Aesthetic Plastic Surgery

# Detection of Baseline Emotion in Brow Lift Patients Using Artificial Intelligence

--Manuscript Draft--

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| **Abstract:** | BACKGROUND:<br>The widespread popularity of browlifts and blepharoplasties speaks directly to the importance that patients place on the periorbital region of the face. In literature, most aesthetic outcomes are based on instinctive analysis of the aesthetic surgeon, rather than on patient assessments, public opinions, or other objective means. We employed an artificial intelligence system to objectively measure the impact of brow lifts and associated rejuvenation procedures on the appearance of emotion while the patient is in repose.<br>METHODS:<br>We retrospectively identified all patients who underwent bilateral brow lift for visual field obstruction between 2006 and 2019. Images were analyzed using a commercially available facial expression recognition software package (FaceReader™, Noldus Information Technology BV, Wageningen, Netherlands). The data generated reflected the proportion of each emotion expressed for any given facial movement and the action units associated.<br>RESULTS:<br>A total of 52 cases were identified after exclusion. Preoperatively, the angry, happy, sad, scared, and surprised emotion were detected on average of 13.06%, 1.68%, 13.06%, 3.53%, and 0.97% among all the patients, respectively. Postoperatively, the angry emotion average decreased to 5.42% (p=0.009). The happy emotion increased to 9.35% (p=0.0013), while the sad emotion decreased to 5.42%. The scared emotion remained relatively the same at 3.4%, and the surprised emotion increased to 2.01%, however, these were not statistically significant.<br>CONCLUSION:<br>This study proposes a paradigm shift in the clinical evaluation of brow lift and other facial aesthetic surgery, implementing an existing facial emotion recognition system to quantify changes in expression associated with facial surgery. |

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|---|---|
| **Response to Reviewers:** | Thank you reviewers for the thoughtful and helpful commentary. We have responded in a bullet style format and included that in the revision. |

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Dr. Bahman Guyuron
Editor-in-Chief
*Aesthetic Plastic Surgery*
November 16, 2020

Dear Dr. Guyuron:

I am pleased to submit an original article entitled "Detection of Baseline Emotion in Brow Lift Patients Using Artificial Intelligence" by Thanapoom Boonipat, Jason Lin, and Uldis Bite for consideration for publication in *Aesthetic Plastic Surgery*.

In this manuscript, we utilized a facial expression recognition software called FaceReader to track changes in emotional expression for patients undergoing brow lifts, comparing before and after surgical intervention. In this manner, we were able to quantify changes in facial emotional expression associated with facial surgery. The use of software such as these opens the way to simple, real time, and objective evaluations of outcomes that are relevant for both surgeons and patients.

We believe that this manuscript is appropriate for publication in *Aesthetic Plastic Surgery* as it links facial expression recognition technology to analyze emotional expression outcomes following browlift and blepharoplasty procedures.

This manuscript has not been published and is not under consideration for publication elsewhere. We have no conflicts of interest to disclose.

Thank you for your consideration.

Sincerely,

Thanapoom Boonipat, MD
Division of Plastic and Reconstructive Surgery
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**Reviewer #1:**

The Authors describe a new approach to evaluate the results on the facial expression after browlift.

They rely upon a computerized model able to compare the preop with the postop modifications after activation of group of mimic muscles recruited to express standard facial expressions.

The Authors examine 52 cases, 50 had an endoscopic brow lift approach, in 5 patients the brow lift was direct ( total 55 patients, 3 more than the total number examined).

50 patients also had concurrent upper eyelid blepharoplasties,

9 had upper eyelid ptosis repair,

4 had canthopexies,

5 had facelifts,

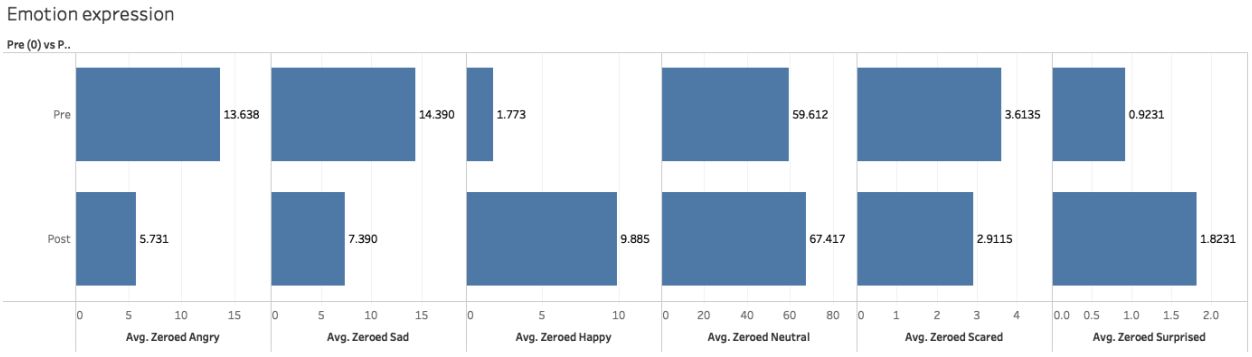
5 had fat grafting to the face,

and 14 had lower eyelid blepharoplasties.

