# Effect of environmental factors on myopic LASIK enhancement rates

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**Purpose:** To determine whether environmental factors affect laser in situ keratomileusis (LASIK) enhancement rates.

**Setting:** Wake Forest University Eye Center, Winston-Salem, North Carolina, USA.

**Methods:** This retrospective chart review comprised 368 consecutive eyes of 191 myopic patients who had LASIK by the same surgeon (K.A.W.). All patients had surgery in 2000 with the Visx Star S2 excimer laser. Refractive outcome, visual acuity, and enhancement rates were monitored closely for 1 year. Fifty-seven eyes (15.5%) had an enhancement procedure. Using enhancement procedure or percentage of correction as the outcome measure, factors that were suspected to affect LASIK results and the need for enhancement were examined; specifically, age, eye, sex, pachymetry, corneal curvature (K), preoperative spherical equivalent, ablation depth, and environmental factors (procedure room temperature, procedure room relative humidity, outdoor temperature, and outdoor relative humidity).

**Results:** Using univariate and multivariate analysis, LASIK enhancement rates strongly correlated with the following variables: procedure room humidity ($P$ = .003; odds ratio [OR] = 1.093; 95% confidence intervals [CI], 1.030-1.160), 2-week preoperative mean outdoor humidity ($P$ = .011; OR = 1.054; 95% CI, 1.012-1.096), outdoor temperature ($P$ = .0059; OR = 1.039; 95% CI, 1.011-1.068), and age ($P$ = .0497; OR = 1.034; 95% CI, 1.001-1.070). The percentage of correction strongly correlated with the following variables: procedure room humidity ($P$ = .021), 2-week preoperative mean outdoor humidity ($P$ = .001), outdoor temperature ($P$ = .0052), and room temperature ($P$ = .017).

**Conclusions:** The 2-week-preoperative mean outdoor relative humidity, procedure room relative humidity, outdoor temperature, and procedure room temperature may have to be considered during LASIK planning. The effect of these environmental variables on LASIK outcomes warrants further evaluation.

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To optimize outcomes of laser in situ keratomileusis (LASIK) refractive surgery, many variables are taken into account in determining the specific nomogram used by each physician. The major elements that must be considered include patient factors, refractive factors, operative technique, and postoperative factors.[1] Two well-known variables that affect final outcome are degree of myopia and age.[2] Other factors that may affect final visual outcome include equipment, operative speed, surgical technique, individual eye characteristics, and procedure room environment.[1,3–5]

Many factors can be ignored if the surgeon has a consistent technique and/or uses the same equipment for all patients. Variables that may influence the outcome that are not under the physician's control include corneal hydration status,[6] outdoor humidity, and outdoor temperature. The goal of LASIK should be for a maximum number of patients to achieve emmetropia with a single procedure. In this study, we evaluated variables that may influence LASIK outcomes and at-

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tempted to determine whether uncontrollable environmental variables have an effect on LASIK results and undesirable enhancement rates.

## Patients and Methods

The study comprised 191 myopic patients (368 eyes) who had LASIK at the Wake Forest University Eye Center in 2000. Enhancement data were collected on all patients for a minimum of 1 year. Since most patients who have LASIK will seek improvement if they are not emmetropic, our policy is to enhance any patient who requests surgery that improves to emmetropia regardless of the refractive error. For this study, we considered enhancement rates to be the gold standard for successful LASIK outcome.

Informed consent was obtained from all participants; no internal review board approval was required. The same surgeon, using the same excimer laser and identical techniques in all patients, performed all procedures throughout the year.

The nomogram used for all procedures was based on personal communication with Jeff Machat, MD. For myopic patients, the refraction in minus cylinder form was used. Eighty-five percent of the sphere and 100% of the cylinder were programmed into the Visx laser. The nomogram was not changed during the year, and age was not factored into the nomogram.

According to Visx guidelines, the procedure room humidity was maintained at no less than 35% and no more than 65% and room temperature was kept between 60°F and 80°F (15°C and 27°C). When humidity was less than 35%, humidifiers were used to increase room humidity to the recommended conditions (Visx Star S2 Excimer Laser System Operator's Manual, 5-1-5-6, 1999). No room had to be dehumidified during the study period.

