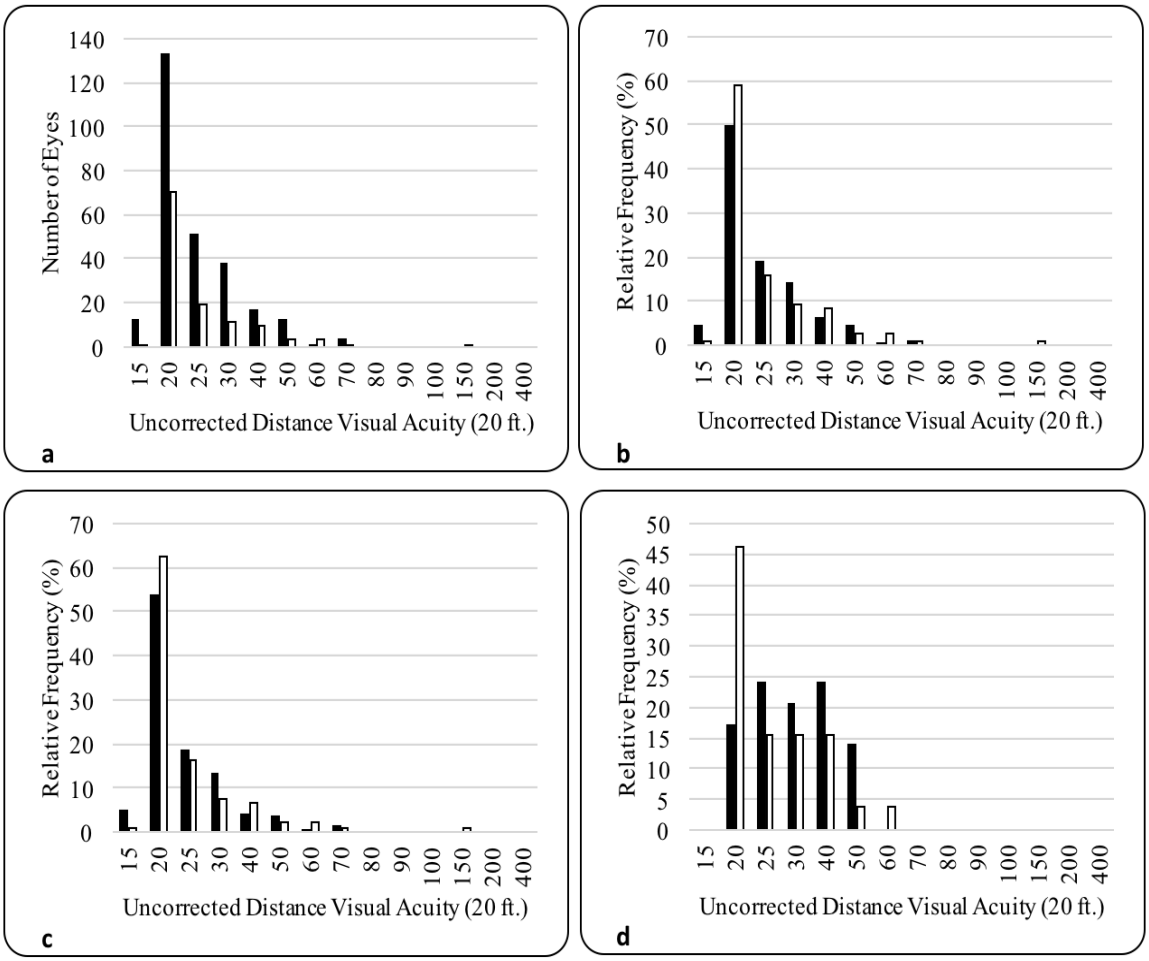

Figure 3. Uncorrected Distance Visual Acuities at One Month Post-Operatively. The total number of eyes and relative frequency of UDVA outcome plotted for each treatment type. Solid bars show VISX treated eyes; hollow bars show Alcon treated eyes. a) The total number of treated eyes on each excimer laser. b) The relative frequency of UDVA outcomes for all treated eyes. c) The relative frequency of UDVA outcomes for LASIK treated eyes. d) The relative frequency of UDVA outcomes for ASA treated eyes.