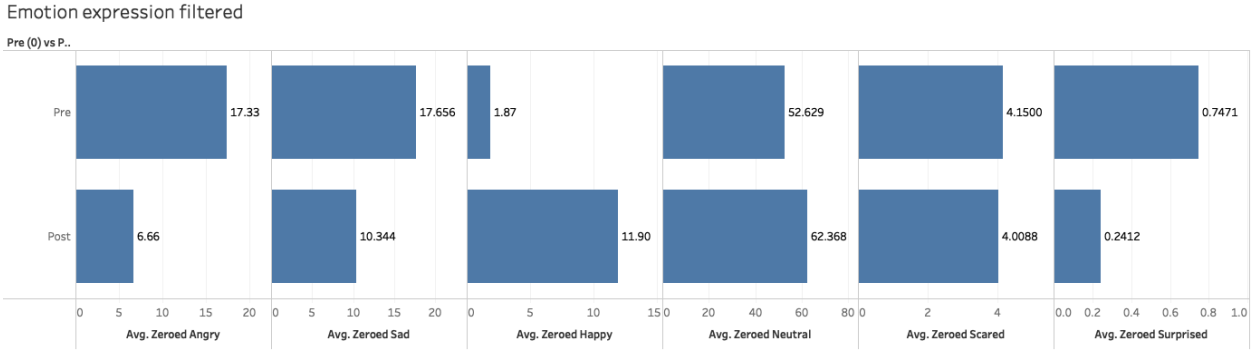
Only for statistical purposes, at first sight, there is a strong dishomogeneity as to concern the surgical procedures carried out and even if all of them concurred to a single aim, namely to just modify the facial expressions, methodologically it seems able in such a little number of patients to be misleading.

**Response #1**

Thank you for your response. We filtered out all other procedures except upper blepharoplasties since everyone had them and observed that the trends remained largely the same. We have included this in the manuscript as a supplementary figure.




Average of Zeroed Angry , average of Zeroed Sad, average of Zeroed Happy, average of Zeroed Neutral, average of Zeroed Scared and average of Zeroed Surprised for each Pre (0) vs Post (1). The data is filtered on Date after surgery and Clinic Number. The Date after surgery filter includes values greater than or equal to 42. The Clinic Number filter excludes 2393324, 4472460 and 7025486. The view is filtered on Pre (0) vs Post (1), which keeps Pre and Post.




Average of Zeroed Angry , average of Zeroed Sad, average of Zeroed Happy, average of Zeroed Neutral, average of Zeroed Scared and average of Zeroed Surprised for each Pre (0) vs Post (1). The data is filtered on Date after surgery, Clinic Number, Face lift (Yes=1), Cathopexy/canthoplasty (Yes=1), Fat grafting to face (Yes=1), Upper lid ptosis repair (Yes=1) and Lower lid blepharoplasty (Yes=1). The Date after surgery filter includes values greater than or equal to 42. The Clinic Number filter excludes 2393324, 4472460 and 7025486. The Face lift (Yes=1) filter keeps No. The Cathopexy/canthoplasty (Yes=1) filter keeps No. The Fat grafting to face (Yes=1) filter keeps No. The Upper lid ptosis repair (Yes=1) filter keeps No. The Lower lid blepharoplasty (Yes=1) filter keeps No. The view is filtered on Pre (0) vs Post (1), which keeps Pre and Post.

**Reviewer #2:** very nice idea to involve AI in aesthetic surgery outcome evaluation.
-I recommend authors to explain more about the system they used, and action unites.
- The sample of pictures they have used are not standardized and for a forehead lift procedure, the preoperative picture has no hair in the forehead and postoperative picture is covered with hair, how does this affect the AI's results?
- Recommend more pre and post op pictures

**Response #2**
Thank you for your recommendations and feedback. We have included standardized more standardized pre- and post- op photos.

**Reviewer #3:** ORIGINALITY
Congratulations to the authors, I considera an original manuscript.

MATERIAL Y METHODS
-I suggest including more keywords
-As we know facial aesthetics procedures, in particularly the fase lift, are not designed to change the original facial features, their main objective is to try to reposition the sagging soft tissues.
-However, I consider that is good to explore what are the changes that are altered directly or indirectly in facial mimicry, in all procedures of facial lifting.
-I also think it is important to consider which technique was chosen (plane of dissection, which structures were pulled, strength of the lift, vectors used, etc).

**Response**
All facelifts were performed using standard SMAS lift approaches. The brow lifts were performed using a modified endoscopic approach. The operative details has been updated in the manuscript.

-It would be logical understand that when lifting the drooping soft tissues, in particular the eyebrows and the external palpabral corners (crow´s feet wrinkles), the mimicry of facial emotions is slightly altered
-¿Did the authors consider what were the main motivations that patients requested from their plastic surgeon, and more specifically the universal patterns of emotions?

**Response**
The main indications and patient motivations behind these procedures were eye obstruction and the desire to look less sad or tired. This has also been additionally documented in the manuscript.

-In relation to the above, I think it is a Good time to ask ourselves what are the changes that we have in facial emotions, and of course what emotional characteristics patients do not want to alter.

-I consider a really interesting study. It is clear that a correlation of patient´s wishes, with respect to changes in their facial emotions, before and after the procedire would be very appripiate.
-I believe that there is a global consensus that all facial aesthetic procedures, regardless of the technique of choice, have the main objective of not altering the original characteristics of facial expresión.

**Response**
We did not conduct a survey for the patients post-operatively, but all were happy with their results.

CONCLUSIONS
-Increase de manuscript.
-Modify the perspective of the manuscript, in relation to the relevance of the ideal, that is, comparision of facial mimetics before and after, and control in the médium and long term.

-Due to the bias that it may involve, it is important to consider and standarize the degree of emotion that you are trying to document, for example; smile (slight, moderate, increased)

**Response**
In an effort to standardize the degree of emotion, all patients were instructed to be neutral during their photographs. This has been updated in the manuscript.

-I suggest describing and standardizing the análisis times of postoperative photographs. Postoperative control time.

