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# NEUROSENSORY RECOVERY PATTERN AND CLINICAL RISK FACTORS AFTER LE FORT I OSTEOTOMY: A 24-MONTH PROSPECTIVE COHORT STUDY

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## ABSTRACT

**Objective:** To establish the infraorbital nerve neurosensory disturbance (NSD) recovery trajectory using the Zuniga classification (Levels A, B, C) over 24 months following Le Fort I osteotomy (LF1O), evaluate subjective-objective correlations, and identify clinical risk factors.

**Methods:** A prospective longitudinal cohort study enrolled 60 patients undergoing LF1O, followed at seven standardized timepoints over 24 months. Sensory function was assessed using the Visual Analog Scale (VAS) for subjective evaluation and the Zuniga classification for objective evaluation: Level A (two-point discrimination, TPD), Level B (static light touch, SLT), and Level C (pain threshold, PT). Statistical analyses included RM-ANOVA, Friedman test, Cochran's Q, and Chi-square tests.

**Results:** Subjective NSD peaked at 2 weeks (83.5%) and declined linearly to 2.8% at 24 months. Level C fibers fully recovered by 3 months; Level A deficits persisted in 3.33% of patients at 24 months. Age ≥25 years was the only significant risk factor delaying recovery during the acute phase (2 weeks: $p = 0.035$; 6 weeks: $p = 0.049$). Sex and surgical technique had no significant impact. VAS scores correlated strongly with Level A deficits ($\rho = 0.76$–$0.91$).

**Conclusion:** Post-LF1O NSD predominantly follows a neuropraxic pattern with 97.2% spontaneous recovery at 24 months. Age delays early recovery but does not affect long-term outcomes. Level A assessment most accurately reflects patient-reported paresthesia and should be prioritized in long-term sensory follow-up after LF1O.

***Keywords:*** Le Fort I osteotomy, infraorbital nerve, neurosensory disturbance, Zuniga classification.

## 1. INTRODUCTION

Le Fort I osteotomy (LF1O) is a cornerstone procedure in orthognathic surgery, enabling multi-directional repositioning of the maxilla to correct skeletal discrepancies and restore facial aesthetics and function. However, the dissection and mechanical traction inherent to the procedure, particularly in the mid-facial region, frequently injure the infraorbital nerve, resulting in neurosensory disturbance (NSD) of the infraorbital skin, alar base, upper lip, and oral mucosa [1, 2]. Although most injuries involve temporary mechanical compression (neuropraxia), NSD remains the most anxiety-provoking postoperative complication, directly impairing patient quality of life [1, 2].

Recent literature has systematically characterized the spontaneous NSD recovery trajectory after LF1O. The longitudinal study by Alolayan and Leung (2021) reported an NSD incidence of 81.8% at 2 weeks, declining to 19.7% at 6 months and 3.2% at 24 months [4]. Din et al. (2021) reported a 17.9% NSD residual rate at 12 months [5]. A cross-sectional analysis by Alali et al. (2025) found that at 6 months, approximately 66% of patients still reported subjective paresthesia and 25% had objective Level A sensory abnormalities [3]. Inconsistencies across reports largely reflect heterogeneous assessment methods and variable follow-up durations [6, 7].

The Zuniga and Essick classification is recognized as the gold-standard framework for peripheral sensory nerve evaluation, stratifying dysfunction by fiber subtype: Level A (two-point discrimination, large myelinated A-alpha/beta fibers), Level B (static light touch, small A-beta fibers), and Level C (pain and thermal thresholds, unmyelinated A-delta/C fibers). Despite its clinical utility, long-term longitudinal studies applying this classification to maxillary surgery remain limited [6, 7]. The impact of clinical risk factors such as age, sex, and osteotomy technique (single-piece vs. multi-piece) on the speed and completeness of neurosensory recovery also lacks consensus [7].

This 24-month prospective cohort study was therefore designed to: (1) characterize the infraorbital nerve NSD recovery trajectory using the Zuniga classification; (2) evaluate the correlation between subjective perception and objective sensory measures; and (3) identify clinical risk factors that influence the rate of sensory recovery after LF1O.

## 2. SUBJECTS AND METHODS

### 2.1. Study population, setting, and period

The study was conducted at Van Hanh General Hospital from January 2022 to December 2024. Sixty adult Vietnamese patients indicated for LF1O to correct maxillary skeletal discrepancies within an orthognathic surgical plan were enrolled. All procedures were performed under general nasotracheal anesthesia by the same experienced maxillofacial surgical team with more than 10 years of orthognathic surgical practice.