Fewer eyes had distance visual acuity measurements available up to one year either because their next visit to the clinic was outside the time frame of one year or because they were lost to follow up. These eyes showed the same relative trend as the one month post-operative eyes. Up to one year, 191 eyes were evaluated after treatment with the VISX laser, and 58 eyes were evaluated after treatment with the Alcon laser (Figure 4a). Overall,

51% of VISX treated eyes and 68% of Alcon treated eyes showed an UDVA of 20/20 or better at their latest follow-up within their first year prior to surgery ($X^2(2, N = 249) = 8.700$ $p = 0.0129$) (Figure 4b). Of LASIK-treated eyes only, 170 eyes were treated using the VISX laser while only 46 eyes were treated using the Alcon laser; 51% of LASIK VISX eyes and 63% of LASIK Alcon eyes were 20/20 or better in this time frame ($X^2(2, N = 216) = 5.053$, $p = 0.0799$) (Figure 4c). Within one year, the number of ASA-treated eyes measured for UDVA was much lower, with 21 VISX and 12 Alcon eyes presented. Given the measurements on these few eyes, 52% of VISX treated eyes and 83% of Alcon treated eyes were 20/20 or better by their latest post-operative appointment up to one year ($X^2(2, N = 33) = 4.314$, $p = 0.1157$) (Figure 4d).

Near Vision Correction

Included monovision eyes totaled 91 on the VISX laser and 48 on the Alcon laser. Of these eyes, only 62 VISX and 35 Alcon eyes had available, recorded near visual acuities at least one month post-operatively. With these measured values, the same general increasing trend toward J1+ outcomes was exhibited in both groups at one month post-operatively (Figure 5a). Between the two groups at that time, 47% of VISX eyes and 54% of Alcon eyes were measured to see J1+ ($X^2(2, N = 97) = 2.519$, $p = 0.2839$) (Figure 5b). When analyzing the one month post-operative results of LASIK-treated monovision eyes, 49% of VISX eyes and 59% of Alcon eyes were J1+ ($X^2(2, N = 82) = 2.034$, $p = 0.3618$) (Figure 5c). Similar to the distance eye groups, the ASA-treated eyes were far