**Response**
We have reproduced a table of the time (in days) for the post-op photograph since the surgery. The number of days for the post-operative photos ranged from 10 days to 4,046 days with an average of 333 days and a median of 138 days.

| Pre-op | Post-op | Days passed for Post-op photograph |
|---|---|---|
| 12/11/12 | 4/9/13 | 55 |
| 2/4/10 | 10/19/11 | 622 |
| 4/21/11 | 5/1/12 | 214 |
| 5/8/12 | 5/26/16 | 1464 |
| 9/23/14 | 2/2/15 | 50 |
| 9/4/14 | 12/18/14 | 45 |
| 3/30/17 | 8/2/18 | 419 |
| 1/6/06 | 6/2/06 | 144 |
| 9/9/14 | 4/7/15 | 92 |
| 12/31/07 | 3/18/08 | 21 |

| | | |
|---|---|---|
| 4/7/15 | 6/23/15 | 76 |
| 9/13/16 | 4/20/17 | 218 |
| 7/16/13 | 12/9/14 | 403 |
| 2/12/07 | 8/19/08 | 491 |
| 2/23/06 | 7/19/06 | 145 |
| 10/22/13 | 1/23/14 | 66 |
| 11/19/15 | 12/21/16 | 21 |
| 7/14/15 | 4/7/16 | 157 |
| 11/11/14 | 10/5/15 | 236 |
| 1/7/16 | 6/29/16 | 173 |
| 8/16/18 | 6/5/19 | 173 |
| 6/16/16 | 8/23/17 | 324 |
| 12/15/15 | 4/14/16 | 118 |
| 9/4/12 | 5/14/15 | 932 |
| 5/25/12 | 6/6/13 | 43 |
| 11/26/12 | 1/4/16 | 1081 |
| 4/29/11 | 11/22/11 | 161 |
| 7/17/06 | 11/17/06 | 45 |
| 1/18/10 | 5/12/10 | 61 |
| 1/10/07 | 2/2/09 | 19 |
| 3/27/12 | 10/22/13 | 368 |
| 1/2/08 | 9/1/09 | 607 |
| 5/25/12 | 8/24/12 | 78 |
| 5/16/17 | 5/3/18 | 351 |
| 4/7/15 | 8/19/15 | 42 |
| 7/27/17 | 4/3/18 | 246 |
| 6/2/16 | 1/10/17 | 99 |
| 11/4/14 | 1/14/15 | 70 |
| 6/21/12 | 9/20/12 | 10 |
| 10/22/19 | 3/2/20 | 82 |
| 10/8/15 | 1/28/16 | 43 |
| 9/9/09 | 6/15/10 | 216 |
| 4/15/14 | 6/26/14 | 34 |
| 5/31/18 | 2/11/19 | 59 |
| 12/4/08 | 4/23/09 | 93 |
| 9/19/11 | 9/30/14 | 1033 |
| 1/27/11 | 9/26/13 | 770 |
| 2/18/14 | 8/9/18 | 1632 |
| 9/17/15 | 10/23/15 | 11 |
| 4/6/17 | 12/6/18 | 512 |
| 9/22/17 | 1/4/19 | 401 |

| | | |
|---|---|---|
| 2/17/17 | 7/25/17 | 1649 |
| 2/4/16 | 5/26/16 | 1808 |
| 2/7/11 | 5/4/11 | -41 |
| 4/8/09 | 5/9/11 | 1679 |
| 8/3/16 | 11/15/17 | 4061 |
| 8/7/14 | 5/26/15 | 1901 |
| 9/4/12 | 3/18/13 | 1102 |
| 4/29/11 | 10/5/11 | 994 |
| 1/10/06 | 2/14/17 | 2953 |
| 11/26/13 | 7/17/14 | 636 |
| 1/12/16 | 3/10/16 | 1238 |

Standardize the degree of emotion manifested by patients in pre and postoperative photographs (when asked for an-expresión of joy, anger, sadness, etc.
-I suggest that the patients shown are uniform. Figure 1 pre and postoperative with uncovered forehead, the same por Figure 3.

**Response**
We standardized the pre- and post- op photos by asking the patient to remain in a neutral repose for the photographs. We have included more standardized pre- and post- op photos.

-Document in the text the differences in comparision of facial mimetics when it was added to the procedure; upper and lower blepharoplasty, facelift, etc.
-The ideal would be to compare similar procedures in te future; for example only brow lift with upper and lower blepharoplasty.

**Response**
Thank you for your long and thoughtful response. We have addressed this comment in Reviewer #1's response.

# Detection of Baseline Emotion in Brow Lift Patients Using Artificial Intelligence

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**Short Running Title:** Detection of Baseline Emotion in Brow Lift Patients Using Artificial Intelligence

**Keywords:** Brow lift, Artificial Intelligence, FaceReader

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## ABSTRACT

BACKGROUND:

The widespread popularity of browlifts and blepharoplasties speaks directly to the importance that patients place on the periorbital region of the face. In literature, most aesthetic outcomes are based on instinctive analysis of the aesthetic surgeon, rather than on patient assessments, public opinions, or other objective means. We employed an artificial intelligence system to objectively measure the impact of brow lifts and associated rejuvenation procedures on the appearance of emotion while the patient is in repose.

METHODS:

We retrospectively identified all patients who underwent bilateral brow lift for visual field obstruction between 2006 and 2019. Images were analyzed using a commercially available facial expression recognition software package (FaceReader™, Noldus Information Technology BV, Wageningen, Netherlands). The data generated reflected the proportion of each emotion expressed for any given facial movement and the action units associated.

RESULTS:

A total of 52 cases were identified after exclusion. Preoperatively, the angry, happy, sad, scared, and surprised emotion were detected on average of 13.06%, 1.68%, 13.06%, 3.53%,

and 0.97% among all the patients, respectively. Postoperatively, the angry emotion average decreased to 5.42% (p=0.009). The happy emotion increased to 9.35% (p=0.0013), while the sad emotion decreased to 5.42%. The scared emotion remained relatively the same at 3.4%, and the surprised emotion increased to 2.01%, however, these were not statistically significant.