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***- Inclusion criteria:*** (1) Adults aged ≥18 years with stable general health (ASA I or II); (2) Diagnosed maxillary skeletal discrepancy (including maxillary protrusion, retrusion, asymmetry, or combination) with an indication for LF1O as a standalone or combined bimaxillary procedure; (3) Complete imaging records (panoramic, cephalometric, CBCT) and a pre-established surgical plan; (4) Normal facial sensation at baseline (VAS = 0; TPD < 15 mm); (5) Written informed consent and willingness to comply with 24-month follow-up schedules.

***- Exclusion criteria:*** (1) History of maxillofacial surgery or trauma with potential sensory sequelae; (2) Cleft lip and palate, craniofacial syndrome, or anatomical anomalies altering nerve course; (3) Any pre-existing trigeminal nerve deficit confirmed by clinical examination and history-taking; (4) Peripheral neuropathy, diabetes mellitus, or systemic conditions affecting sensory nerve function.

**2.2. Study methods**

- Study design and sample size: Prospective longitudinal cohort study designed and reported in accordance with STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines. Sample size was calculated using the single-proportion estimation formula: with a reference NSD residual rate of p = 19.7% at 6 months [4], a significance level α = 0.05 (z = 1.96), and a desired precision d = 10%, the minimum required sample size was $n = z^2 \times p \times (1-p)/d^2 \approx 48$ patients. To account for an anticipated 20% attrition rate over 24 months of longitudinal follow-up, the target enrollment was set at 60 patients.

- Surgical procedure: All procedures were performed using the standard Le Fort I technique under general nasotracheal anesthesia by the same experienced surgical team. The osteotomy line was placed approximately 5 mm above the root apices, parallel to the pyriform aperture floor, extending bilaterally from the canine fossa to the pterygomaxillary junction. After down-fracturing the maxilla and repositioning according to the surgical plan, rigid fixation was achieved with L-shaped titanium miniplates placed bilaterally. Patients were categorized into two groups based on osteotomy design: single-piece (1-piece, n = 37) and multi-piece (n = 23), selected according to individual clinical requirements. No cases of adverse osteotomy fracture or major vascular injury were recorded.

- Neurosensory assessment schedule and zones: Infraorbital nerve function was comprehensively evaluated at seven standardized timepoints: pre-operatively (T0, baseline) and post-operatively at 2 weeks (T1), 6 weeks (T2), 3 months (T3), 6 months (T4), 12 months (T5), and 24 months (T6). All tests were conducted in a quiet examination room with adequate lighting and ambient temperature of 22–24°C; patients were seated upright with eyes closed throughout objective testing to eliminate visual cues. The test area was divided into four fixed bilateral zones: right infraorbital region, left infraorbital region, right upper lip, and left upper lip. Each zone was assessed with all four tests sequentially within the same visit.

- Subjective assessment (VAS): Patients self-rated the severity of paresthesia and sensory impairment using a 10-cm Visual Analog Scale (VAS; 0 = normal sensation, 10 = complete anesthesia). VAS scoring was completed prior to objective testing to prevent anticipatory bias. NSD was defined as VAS > 0.

- Level A – Two-Point Discrimination (TPD): A millimeter-calibrated Boley gauge was used. Both tips were applied simultaneously to the skin with just sufficient contact force (~10 g), starting at a separation of 20 mm and decreasing by 1 mm after each trial. Single-point stimuli were interspersed among two-point trials to verify response reliability. The TPD threshold was recorded as the minimum inter-tip distance (mm) at which the patient correctly identified two distinct points in ≥ 3 of 4 trials per zone. Normal reference: TPD < 15 mm; abnormal when TPD ≥ 15 mm or the patient was unable to discriminate at the maximum distance of 20 mm.

- Level B – Static Light Touch (SLT): Standardized Semmes-Weinstein (SW) monofilaments ranging from filament 2.83 (0.008 g) to 6.65 (447 g) were used. Each filament was applied perpendicular to the skin and maintained for 1.5 seconds until it bowed, then slowly withdrawn. Testing began with the lightest filament and progressed to heavier filaments until the patient reliably detected contact in ≥ 3 of 4 trials per zone. The SLT value was recorded as the force (g) of the lightest filament detected. Normal reference: SLT ≤ 0.008 g (SW 2.83); abnormal when SLT > 0.016 g (SW 3.61 or higher).