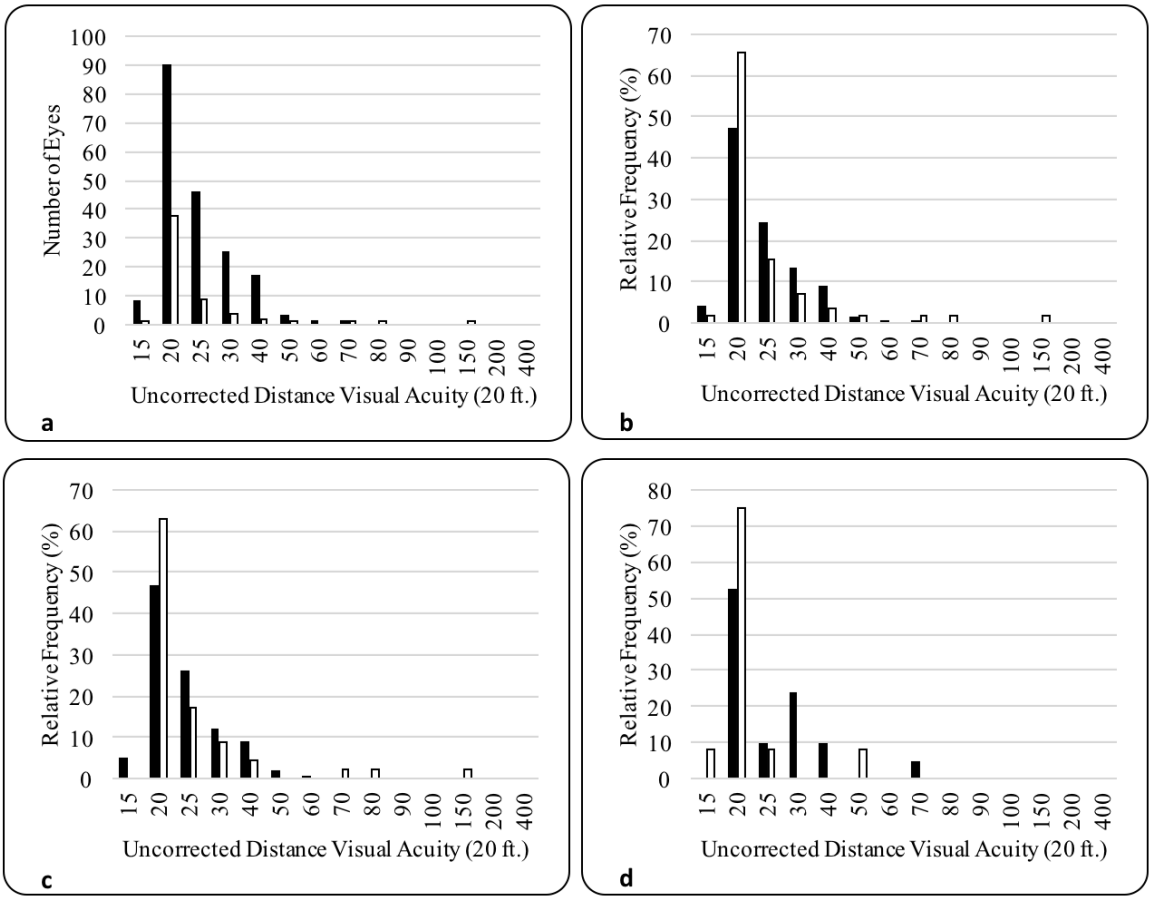

Figure 4. Uncorrected Distance Visual Acuities at Up to One Year Post Operatively. The total number of eyes plotted in addition to the relative frequency of visual outcomes on each laser for each treatment type. The solid bars represent VISX eyes, and the hollow bars represent Alcon eyes. a) The total number of eyes with UDVA measurements available up to one year post-operatively. b) Relative frequencies of UDVA outcomes for all treated eyes. c) Relative frequencies of UDVA outcomes for LASIK treated eyes. d) Relative frequencies of UDVA outcomes for ASA treated eyes.

fewer in number with 9 eyes treated on the VISX and 6 eyes treated on the Alcon laser included in this study**.** The relative frequency of J1+ ASA-treated eyes at one month post-operatively was 33% on both the VISX and Alcon lasers ($X^2(2, N = 15) = 0.875$, $p = 0.6456$) (Figure 5d).