CONCLUSION:

This study proposes a paradigm shift in the clinical evaluation of brow lift and other facial aesthetic surgery, implementing an existing facial emotion recognition system to quantify changes in expression associated with facial surgery.

Level of Evidence: Level III, Diagnostic Study

**Keywords:** Brow lift, Artificial Intelligence, FaceReader, Endoscopic Browlift, Blepharoplasty, Facial Expression, Facial Aesthetic Surgery

## INTRODUCTION

The aesthetic significance of the periorbital region of the human face has been appreciated since ancient times.[1,2] So much of human emotion is communicated through the appearance and movement of the eyes and brows. The widespread popularity of techniques such as glabellar chemodenervation, brow lift, and blepharoplasty speaks directly to the importance that patients place on this region of the face.[3] However, as with all forms of aesthetic facial rejuvenation or enhancement, there are neither objective nor

universally accepted methods to measure the change achieved by surgical rejuvenation of the periorbital region. In plastic surgery literature, most of what is considered an aesthetically pleasing outcome is based on instinctive analysis of the aesthetic surgeon, rather than on patient assessments, public opinions, or other objective means of evaluation.[2] The appearance of emotional expression is an important measure of a successful surgical outcome as this is one of the face's essential functions.[4]

Seven cardinal facial movement patterns have been detected universally, corresponding to the emotions of happiness, sadness, anger, surprise, fear, disgust, and neutrality.[5] Patients desiring brow lifts often complain that they look tired, sad, or angry even though they do not intend to express such feelings.[6]

We tested a commercially available artificial intelligence system trained and validated using the Amsterdam Dynamic Facial Expression Set,[7] which contains highly standardized images of different emotional expressions. Using machine learning, this artificial intelligence system can analyze image data and provide an objective measure of facial expression, generating a relative breakdown of each of the 7 basic emotions as well as the action units associated with these emotions. We employed this system to measure the impact of the brow lift and associated rejuvenation procedures on the appearance of emotion while the patient is in repose. To our knowledge, this is the first report on the use of an artificial intelligence method to analyze baseline appearance of emotion in brow lift patients.

## METHODS

After obtaining institutional review board approval, we retrospectively identified all patients who underwent bilateral brow lift for visual field obstruction between 2006 and 2019. We excluded those patients without postoperative photos, ones with post operative photos without resolution of bruising, those with less than 6 weeks of post op photos, those with concomitant diagnoses such as facial paralysis, those with any Botox injection within the last 6 months prior to the pre or post operative photos, and patients who underwent complex head and face reconstructive procedures in addition to brow lift. Patients with brow lift and concurrent aesthetic procedures were included.

All facelifts were performed using standard SMAS lift approaches. The brow lifts were performed using a modified endoscopic approach. Two 1-cm paramedian incisions were placed at the upper forehead bilaterally within the hairline, either at the level of the peak of the brow or slightly more medial to the peak. For the temporal lift portion of the procedure, bilateral 2.5-cm incisions were placed either parallel to or 1-2 cm posterior to the temporal hairline, starting superiorly 1 cm inferior to the temporal fusion line.

Dissection was performed to the level of the deep temporal fascia then proceeding anteriorly over the deep temporal fascia toward the sentinel vein. Further dissection was performed over the frontal bones by continuing the dissection medially through the temporal line of fusion and thus entering the subperiosteal plane. The forehead tissue was elevated in a blind fashion from lateral to medial and inferior to superior, except for the $2cm^2$ area above the supraorbital rim. The endoscope was introduced, the sentinel vein was

identified and all attachments surrounding the sentinel vein were dissected completely. The forehead incisions were then dissected down to the subperiosteal plane. The dissection of the forehead incision was performed by making an incision through the skin, then spreading with scissors perpendicular to the incision to identify and avoid injuring the sensory branches of the supraorbital nerve. Once all the periosteum was elevated through the temporal and forehead incisions, the periosteum was divided at the level of the supraorbital rim across the forehead in its entirety, with care taken not to injure the supraorbital and supratrochlear neurovascular bundles. Two Endotine devices (CoApt Systems Inc, Palo Alto, CA) were utilized to engage the periosteum above the level of the transverse periosteal incision. By cutting the periosteum across the lower forehead and placing tension on the periosteum superior to the cut, the superior pull on the periosteum created a separation at the level of the periosteal cut, transferring tension from the periosteum to the superficial brow tissue.

We obtained pre and post-operative images in repose for all patients. Photos were obtained using a Canon XH-A1S 3CCD HDV Camcorder positioned 1.5 meters away from the patient. In an effort to standardize the degree of emotion, all patients were instructed to be neutral during their photographs. For patients with multiple postoperative photos, the most recent one was chosen for analysis. Images were analyzed using a commercially available facial expression recognition software package (FaceReader™, Noldus Information Technology BV, Wageningen, Netherlands). The data generated from the software reflected the proportion of each emotion expressed for any given facial movement and the action units associated. The software's capability to classify facial expressions was

achieved by training an artificial neural network using more than 10,000 images that were manually annotated by trained experts.[8-10] The system assesses the movements of more than 500 facial landmarks on each face to perform the classification. Differences between paired continuous variables were assessed using the nonparametric Wilcoxon signed-rank test comparing facial emotions detected by the facial expression recognition technology pre- and post-operatively. All statistical analysis was performed using JMP (SAS Institute Inc.). A value of $p < 0.05$ was considered statistically significant.