- Level C – Pain Threshold (PT): A calibrated force-measuring algometer pin was used. The tip was applied to the skin and force was increased at a rate of approximately 5 g/second until the patient first reported a sharp, pricking sensation; at that point the force was recorded and the instrument immediately withdrawn. The test was repeated 4 times per zone with 30-second inter-trial intervals. The PT value was the mean of ≥ 3 valid trials. Normal reference: individual T0 baseline; abnormal when PT exceeded 150% of the patient's own baseline value.

- Measurement bias control: A single-blind design was applied for all sensory assessments. Two independent examiners (E1 and E2) alternated assessments according to a pre-established schedule; neither had participated in the surgical procedure and both were blinded to: (a) results from all prior visits; (b) each patient's specific osteotomy technique (single-piece or multi-piece); and (c) any detailed surgical parameters. Data sheets were numerically coded and maintained by a research coordinator not involved in testing. Intra-rater reliability was assessed by repeating measurements on 15 randomly selected patients one week apart. Inter-rater reliability was quantified using the Intraclass Correlation Coefficient (ICC) for continuous variables and Cohen's Kappa (κ) for categorical classifications; minimum thresholds of ICC > 0.85 and κ > 0.75 were required before the dataset was approved for analysis.

**2.3. Study variables and indicators**

- The study variables included age, sex, Le Fort I osteotomy technique, follow-up duration, and indicators of infraorbital nerve sensory function.

- Age was recorded in years and categorized into two groups: <25 years and ≥25 years. Sex was classified as male or female. The Le Fort I osteotomy technique was classified into two groups: one-piece osteotomy and multi-piece osteotomy.

- Infraorbital nerve sensory function was assessed at the following time points: before surgery and at 2 weeks, 6 weeks, 3 months, 6 months, 12 months, and 24 months after surgery.

- Subjective assessment was performed using the Visual Analog Scale (VAS), in which 0 indicated normal sensation and 10 indicated complete sensory loss. Subjective neurosensory disturbance was defined as VAS > 0.

- Objective assessment was performed according to the Zuniga and Essick classification, including Level A for

two-point discrimination, Level B for static light touch, and Level C for pain threshold. The results were recorded in the areas innervated by the infraorbital nerve, including the bilateral infraorbital and upper lip regions.

- The primary outcome was postoperative infraorbital nerve neurosensory disturbance, particularly the rate of persistent neurosensory disturbance at each follow-up time point. The factors analyzed included age, sex, and Le Fort I osteotomy technique.

### 2.4. Statistical analysis

Data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation or median and interquartile range, while categorical variables were expressed as frequency and percentage.

Changes over time were assessed using repeated-measures ANOVA, Friedman test, or Cochran's Q test, as appropriate. Risk factors for neurosensory disturbance were analyzed using the Chi-square test or Fisher's exact test. Correlations between VAS scores and objective Zuniga measures were evaluated using Spearman's correlation coefficient. A p-value <0.05 was considered statistically significant..

### 2.5. Ethical approval

Ethical approval was obtained from the Institutional Ethics Committee of Tra Vinh University (Ref: 185/GCN. ĐC-HĐĐ) and Van Hanh General Hospital (Ref: 01/2025/GCN-HĐĐ). All patients provided written informed consent prior to enrollment. Data were anonymized and used exclusively for research purposes.

## 3. RESULTS

Reliability analysis on 15 randomly selected patients yielded ICC values of 0.87–0.93 (Levels A and C) and ICC = 0.88 (Level B; 95% CI: 0.79–0.94; p < 0.001), confirming excellent measurement consistency throughout the 24-month observation period.

**Table 1. Baseline demographic and clinical characteristics (N = 60)**

| Clinical characteristic | Value |
|---|---|
| Age (years) | 25.45 ± 4.75 |
| Sex (Female/Male) | 37 (61.67%) / 23 (38.33%) |
| **Le Fort I osteotomy technique** | |
| Single-piece (1-piece) | 37 (61.67%) |
| Multi-piece | 23 (38.33%) |
| Follow-up duration (months) | 25.80 ± 2.35 |

The cohort comprised 60 patients (37 female, 61.67%; 23 male, 38.33%), with a mean age of 25.45 ± 4.75 years. Single-piece LF1O predominated (61.67%; n = 37), reflecting a preference for maximally conservative handling of the maxillary neurovascular bundle. Mean follow-up was 25.80 ± 2.35 months (Table 1).