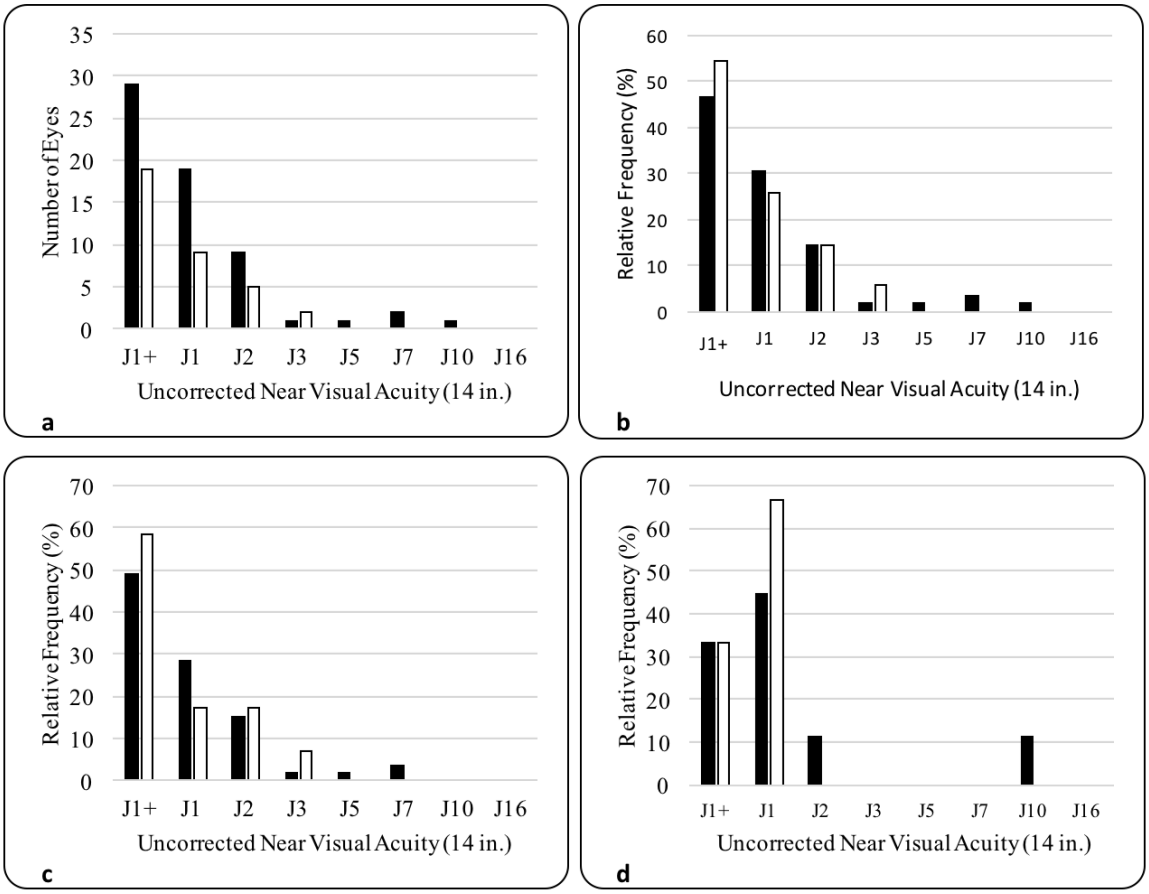

Figure 5. Uncorrected Near Visual Acuities for Monovision Eyes at One Month Post-Operatively. A graphical representation of the total number of monovision eyes with measured near visual acuities at one month post-operatively. Solid bars represent VISX eyes, and hollow bars represent Alcon eyes. a) The total number of eyes with measurements. b) Relative frequency of all treatments' visual outcomes. c) Relative frequency of LASIK-treated near vision outcomes. d) Relative frequency of ASA-treated near vision outcomes.

For monovision patients who followed up within one year after their initial treatment, 56 total eyes were identified with their corresponding near visual acuity measurement (41 VISX, 15 Alcon) (Figure 6a). Overall frequency of eyes measuring at J1+ by that point was 39% and 21% on the VISX and Alcon lasers respectively ($X^2(2, N = 55) = 3.643$, $p = 0.1618$) (Figure 6b). For only LASIK-treated monovision eyes, 12 eyes

(37.5%) on the VISX and 2 eyes (20%) on the EX500 were recorded as J1+ by their latest appointment up to one year ($X^2(2, N = 42) = 2.562$, $p = 0.2778$) (Figure 6c).