## RESULTS

### *Patient characteristics:*

A total of 52 cases were identified after exclusion. We excluded 1 patient with unilateral brow lift, 2 patients with facial paralysis, 1 patient with multiple facial reconstruction procedures, 7 with less than 6 weeks post-operative photos or significant bruising in the last available postoperative photo, 3 patients with Botox injection, and 2 with no standardized postoperative photos. The endoscopic brow lift approach was used in 50 patients and the direct approach was used in 5 patients (**Table 1**). 50 patients also had concurrent upper eyelid blepharoplasties, 9 had upper eyelid ptosis repair, 4 had canthopexies, 5 had facelifts, 5 had fat grafting to the face, and 14 had lower eyelid blepharoplasties. To account for the homogeneity of the procedures, we also filtered out all other procedures (face lift, fat grafting to face, lower lid blepharoplasty, and canthopexy) except for upper blepharoplasties and observed that the trends remained largely similar (see supplemental figure 1). Average age at presentation was 61.6 years old (range: 36.5-86 years). Post-operative photos were obtained on average 53 weeks after the

brow lift (range: 42 days to 11 years). **Figure 1** shows an example case of a patient before and after their brow lift.

Preoperative and postoperative standardized photos of these patients were analyzed using FaceReader. The software analyzed the emotions expressed in each photos and the action units in each expression.

***Emotion detected:***

Preoperatively, the 'angry' emotion was detected on average of 13.06%, the 'happy' emotion averaged 1.68%, the 'sad' emotion averaged 13.06%, the 'scared' emotion averaged 3.53%, and the 'surprise' emotion averaged 0.97% among all the patients (**Figure 2**). Postoperatively, the 'angry' emotion decreased to 5.42% when averaging among all the patients (p=0.009). The 'happy' emotion increased to 9.35% (p=0.0013), while the 'sad' emotion decreased to 5.42%. The 'scared' emotion remained relatively the same at 3.4%, and the 'surprise' emotion increased to 2.01%, however, these were not statistically significant.

**Table 2** shows the number of cases where the emotion change increased, decreased, or had no change preoperatively and postoperatively. In 36.5% of cases, the percentage of the 'angry' emotion detected decreased compared to preoperative values, but increased in 15.4% of cases. Similarly, the percentage of the 'sad' emotion detected decreased in 40.4%

of cases, but increased in 7.7% of cases. Conversely, percentage of the ‘happy’ emotion detected increased in 42.3% of cases and decreased in 3.8% of cases. For the ‘scared’ emotion, there were 17.3% of cases where the percentage of the ‘scared’ emotion detected increased, and 13.5% of cases where the percentage decreased. Finally, for the ‘surprise’ emotion, there were 17.3% of cases that showed an increase, and 5.8% of cases where the percentage decreased.

Looking at the subset of the data for concomitant procedures with facelift or lower lid blepharoplasty, there were no significant changes in the trends of the findings reported above.

***Action unit:***

The action unit (AU) changes correspond to what can be expected after brow lift surgery, with less brow lowering AUs and more brow raiser AUs. The software detects AUs in intensity from lowest to highest. The standardized AUs around the periorbital region are shown in **Figure 3**. Preoperatively, the brow lowerer AU was the most commonly detected, with an average of 13 patients displaying lowest intensity, 6 patients with low intensity, 2 each with mid and high intensity, and 3 with highest intensity. This decreased markedly postoperatively, with 10 patients displaying brow lowerer AU with lowest intensity, 1 patient with a low intensity, and 1 with mid intensity, with none expressing an high or highest intensity. The upper lid raiser AU became the most common AU detected in the periorbital region after surgery: 9 and 12 patients displayed increased intensity in the upper lid raiser AUs in the left and right eye, respectively. Two patients had 2 units of

improvement in the upper lid raiser AUs, and 2 and 3 patients had 3 units of improvement in the left and right upper lid raiser AU. **Table 3** summarizes the results of these findings.

## DISCUSSION

We report the use of artificial intelligence on the evaluation of baseline emotions in brow lift patients before and after surgery, during neutral or repose expression. The notable findings of our paper included the marked increase in the happy emotion as well as the decrease in both the angry and sad emotions expressed in repose.

In the past, multiple publications have attempted to objectively assess surgical outcomes in facial cosmetic surgery, using a variety of methods such as patient satisfaction surveys, perception of the patients by other people, quality of life measurements, anthropometric measurements, and three-dimensional digitization of landmarks.[1,1,11,12] More recently, other objective methods included use of eyetracking technology to evaluate outcomes of upper blepharoplasty, brow lift, and other facial surgeries by focusing on the observer's attention after surgical intervention.[13,14] We previously also showed that rejuvenation surgery reduced the average age estimated by lay observers by about 5 years.[13] The software version we utilized did not have age estimate, but we assumed it will be similar given the similar patient population compared to our previous study.

One can argue that in aesthetic surgery, the most important outcome is the patient's satisfaction.[1] However, people's perception of themselves and their surgical outcome are influenced by their social interactions and how others perceive them.[15,16] The main

indications and patient motivations behind these procedures were eye obstruction and the desire to look less sad or tired. It has been shown that in brow lift surgery, observers often expressed that the surgery made the subject look younger and more energetic.[2,13] Although these are useful outcome measurements, they rely on a small subset of personal judgments and inherited prejudices and personal experiences.

Advances in machine learning algorithms have led to the development of software applications that can quantify the proportion of different emotions expressed in a facial expression. Ekman and Friesen[5] pioneered the Facial Action Coding System (FACS) for categorizing human facial expressions into discrete action units. While they initially defined 44 FACS action units, more than 7,000 different action unit combinations have been identified since.[17] Based on this research, Noldus developed FaceReader, a commercially available artificial intelligence system trained and validated using the Amsterdam Dynamic Facial Expression Set,[7] a highly standardized set of images containing the different emotional expressions of more than 10,000 images that were annotated manually by trained experts.[8-10] The FaceReader software was shown to have an accuracy of 80% when tested against FACS.[18] Using this artificial intelligence software, we are able to eliminate the problems of having small subsets and personal prejudices. In addition, the software can achieve absolute reliability and eliminate intra- or interobserver differences.