**Table 2. Rates and levels of infraorbital neurosensory disturbance (NSD) recovery over 24 months**

| Timepoint | Subjective NSD (%) | Level A - TPD (mm ± SD; n abn.%) | Level B - SLT (g; n abn.%) | Level C - Pain Threshold (g; n abn.%) |
|---|---|---|---|---|
| Pre-op (T0) | 0.0% | 8.15 ± 2.10<br>0 (0.00%) | 0.006 ± 0.002<br>0 (0.00%) | 35.80 ± 12.45<br>0 (0.00%) |
| 2 Weeks (T1) | 83.5% | 17.20 ± 4.50<br>48 (80.00%) | 0.019 ± 0.025<br>43 (71.67%) | 75.40 ± 21.60<br>9 (15.00%) |
| 6 Weeks (T2) | 62.1% | 10.45 ± 2.80<br>34 (56.67%) | 0.009 ± 0.003<br>26 (43.33%) | 33.50 ± 14.80<br>2 (3.33%) |
| 3 Months (T3) | 41.2% | 9.12 ± 2.55<br>21 (35.00%) | 0.008 ± 0.002<br>12 (20.00%) | 34.10 ± 13.20<br>0 (0.00%) |
| 6 Months (T4) | 22.5% | 8.50 ± 2.15<br>11 (18.33%) | 0.007 ± 0.001<br>4 (6.67%) | 35.20 ± 11.50<br>0 (0.00%) |
| 12 Months (T5) | 8.4% | 8.18 ± 2.05<br>3 (5.00%) | 0.007 ± 0.001<br>1 (1.67%) | 35.60 ± 10.80<br>0 (0.00%) |
| 24 Months (T6) | 2.8% | 8.10 ± 1.95<br>2 (3.33%) | 0.006 ± 0.002<br>0 (0.00%) | 35.75 ± 9.90<br>0 (0.00%) |
| Time-effect test (p) | | RM-ANOVA<br>p < 0.001 | Friedman<br>p < 0.001 | RM-ANOVA<br>p < 0.001 |

*abn. = abnormal; Cochran's Q p < 0.001 for subjective NSD proportion; RM-ANOVA: normally distributed continuous; Friedman: non-parametric ordinal.*

Table 2 demonstrates that subjective NSD peaked at 2 weeks (83.5%) and declined significantly over time to 2.8% at 24 months (Cochran's Q, p < 0.001). Objective recovery followed a fiber-dependent pattern: Level C fibers (A-delta/C, unmyelinated) recovered fastest, with 100% of patients returning to normal by 3 months (RM-ANOVA, p < 0.001). Level B fibers achieved complete recovery by 24 months. Level A fibers (A-alpha/beta, large myelinated) showed the slowest recovery; at 24 months, 3.33% of patients remained abnormal on TPD.

**Table 3. Risk factor analysis and subjective–objective correlations over 24 months (N = 60)**

| Factor analyzed | 2 wks (T1) | 6 wks (T2) | 3 mo (T3) | 6 mo (T4) | 12 mo (T5) | 24 mo (T6) |
|---|---|---|---|---|---|---|
| **Risk factors – p-value (Chi-square test)** | | | | | | |
| Sex (Male vs. Female) | 0.317 | 0.615 | 0.881 | 0.555 | 0.955 | 0.934 |
| LF1O technique (Single-piece vs. Multi-piece) | 0.215 | 0.148 | 0.142 | 0.086 | 0.094 | 0.503 |
| Age (<25 vs. ≥25 years) | 0.035* | 0.049* | 0.159 | 0.802 | 0.814 | 0.570 |
| **Subjective (VAS) vs. objective (Zuniga) correlation – Spearman's ρ** | | | | | | |
| Level A: Two-point discrimination (A-α/β fibers) | 0.82** | 0.79** | 0.85** | 0.76** | 0.88** | 0.91** |
| Level B: Static light touch (Small A-β fibers) | 0.65* | 0.61* | 0.55* | 0.48 | 0.32 | N/A |
| Level C: Pain threshold (A-δ/C fibers) | 0.42 | 0.28 | N/A | N/A | N/A | N/A |

** p < 0.05; ** p < 0.01. N/A: correlation not computed as Level B and C abnormality rates reached zero.*

Chi-square analysis (Table 3) identified age ≥25 years as the only significant risk factor delaying recovery during the acute phase (2 weeks: p = 0.035; 6 weeks: p = 0.049). Sex and LF1O technique were not significantly associated with NSD rates at any timepoint (p > 0.05). Spearman's ρ between VAS and Level A remained consistently high throughout 24 months (ρ = 0.76–0.91; p < 0.01), while Level B correlations declined progressively and Level C correlations became unavailable as abnormality rates reached zero.