Using the enhancement rate or the percentage of correction as the outcome measure, variables that could influence the enhancement rate were evaluated. The variables included age, sex, eye (right/left), time of year (season), ablation depth, pachymetry, corneal curvature (K), preoperative spherical equivalent (SE), procedure room temperature, procedure room humidity, outdoor relative humidity, and outdoor temperature. Data were collected on each patient at the time of surgery except the outdoor temperature and humidity data, which was provided by the National Weather Service.

The variables were initially fit into a univariate model, using enhancement as the outcome, to determine whether any variables correlated with enhancement rates. A statistical technique was used to adjust for patients having LASIK in both eyes while other patients had LASIK in only 1 eye. This adjusted for the correlation of data within a patient, such as age or sex, while fitting a model to the overall population. Additionally, a multivariate analysis was performed on the data, to determine the correlation of the variables with the enhancement rate or the percentage of correction.

**Table 1.** Demographics of study population.

| Parameter | Result |
|---|---|
| Patients | 191 |
| Eyes | 368 |
| Men | 89 |
| Women | 102 |
| Right eyes | 185 |
| Left eyes | 183 |
| Mean age, y | 41 |
| Mean preop SE, D | −4.86 |
| Mean postop SE, D | −0.30 |
| Undercorrections† | 50 |
| Overcorrections† | 7 |
| Total undercorrections‡ | 95 |
| Total overcorrections‡ | 13 |
| Enhancements | 57 |

SE = spherical equivalent
*Based on ≥3-month follow-up measurement
†Eyes receiving enhancement
‡All eyes

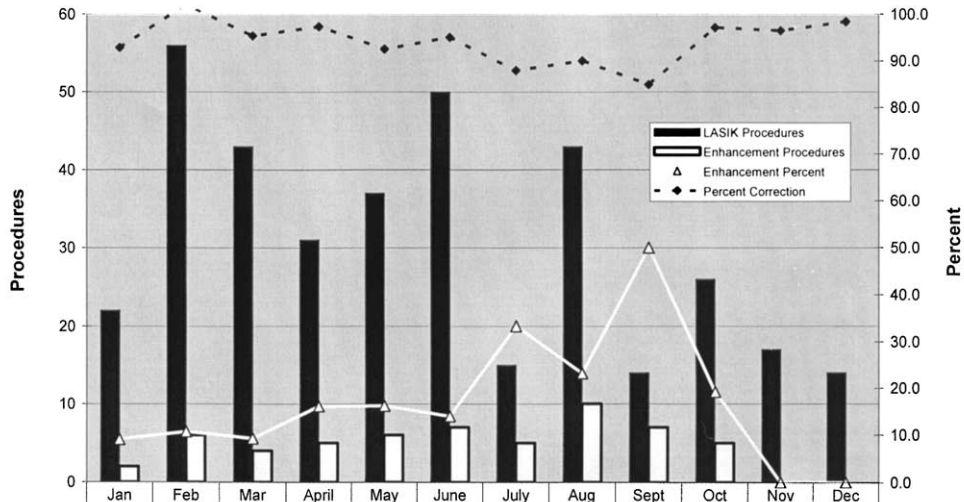
## Results

Demographics of the patients participating in this retrospective chart study are summarized in Table 1. The mean postoperative SE based on a follow-up of 3 months

**Table 2.** Preoperative UCVA of enhancement patients on day of enhancement procedure.

| UCVA | Number of Eyes |
|---|---|
| 20/15 | 0 |
| 20/20 | 0 |
| 20/25 | 0 |
| 20/30 | 7 |
| 20/40 | 22 |
| 20/50 | 5 |
| 20/60 | 8 |
| 20/70 | 7 |
| 20/80 | 1 |
| 20/100 | 5 |
| 20/200 | 1 |
| 20/300 | 0 |
| 20/400 | 1 |
| CF | 0 |