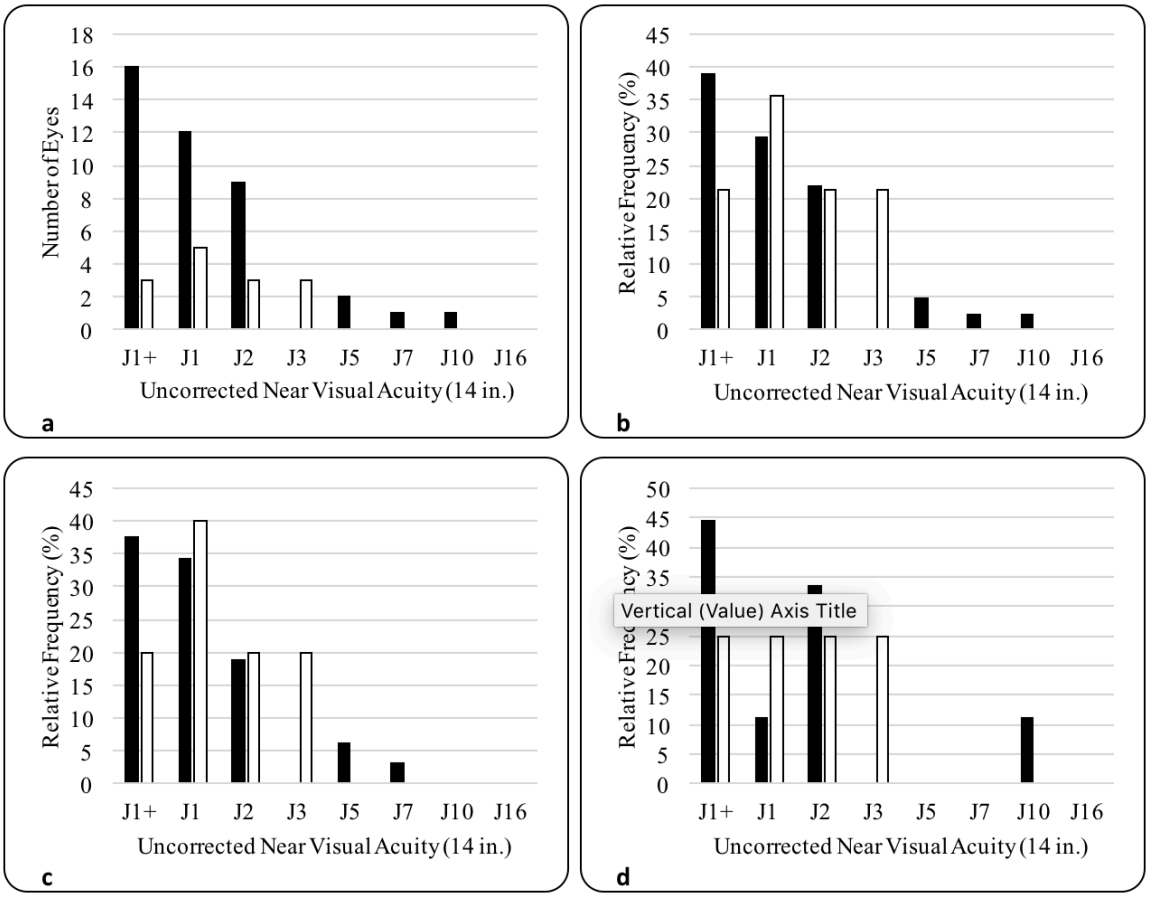

Figure 6. Uncorrected Near Visual Acuities for Monovision Eyes at Up to One Year Post-Operatively. The total number of eyes and relative frequencies for monovision treated eyes on both the VISX (shaded) and EX500 (unshaded) excimer lasers. a) Graphical representation of total eyes available for UNVA measurement up to one year after their original procedure. b) Relative frequencies of UNVA measurements for all treatment types up to one year post-operatively. c) Relative frequencies of UNVA measurements for LASIK-treated eyes up to one year post-operatively. d) Relative frequencies of UNVA measurements for ASA-treated eyes up to one year post-operatively.

Monovision eyes treated with ASA in the same time frame were again fewer in number with 9 eyes treated with the VISX and 4 with the EX500. In this small sample, 4 VISX

eyes (44%) and 1 Alcon eye (25%) were J1+ when measured ($X^2(2, N = 13) = 1.197$, $p = 0.5497$) (Figure 6d).

Refractive Outcomes

At one month post-operatively, a total of 274 VISX eyes and 149 EX500 eyes had recorded manifest refractions or were measured at their target visual outcome (i.e. 20/20 for distance eyes and J1+ for monovision eyes). The VISX-treated eyes presented with 250 (91%) eyes within 1.00 D of target RSE and 212 (77%) eyes within 0.50 D of target RSE. Measured EX500 eyes presented with 134 (90%) eyes within 1.00 D of target RSE and 101 (68%) eyes within 0.50 D of target RSE ($X^2(2, N = 423) = 1.396$, $p = 0.4975$) (Figure 7a).