While we only looked at patients in repose, this was a relevant marker in brow lift patients for several reasons. Patients desiring such procedures often have primary complaints that

they look tired or angry when they were not trying to express any emotion.[2] The goal of the brow lift operation is to correct the position of the brow, mostly in its neutral, relaxed position. Thus, the vast body of literature on brow position aesthetics have focused on its position in repose.[19]

Our findings of the increased happy emotions, and the decreased sad and angry emotions detected are consistent with more traditional assessments of these same emotions using surveys. Thus, our findings also confirmed the applicability of the software for the objective measurement of outcomes.[2] Although we have professional photographers and specifically instructed each patient to not express any emotion, we admitted that we cannot completely control patients' expression and part of the happy emotion. However, we did correlate this emotional expression with the periorbital facial action unit.

An interesting finding is the minimal increase in the scared or the surprised emotion detected. In brow lifts, the 'surprised' or 'scared' looks are effects known to be avoided.[20] We also demonstrated the software's ability to evaluate for negative outcomes as well.

When analyzing action units, brow lift surgery changes the action units around the periorbital region, including the inner brow raiser and lowerer, the outer brow raiser and the upper lid raiser.[21,22] We found the most significant changes were decreased activation of the brow lowerer AU and increased activation of the upper lid raiser. Our findings correlated well with the known AUs associated with emotions. For example, sadness is associated with increased brow lowerer and decreased inner brow raiser. Anger is associated with increased brow lowerer and decrease upper lid raiser, which decreased

and increased, respectively, in our findings. The surprise emotion is associated with outer brow raiser, which increased only slightly in our findings. This is important as it shows the effectiveness of our brow lift procedure without causing a 'startled' or surprised look. In addition to brow lifts, many of the patients had combined procedures such as blepharoplasties, ptosis repair, and canthopexies. However, this was not performed with equal frequencies on all patients and thus imposes limitations on the accuracy of the statistical outcome.

With its ease of use and real time results, the software can be a useful tool for both surgeons and patients to evaluate surgical outcomes, allowing for future refinement and advancements in surgical intervention.

## CONCLUSION

This study proposes a paradigm shift in the clinical evaluation of brow lift and other facial aesthetic surgery, implementing an existing facial emotion recognition system to quantify changes in expression associated with facial surgery. The use of software such as these opens the way to simple, real time, and objective evaluations of outcomes that are relevant for both surgeons and patients.

## FIGURE LEGENDS

**Figure 1a.** Pre and postoperative photographs of a 57-year-old female who underwent endoscopic brow lift and upper and lower blepharoplasty, facelift, and fat grafting to the face.

**Figure 1b.** Pre and postoperative photographs of a 54-year-old female who underwent endoscopic brow lift and upper blepharoplasty.

**Figure 1c.** Pre and postoperative photographs of a 58-year-old male who underwent endoscopic brow lift and upper blepharoplasty.

**Figure 2.** Comparison between pre- and post-operative emotion detected in repose. Preoperatively, 'angry' emotion detected was 13.06%, 'happy' emotion averaged 1.68%, 'sad' emotion averaged 13.06%, 'scared' emotion averaged 3.53%, and 'surprise' emotion averaged 0.97% averaged among all the patients. Postoperatively, averaged 'angry' emotion decreased to 5.42% ($p=0.009$). 'Happy' emotion increased to 9.35% ($p=0.0013$), while 'sad' emotion decreased to 5.42%. 'Scared' emotion remained relatively the same at 3.4%, and 'surprise' emotion increased to 2.01%, however, these were not statistically significant. * denotes p-values $< 0.05$.

**Figure 3.** Standardized action units around the periorbital region include the Inner Brow Raiser, Outer Brow Raiser, Brow Lowerer, and Upper Lid Raiser.

## TABLE LEGENDS

**Table 1.** The endoscopic brow lift approach was used in 50 patients and the direct approach was used in 5 patients. 50 patients also had concurrent upper eyelid blepharoplasties, 9 had upper eyelid ptosis repair, 4 had canthopexies, 5 had facelifts, 5 had fat grafting to the face, and 14 had lower eyelid blepharoplasties.

**Table 2.** Facial emotional expressions preoperatively were compared with those detected postoperatively.

**Table 3.** The number of patients expressing certain action unit intensities around the periorbital region were recorded pre and postoperatively.

## SUPPLEMENTARY FIGURE LEGENDS

**S1a.** Emotional expressions (as percentages) of patients in repose pre- and post-operatively without filtering out other concurrent facial surgical procedures such as canthopexies, facelifts, lower eyelid blepharoplasties, and fat grafting to the face. Comparing that with the results after filtering out these procedures **S1b.** we note that the overall trends remain the same.

## COMPLIANCE WITH ETHICAL STANDARDS

(1) The authors declare that they have no conflicts of interests to disclose.

(2) This study was approved by the institutional review board (IRB).

(3) Informed consent was obtained from all participants.