CF = counting fingers; UCVA = uncorrected visual acuity




| | Jan | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LASIK Procedures | 22 | 56 | 43 | 31 | 37 | 50 | 15 | 43 | 14 | 26 | 17 | 14 |
| Enhancement Procedures | 2 | 6 | 4 | 5 | 6 | 7 | 5 | 10 | 7 | 5 | 0 | 0 |
| Δ Enhancement Percent | 9.1 | 10.7 | 9.3 | 16.1 | 16.2 | 14.0 | 33.3 | 23.3 | 50.0 | 19.2 | 0.0 | 0.0 |
| Percent Correction | 92.8 | 102.00 | 95.4 | 97.4 | 92.5 | 95.0 | 88.0 | 90.0 | 84.9 | 97.1 | 96.5 | 98.4 |

Month

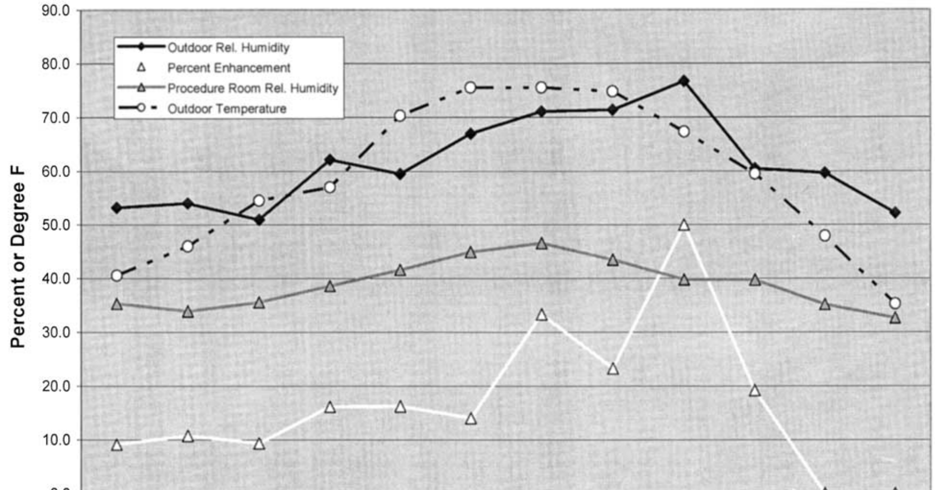
**Figure 1.** (Walter) Number of LASIK procedures each month during 2000, the enhancements the eyes required, with the resulting percentage of eyes having enhancement, and the corresponding monthly mean percentage of correction.

or longer was −0.30 diopter (D). Fifty-two eyes of 28 patients were lost to follow-up 3 months or longer after the primary LASIK procedure. The remaining 165 patients had a mean follow-up of 7.1 months. Although the lost-to-follow-up rate was significant (14.1% eyes, 14.5% patients), it was assumed that if patients did not return for an enhancement within 1 year, they were satisfied with their results.

The overall number of eyes receiving an enhancement was 57 (15.5%) and the total number of patients, 38 (19.7%). The number of undercorrected eyes from the primary procedure was 95 at 3 months or more of follow-up; 50 eyes required an enhancement procedure. Three months or more post-LASIK, the number of overcorrected eyes from the primary procedure was 13; 7 had an enhancement procedure. Undercorrection and overcorrection were defined as 0.25 D or more beyond the intended correction. Eight patients were targeted for monovision (5 patients, −1.5 D; 2 patients, −1.3 D; and 1 patient, −2.0 D), and the target SE was taken into consideration when determining undercorrection or overcorrection results. The mean SE in the enhancement group was −1.1 D (range +1.9 to −3.5 D). In the 50 undercorrected eyes that required enhancement, the mean SE was −1.35 D. In the 7 overcorrected eyes that had enhancement, the mean SE was +0.86 D. The preoperative uncorrected visual acuity before the enhancement procedure is shown in Table 2. The mean time to enhancement after the primary procedure was 7.25 months (range 3 to 18 months).