By their latest appointment up to one year after their treatment, 192 VISX eyes and 69 Alcon eyes were refracted or were measured at their target visual outcome. Similar relative frequencies were found for each laser. The VISX was found with 178 (92%) eyes within 1.00 D of target RSE and 141 (73%) eyes within 0.50 D of target RSE. The EX500 produced 64 (93%) eyes within 1.00 D of target RSE and 47 (68%) eyes within 0.50 D of target RSE ($X^2(2, N = 261) = 0.1997$, $p = 0.9050$) (Figure 7b).

Enhancement Rate

The recorded number of retreatments or enhancements on each laser was 40 and 10 eyes on the VISX and EX500 lasers respectively. The details of these enhancements are summarized in Table 3. An enhancement treatment was labeled as a touch up if it was aimed at improving the patient's vision toward the previous refractive aim.

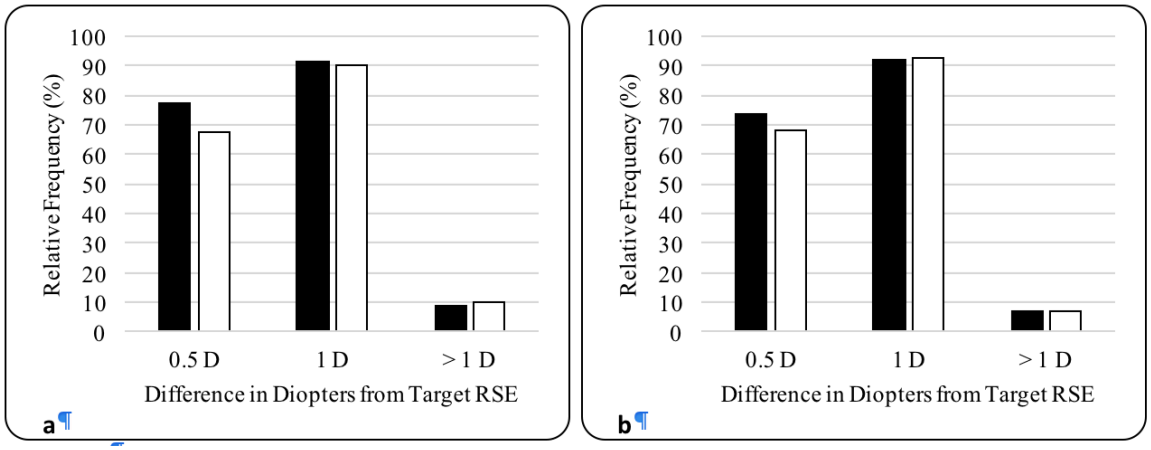

Figure 7. Refractive Outcomes for All Treated Eyes at One Month and Up to One Year Post-Operatively. The relative frequency of eyes falling either 0.5 D, 1.00 D, or more than 1.00 D away from the target RSE. a) Relative frequency of eyes with manifest refractions conducted at their one month post-operative appointment. b) Relative frequency of eyes with manifest refractions conducted at their latest appointment up to one year post-operatively.

Certain criteria resulted in the exclusion of retreated eyes from statistical calculations. These included reversal of monovision, enhancement for monovision (where distance vision was the original target), or achievement of initial refractive target. Ultimately, 12 VISX eyes and 3 Alcon eyes were excluded from the enhancement calculations in order to limit the effects of confounding factors not related to the laser's function. After these exclusions, the enhancement rate for the VISX was 8% (28 eyes) and the Alcon was 4% (7 eyes) ($X^2(1, N = 35) = 2.41$, $p = 0.1205$) (Table 3).

Table 3. Enhancement Data. The total number of enhancements were recorded. Touch ups referred to improvements upon a previously planned treatment (i.e. improvement on a distance vision target after initial insufficient distance treatment). This also includes a set of exclusion criteria related to these enhancements, including enhancements conducted to reverse an initially chosen treatment and enhancements performed even though the initial target had been achieved. One eye targeted for intermediate vision improvement (i.e. computer reading) after distance vision correction was excluded from EX500-treated eyes.