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Figure



**Preoperatively**

**Postoperatively**

Figure



Preoperatively

Postoperatively

Figure

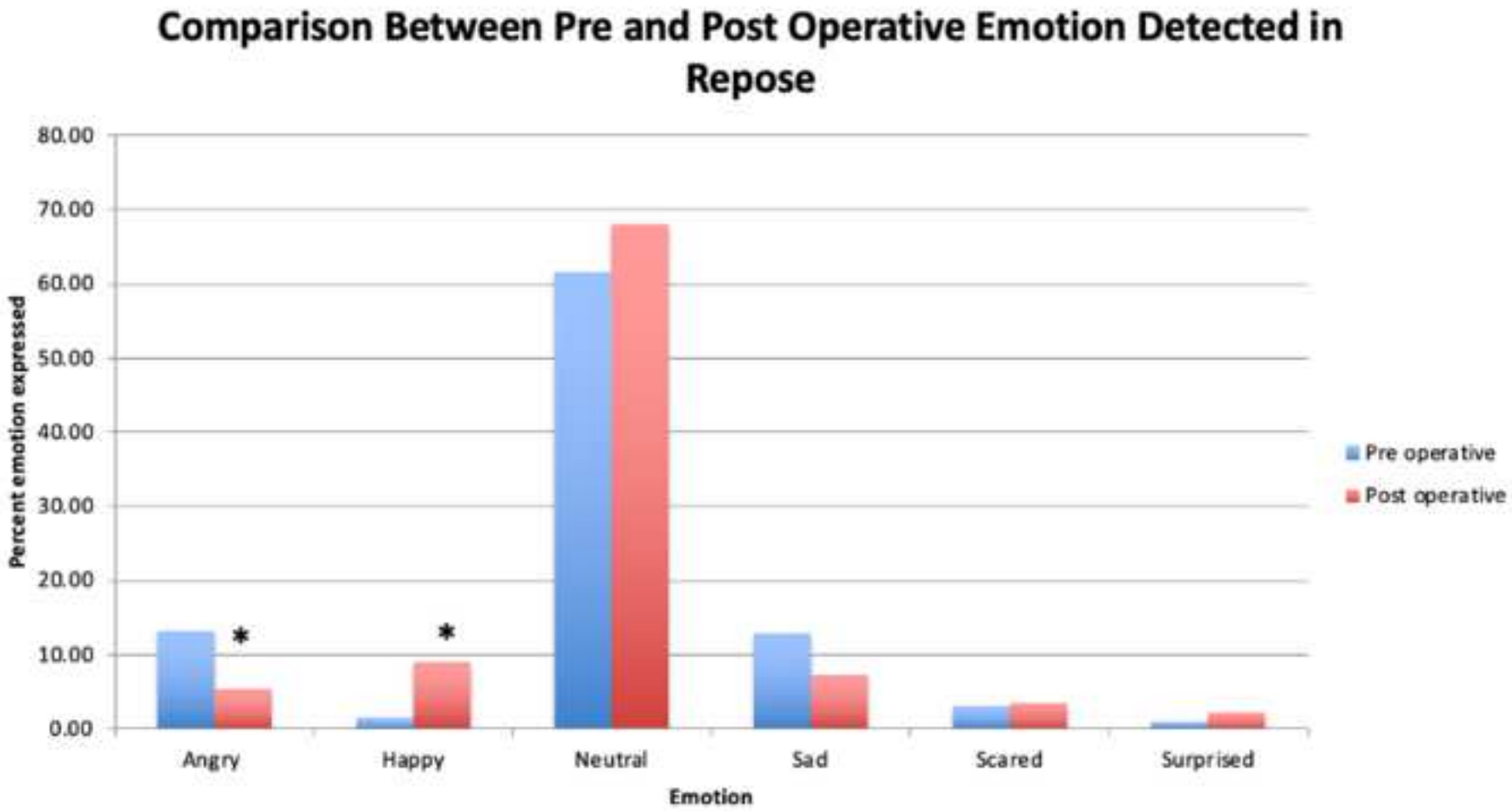


**Preoperatively**

**Postoperatively**

Figure

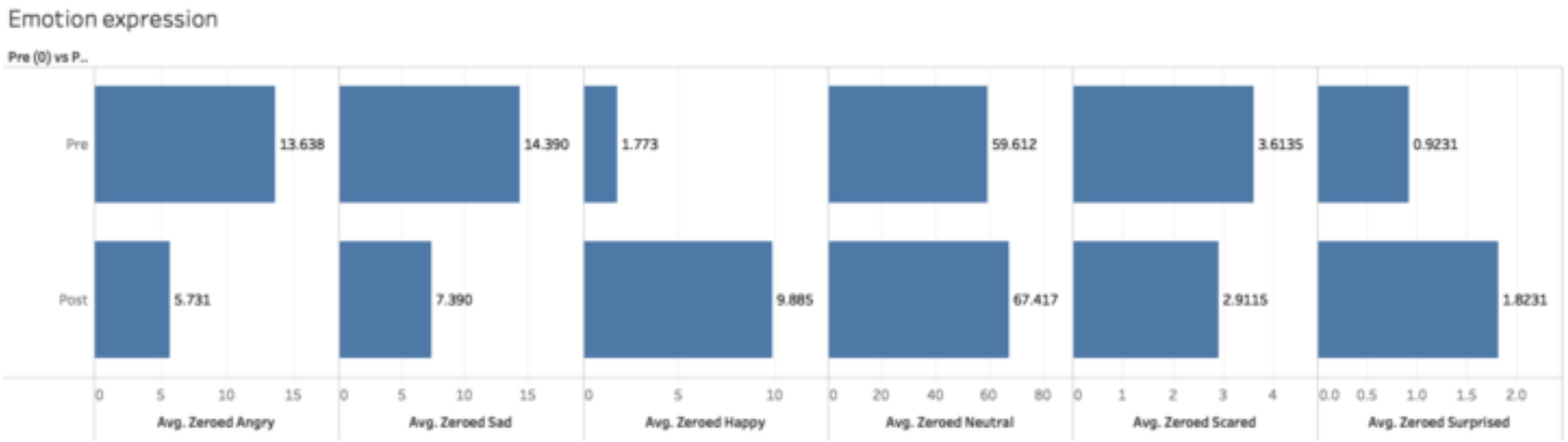
Click here to access/download;Figure;Figure 2.png



| AU 1 | AU 2 | AU 4 | AU 5 |
|---|---|---|---|
|  |  |  |  |
| Inner Brow Raiser | Outer Brow Raiser | Brow Lowerer | Upper Lid Raiser |