Figure 1 shows the number of LASIK procedures performed each month during 2000 and the corresponding enhancements required. There was an increase in enhancements required in eyes done during the summer season. Additionally, the percentage of correction (calculated by SE achieved/SE attempted × 100) shows a slight tendency toward overcorrection in February and undercorrection during the more humid months. Figure 2 shows the apparent correlation between enhancement rates by the month the procedure was performed and the corresponding humidity and temperature for that month. Since all procedures were done with the same nomogram, by the same surgeon (K.A.W.), using the same equipment and same laser software, humidity and/or temperature appeared to have a strong influence on LASIK outcomes.

Using univariate analysis of all measurable data (Table 3), LASIK enhancement rates strongly correlated with procedure room humidity ($P$ = .003; odds ratio [OR] = 1.093; 95% CI, 1.030-1.160), 2-week-preop-




| | Jan | Feb | Mar | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outdoor Rel. Humidity | 53.2 | 54.0 | 50.9 | 62.1 | 59.5 | 67.0 | 71.1 | 71.4 | 76.7 | 60.5 | 59.6 | 52.1 |
| Percent Enhancement | 9.1 | 10.7 | 9.3 | 16.1 | 16.2 | 14.0 | 33.3 | 23.3 | 50.0 | 19.2 | 0.0 | 0.0 |
| Procedure Room Rel. Humidity | 35.3 | 33.9 | 35.6 | 38.6 | 41.6 | 45.0 | 46.6 | 43.5 | 39.8 | 39.8 | 35.2 | 32.6 |
| Outdoor Temperature | 40.6 | 46 | 54.5 | 57 | 70.3 | 75.5 | 75.5 | 74.8 | 67.3 | 59.5 | 47.9 | 35.3 |

Month

**Figure 2.** (Walter) Monthly comparison between outdoor humidity, procedure room humidity, and outdoor temperature with the percentage of enhancement rates.

erative mean outdoor humidity (*P* = .011; OR = 1.054; 95% CI, 1.012-1.096), outdoor temperature (*P* = .0059; OR = 1.039; 95% CI, 1.011-1.068), and age (*P* = .0497; OR = 1.034; 95% CI, 1.001-1.070) (Table 4). In the multivariate analysis, LASIK enhancement rates strongly correlated with procedure room humidity. Each 1% rise in humidity increased the odds for enhancement by 9.3%.

Using univariate analysis of all measurable data, the percentage of correction strongly correlated with procedure room humidity (*P* = .021), 2-week-preoperative mean outdoor humidity (*P* = .001), outdoor temperature (*P* = .0052), and room temperature (*P* = .017) (Table 5). Increases in these variables correlated with a decrease in percentage of correction (undercorrection). Although outdoor temperature, room temperature, and the 2-week-preoperative mean outdoor humidity were significant by themselves, when combined with the room humidity in the same model, the effect of these variables was not significant. Therefore, in the multivariate analysis, percentage of correction strongly correlated with procedure room humidity only. Temperature and 2-week-preoperative mean outdoor humidity were important factors, but in combination with room humidity, no new information was gained. Table 6 compares the mean postoperative SE by the

**Table 3.** Statistics of procedure and environment.

| Measure | Mean ± SD | Range |
|---|---|---|
| Age (y) | 41.20 ± 8.81 | 22–70 |
| Ablation depth (μm) | 49.03 ± 23.97 | 9.00–117.00 |
| Corneal curvature (D) | 44.59 ± 1.37 | 40.60–48.00 |
| Pachymetry (μm) | 571.27 ± 38.21 | 470.00–660.00 |
| Procedure room temperature | 72.25 ± 1.66 | 67.70–78.00 |
| Outdoor temperature | 58.68 ± 14.16 | 35.3–75.5 |
| 2-week preop outdoor humidity | 62.12 ± 9.22 | 44.03–79.63 |
| Procedure room humidity | 39.19 ± 5.80 | 23.00–52.00 |