REASON FOR ENHANCEMENT	VISX	EX500
Touch Up	33	8
Correction for Distance (Initially MV)	3	0
Correction for MV (Initially Distance)	4	1
Other	0	1
TOTAL ENHANCEMENTS	40	10
REASON FOR EXCLUSION		
Enhancement >1 year from original procedure	4	0
Enhancement after achieving initial target RSE	1	1
Reversal of Initially Selected Treatment	7	2
TOTAL EYES EXCLUDED	12	3
TOTAL INCLUDED ENHANCEMENT EYES	28	7
Relative Frequency of Enhancement (%)	7.82	4.19

DISCUSSION

The primary goal of this study was to establish a statistically identical correlation in visual outcomes between the WaveLight® EX500 and VISX STAR S4 IR® excimer lasers for the treatment of hyperopic refractive errors and hyperopic astigmatism. To accomplish this, eyes treated for these refractive errors using the two lasers with at least one month and up to one year of post-operative visits were analyzed retrospectively for distance and near visual outcomes, refractive outcomes, and the number of enhancements (or repeat surgeries) on each laser. Eyes corrected for distance and eyes corrected for reading vision were evaluated separately and shall be discussed separately with respect to visual outcomes; however, refractive outcomes were analyzed as two groups: one month and up to one year post-operatively because the difference from the target refraction was evaluated rather than visual acuity. The difference between target refraction for distance eyes was compared to a "plano" target, while near vision eyes were aimed to specific age-based refractive targets (between -0.75 and -2.50).

For distance-treated eyes analyzed collectively, the X^2 tests indicated no difference between the two lasers at one month post-operatively when all treatment types were analyzed collectively (irrespective of LASIK or ASA). Specific treatment modalities were also analyzed individually. For LASIK-treated eyes one month post-operatively, both lasers produced comparable results in visual acuity. ASA-treated eyes were similarly comparable; however, due to the fewer number of eyes treated, trends in visual acuity outcomes were less apparent. Still, no statistically significant difference was calculated between the two lasers.

Similarly, for distance eyes evaluated up to one year post-operatively, the two lasers produced similar trends near 20/20 uncorrected visual acuity. When comparing the two lasers without identifying any particular treatment type (LASIK or ASA), the two lasers produced significantly different results in visual acuity outcomes ($p < 0.05$). Eyes undergoing LASIK exhibited no statistical differences by one year post-operatively between either laser; ASA-treated eyes also showed statistically similar results on both lasers in the one year group. Unfortunately, the discrepancy in the overall group cannot only be attributed to laser performance. Moreover, regression in visual acuity following hyperopic LASIK treatments has been demonstrated in previous studies and may affect the results (Jaycock, O'Brart, Rajan, & Marshall, 2005). Additionally, the limited number of eyes measured on the Alcon laser (< 100 eyes) as compared to the VISX laser (>100 eyes) within one year post-operatively reduces the power of this particular measurement as compared to the one month group. With fewer eyes to evaluate on both lasers, the statistical significance of these interpretations must be analyzed further in more expansive studies to determine if this significance would increase or decrease with increased power.

Conversely, for eyes targeted toward reading vision, neither laser proved to be superior to the other. When viewed collectively, all treatment types achieved similar visual acuity outcomes as their distance counterparts. At one month post-operatively, irrespective of treatment type, both lasers produced visual acuities primarily of J1+, equivalent to 20/20 distance vision. No differences could be statistically identified between either laser for LASIK and ASA groups separately by one month post-operatively.

For the group assessed at up to one year post-operatively, no specific trend in visual outcomes could be identified for the monovision group due to the limited number of eyes treated on each laser. With these limited number of treatments, each laser still performed similarly according to measured outcomes. Neither the LASIK or ASA groups showed any statistically different outcomes individually. Much like the group of eyes treated for distance at one year, further studies would need to be conducted with a greater number of measured eyes to confirm the insignificance of these differences.

Refractive outcomes were also assessed both at one month and up to one year post-operatively. For all visual outcomes of 20/20 (distance) or J1+ (near), refractive targets were considered achieved. Not all patients whose one month or one year visual outcome was below 20/20 or J1+ (i.e. 20/20- or J1+-) were refracted possibly due to technician oversight or patient satisfaction. These visual acuities were not considered in final analysis. Of the refractions performed and the refractive targets achieved, both lasers produced nearly identical relative frequencies of refractive outcomes within 1 D by one month post-operatively. Even in the up to one year post-operative group, both lasers produced comparable and statistically equivalent results with respect to refractive outcomes within 1 D.