## 4. DISCUSSION

This study recorded a peak subjective NSD rate of 83.5% at 2 weeks, declining linearly to 2.8% at 24 months, reflecting a 97.2% spontaneous recovery rate. These findings closely parallel those of Alolayan and Leung (2021), who reported a peak incidence of 81.8% and a 3.2% residual rate at 24 months [4], confirming that post-LF1O NSD predominantly follows a neuropraxic pattern driven by soft-tissue traction rather than axonal transection. This high recovery rate is a defining characteristic of infraorbital nerve injuries after LF1O, distinctly superior to outcomes observed after mandibular osteotomies.

The higher 12-month NSD residual reported by Din et al. (2021) at 17.9% [5] likely reflects methodological differences: that study combined assessment of palatal mucosal sensation with cutaneous facial sensation, with palatal recovery substantially slower due to direct injury at the osteotomy line, compared with the predominantly mechanical stretch injury sustained by the infraorbital nerve.

The differential recovery rates across Levels A, B, and C illuminate the injury mechanism at the fiber-subtype level. Level C fibers (unmyelinated A-delta/C) achieved full recovery by 3 months, while Level A fibers (large myelinated A-alpha/beta) still exhibited 3.33% abnormality at 24 months. This is consistent with the quantitative sensory testing (QST) analysis by Luo et al. (2018), demonstrating that orthognathic surgery patients lose discriminative mechanical sensation (large fibers) for significantly longer than pain and thermal sensation (small fibers) [8]. Physiologically, unmyelinated and thinly myelinated fibers are relatively resistant to ischemic traction injury and regenerate rapidly, whereas heavily myelinated large fibers are highly susceptible to ischemia and require extended, complex remyelination, in accordance with the physiological observations of Essick et al. (2007) [9].

The high and sustained Spearman correlations between VAS and Level A (ρ = 0.76–0.91; p < 0.01) throughout 24 months confirm that the paresthesia patients subjectively experience principally reflects impaired discriminative touch from large-fiber dysfunction, consistent with the findings of Alali et al. (2025) [3]. When small fibers (Level C) have recovered but large fibers (Level A) remain impaired, loss of gate-control mechanisms causes ordinary tactile stimuli to be perceived as dysesthesia or allodynia. Phillips et al. (2010) demonstrated that persistent paresthesia exerts a substantial negative impact on patient quality of life after orthognathic surgery [10], underscoring the clinical importance of prioritizing Level A follow-up testing.

Age ≥25 years was confirmed as the sole significant risk factor for delayed acute recovery (2–6 weeks), consistent with the findings of Alolayan and Leung (2021) and Din et al. (2021) [4, 5]. The biological basis encompasses age-related decline in neuroplasticity, peripheral perfusion, and Schwann cell remyelination efficiency, as reviewed by Alolayan and Alzahrani (2024) [7]. Critically, age did not influence long-term recovery outcomes (p > 0.05 from 3 months onward), suggesting that even older patients achieve near-complete sensory recovery when the predominant injury mechanism is neuropraxia.

The multi-piece osteotomy technique produced no significant increase in NSD rates or severity relative to single-piece LF1O at any timepoint (p > 0.05), reinforcing the finding of Alali et al. (2025) that basic surgical technique variables are not primary determinants of NSD outcomes [3]. This finding carries meaningful clinical implications: surgeons may apply multi-piece osteotomy when clinically required without concern for additional long-term neurosensory risk.

Several limitations should be noted. The relatively small single-center sample (n = 60) limits generalizability. Three-dimensional imaging analysis (CBCT) was not integrated to quantify the magnitude of maxillary displacement and its correlation with mechanical tensile strain on the infraorbital nerve. Furthermore, exclusive assessment of cutaneous facial sensation without evaluating palatal mucosal sensation may underestimate the full NSD burden after LF1O.

## 5. CONCLUSION

This 24-month prospective cohort study of 60 LF1O patients confirms that post-surgical NSD predominantly follows a neuropraxic pattern, achieving 97.2% spontaneous recovery by 24 months. Recovery proceeds

in a physiologically coherent, fiber-dependent sequence: Level C fibers recover completely by 3 months, while Level A fibers retain 3.33% abnormality at 24 months. Age ≥25 years is the only statistically significant risk factor, delaying early recovery without affecting long-term outcomes. Osteotomy technique (single-piece vs. multi -piece) and sex do not influence NSD outcomes. Level A assessment (two-point discrimination) most accurately reflects patient-reported paresthesia and should be prioritized in long-term clinical sensory monitoring after LF1O.

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