**Table 4.** Statistical analysis (enhancement rate as outcome measure).

| Variable | *P* Value | Odds Ratio | 95% CI If $P<.05$ |
|---|---|---|---|
| Eye | .537 | — | — |
| Preop SE | .181 | — | — |
| Ablation depth | .218 | — | — |
| K (corneal curvature) | .122 | — | — |
| Pachymetry | .241 | — | — |
| Age | .0497 | 1.034 | 1.001-1.070 |
| Sex | .384 | — | — |
| Procedure room temperature | .377 | — | — |
| Procedure room humidity | .003 | 1.093 | 1.030-1.160 |
| Outdoor temperature | .0059 | 1.039 | 1.011-1.068 |
| 2-week preop outdoor humidity | .011 | 1.054 | 1.012-1.096 |
| Preop BCVA | .933 | — | — |

BCVA = best corrected visual acuity; CI = confidence intervals; SE = spherical equivalent

month the procedure was done with the mean humidity for the month. Residual myopia after LASIK was more prevalent in the late summer, more humid months.

## Discussion

Previous authors[3,6] have suspected a negative influence of high relative humidity and LASIK undercorrections. Our results support this theory and provide substantial evidence that higher procedure room relative humidity increases the odds for subsequent enhancements (OR = 1.093). Most of our patients experienced undercorrections, which most likely indicates a suboptimal amount of tissue ablation. Several explanations can be proposed for the effect of humidity on undesirable LASIK outcomes. The additional moisture in the air may decrease the laser energy absorbed by the stroma. Alternatively, since the mean outdoor humidity before surgery also influenced the results (OR = 1.054), some patient's corneas may become more hydrated before the procedure, resulting in suboptimal tissue ablation.

**Table 5.** Statistical analysis (percentage of correction as the outcome measure).

| Variable | *P* Value |
|---|---|
| Eye | 0.586 |
| Preoperative SE | 0.086 |
| Ablation depth | 0.073 |
| K (corneal curvature) | 0.249 |
| Pachymetry | 0.305 |
| Age | 0.255 |
| Sex | 0.227 |
| Procedure room temperature | 0.017 |
| Procedure room humidity | 0.021 |
| Outdoor temperature | 0.0052 |
| 2-week preop outdoor humidity | 0.001 |
| Preop BCVA | 0.725 |

Based on previous studies,[2,4] factors such as age, refractive errors, operative techniques, and postoperative healing are important in determining a specific nomogram for LASIK surgery. Our nomogram adequately compensates for the degree of myopia but may need further refinement for age (OR = 1.034). Additionally, the current data show that environmental factors should play a role in nomogram development. Since controlling the indoor humidity is difficult and expensive, future nomograms should be expanded to include current procedure room humidity. Some consideration may even be given to include the mean outdoor humidity and outdoor temperature before the procedure. Logically, itinerant surgeons who operate in several geographic locations may have to consider humidity and temperature to improve their results. Data analysis is currently underway to compensate for the exact amounts nomograms should be adjusted according to room relative humidity. Future refractive lasers may be able to measure room humidity and compensate for this with appropriate beam strength. This may supplement wavefront analysis in producing more accurate results.

**Table 6.** Mean preop/postop SE and humidity by month.

| Month | Mean Preop SE (D) | Mean Postop SE* (D) | Mean Procedure Room Humidity (%) | Mean Outdoor Humidity (%) |
|---|---|---|---|---|
| Jan | −4.42 | −0.21 | 35.3 | 53.18 |
| Feb | −4.74 | −0.11 | 33.9 | 54.01 |
| March | −4.34 | −0.16 | 35.6 | 50.92 |
| April | −5.05 | −0.25 | 38.6 | 62.08 |
| May | −6.04 | −0.33 | 41.6 | 59.50 |
| June | −5.14 | −0.41 | 45.0 | 66.95 |
| July | −4.89 | −0.26 | 46.6 | 71.09 |
| Aug | −4.39 | −0.46 | 43.5 | 71.37 |
| Sept | −4.78 | −1.35 | 39.8 | 76.69 |
| Oct | −4.75 | −0.23 | 39.8 | 60.45 |
| Nov | −3.90 | −0.25 | 35.2 | 59.64 |
| Dec | −5.99 | −0.11 | 32.6 | 52.14 |

SE = spherical equivalent
*Based on ≥3-month follow-up

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