The enhancement rate between the two lasers showed almost 8% on the VISX with only 4% on the Alcon laser; however, about half as many eyes were treated on the EX500 than were treated on the VISX of eyes included in this study. When studying enhancement rate in the context of these two lasers, it is necessary to compare the rate of repeat surgery for hyperopic treatments in the context of established literature. Hyperopic LASIK has

been described with enhancement rates between 6% and 12.8% depending on the degree of hyperopia (Hersh, Fry, & Bishop, 2003; Randleman, White, Lynn, Hu, & Stulting, 2009). This study departs from previous literature with respect to the Alcon EX500 excimer laser whose enhancement rate was calculated at approximately 4%; however, with only seven eyes included in the retreatment calculations, the interpretability of this number is greatly diminished. Moreover, this study does not specifically control for different levels of hyperopia which affected retreatment rate in other studies. Despite these potential confounding errors and the apparent difference in relative enhancement rates, no statistically significant difference between the two lasers could be identified.

It follows these calculations and analyses that without any evidence of statistically significant differences in the majority of the aforementioned categories, this study expands on the conclusions of other similar studies conducted comparing other VISX and Alcon lasers. In previously established literature, both the VISX STAR S4 IR® and Alcon WaveLight® EX500 lasers served as safe and effective means of treatment for myopia and myopic astigmatism (J. Kanellopoulos & Asimellis, 2013; Meidani & Tzavara, 2016). Additionally, the CustomVue® option for the VISX STAR S4 IR® laser has been compared to the past generation of Alcon's laser, the Allegretto WaveLight® Eye-Q excimer laser, with equal results for myopic patients (Moshirfar et al., 2011). In another study, one year post-operative outcomes between the two lasers for hyperopia also showed equivalent outcomes between the CustomVue® and Allegretto WaveFront Optimized treatments (Sáles & Manche, 2014). This study did not include any CustomVue® treatments for hyperopic eyes to best assess whether significantly altered visual outcomes appeared

between Wavefront-Optimized EX500 or traditional VISX treatments. A possible basis for any difference between the lasers could theoretically lie in higher order aberrations left untreated by traditional VISX and Wavefront-Optimized treatments; separate studies have been inconclusive regarding the HOA outcomes on these lasers (S. I. Kim et al., 2014; Moshirfar et al., 2011). Moreover, the unique focus on hyperopia using the EX500 compared to the sixth generation VISX STAR S4 IR® provides new insight into the efficacy and safety of each laser. Neither laser produced significantly different outcomes consistently in any of the categories analyzed in this study.

In future research on this topic, a few improvements presented here should be implemented. These include scheduling more consistent follow-ups, especially up to one year. In this study, the "up to one year" group included visual acuity and refractive measurements taken after one month and up to one year post-operatively, but that included measurements anywhere from 2 months to 12 months after the initial procedure. Ongoing post-operative complications or sub-optimal visual stabilizations during that period may have been included in statistical calculations, especially if the condition resolved itself to a point where the patient was satisfied with their vision but did not return for follow-up measurements within one year. It was also common for managing physicians to request that patients return for annual eye exams (after a year post-operatively) if their eyes were healthy and outcomes were acceptable within that 2 to 12-month period. In future studies, visual outcomes should be measured at 1-month, 6-months, and 12-months post-operatively.

While provided post-operative instructions have been relatively standardized at the Boston Eye Group practices, an additional method of following up with patients to ensure compliance with post-operative instructions would help improve interpretability of the results as well. For example, not all patients undergoing ASA used the NSAID eye drops prescribed for pain, and no method of ensuring compliance with Vitamin C recommendations was consistently employed for these patients. Consistency in post-operative examinations could be improved; namely, manifest refractions should be performed on all patients irrespective of visual acuity outcome to best determine quantifiable outcomes for each laser. Several patients were identified as having lost best corrected visual acuity (BCVA) after LVC; these eyes were included in calculations, but further analysis is required to determine if those losses occurred due to some cause independent of the treatment laser.

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