Supplementary figure 1a

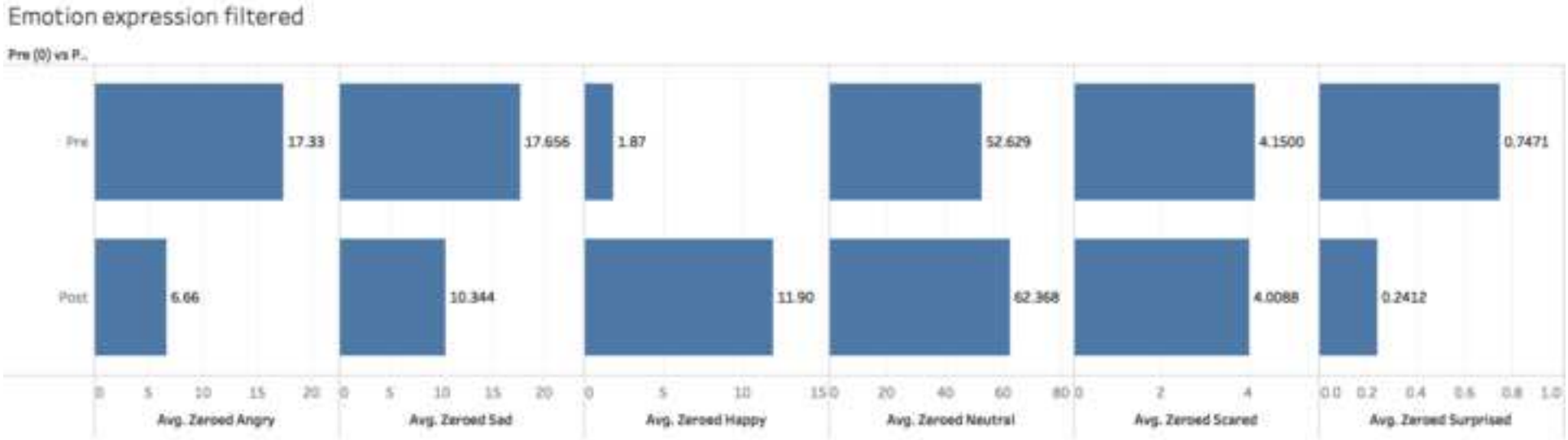
Click here to access/download;Figure;S1a.png




Average of Zeroed Angry , average of Zeroed Sad, average of Zeroed Happy, average of Zeroed Neutral, average of Zeroed Scared and average of Zeroed Surprised for each Pre (0) vs Post (1). The data is filtered on Date after surgery and Clinic Number. The Date after surgery filter includes values greater than or equal to 42. The Clinic Number filter excludes 2393324, 4472460 and 7025486. The view is filtered on Pre (0) vs Post (1), which keeps Pre and Post.

Supplementary figure 1b

Click here to access/download;Figure;S1b.png




Average of Zeroed Angry , average of Zeroed Sad, average of Zeroed Happy, average of Zeroed Neutral, average of Zeroed Scared and average of Zeroed Surprised for each Pre (0) vs Post (1). The data is filtered on Date after surgery, Clinic Number, Face lift (Yes=1), Cathopexy/canthoplasty (Yes=1), Fat grafting to face (Yes=1), Upper lid ptosis repair (Yes=1) and Lower lid blepharoplasty (Yes=1). The Date after surgery filter includes values greater than or equal to 42. The Clinic Number filter excludes 2393324, 4472460 and 7025486. The Face lift (Yes=1) filter keeps No. The Cathopexy/canthoplasty (Yes=1) filter keeps No. The Fat grafting to face (Yes=1) filter keeps No. The Upper lid ptosis repair (Yes=1) filter keeps No. The Lower lid blepharoplasty (Yes=1) filter keeps No. The view is filtered on Pre (0) vs Post (1), which keeps Pre and Post.

| **Table 1** | |
|---|---|
| **Total cases** | 62 |
| **Type of Browlift** | |
| *Direct* | 5 |
| *Endoscopic* | 56 |
| *Open hairline* | 1 |
| **Other procedures performed** | |
| *Upper blepharoplasty* | 58 |
| *Ptosis repair* | 4 |
| *Canthopexy* | 4 |
| *Facelift* | 7 |
| *Fat Grafting* | 6 |
| *Lower blepharoplasty* | 15 |

**Table 2. Emotional change post-op compared to pre-op (number of patients, %)**

| Emotions | Increase | | Decrease | | No change | |
|---|---|---|---|---|---|---|
| Angry | 8 | 12.9% | 23 | 37.1% | 31 | 50.0% |
| Sad | 10 | 16.1% | 22 | 35.5% | 30 | 48.4% |
| Happy | 25 | 40.3% | 2 | 3.2% | 35 | 56.5% |
| Scared | 12 | 19.4% | 8 | 12.9% | 42 | 67.7% |
| Surprised | 12 | 19.4% | 2 | 3.2% | 48 | 77.4% |

Table



**Table 3. Number of patients expressing certain intensity of action unit (AU)**

| | AU Intensity (1-5) | L- AU1 - Inner Brow Raiser | R- AU1 - Inner Brow Raiser | L- AU2 - Outer Brow Raiser | R- AU2 - Outer Brow Raiser | L- AU4 - Brow Lowerer | R- AU4 - Brow Lowerer | L- AU5 - Upper Lid Raiser | R- AU5 - Upper Lid Raiser |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 8 | 8 | 5 | 2 | 12 | 14 | 10 | 6 |
| | 2 | 2 | 2 | 2 | 0 | 6 | 6 | 3 | 3 |
| | 3 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 1 |
| Preoperative | 5 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 |
| | 1 | 8 | 9 | 10 | 4 | 8 | 10 | 11 | 13 |
| | 2 | 2 | 3 | 5 | 0 | 1 | 1 | 3 | 2 |
| | 3 | 0 | 0 | 2 | 0 | 1 | 1 | 3 | 4 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Postoperative | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |