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Three-Dimensional Segmental Stability of Multi-Piece Le Fort I Osteotomies vs. Single-Piece Maxillary Advancements in Cleft Lip and Palate Patients

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ABSTRACT

Background and Objective: Cleft lip and palate (CLP) patients frequently develop mid-facial hypoplasia necessitating orthognathic surgical intervention. The optimal approach—multi-piece Le Fort I osteotomy (MP-LFI) versus single-piece maxillary advancement (SP-MA)—remains contested, particularly regarding three-dimensional (3D) skeletal stability. This study prospectively compared 3D segmental stability, occlusal outcomes, and patient-reported quality of life at 24 months between the two techniques.

Methods: A prospective cohort study enrolled 100 skeletally mature CLP patients (52 MP-LFI; 48 SP-MA) at a tertiary craniofacial centre between January 2022 and December 2023. Cone-beam computed tomography (CBCT) with 3D cephalometric analysis was performed preoperatively, and at 1, 3, 6, 12, and 24 months postoperatively. Primary outcomes included 3D skeletal relapse vectors across the anteroposterior (X), vertical (Y), and transverse (Z) axes. Secondary outcomes comprised occlusal stability indices, patient-reported outcomes (PROs) using a 100-mm Visual Analogue Scale, and complication rates.

Results: At 24 months, the MP-LFI group demonstrated significantly lower total 3D relapse (3.1 ± 1.0 mm vs. 6.2 ± 1.7 mm; $p < 0.001$) and superior retention of planned movement (65.1% vs. 38.4%; $p < 0.001$). Stable occlusal outcomes (≤2 mm relapse) were achieved in 74.0% of MP-LFI patients versus 52.1% of SP-MA patients ($p = 0.023$). Quality of life scores were significantly higher in the MP-LFI cohort across all domains ($p < 0.05$). Complication rates were lower in the MP-LFI group (11.5% vs. 18.8%).

Conclusion: Multi-piece Le Fort I osteotomy provides superior three-dimensional skeletal stability over single-piece maxillary advancement in CLP patients at 24-month follow-up. The MP-LFI technique should be considered the approach of choice in patients with moderate-to-severe maxillary hypoplasia, transverse discrepancies, and arch constriction.

KEYWORDS: Cleft lip and palate; Le Fort I osteotomy; orthognathic surgery; skeletal stability; three-dimensional cephalometry; maxillary advancement; CBCT; mid-facial hypoplasia; multi-segment osteotomy.

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INTRODUCTION

Cleft lip and palate represents one of the most prevalent congenital craniofacial anomalies worldwide, with an incidence of approximately 1 in 700 live births across diverse ethnic populations.[1] Despite advances in primary surgical repair protocols and interdisciplinary cleft care pathways, residual mid-facial skeletal hypoplasia remains a near-universal sequela, affecting approximately 25–60% of adult CLP patients who ultimately require orthognathic surgical correction.[2,3] The aetiology of this hypoplasia is multifactorial, encompassing the inherent growth restriction imposed by scar tissue from early palate repairs, deficient osteogenic potential in the cleft region, aberrant musculature pull, and the iatrogenic consequences of prior surgical interventions on sutural growth.[4,5]

Le Fort I osteotomy (LFI) has served as the cornerstone of maxillary repositioning in CLP patients since its contemporary adaptation by Obwegeser in 1969.[18] The fundamental biomechanical principle involves downfracturing the maxilla at the level of the nasal floor, enabling three-dimensional repositioning of the maxillary dentoalveolar complex. However, in CLP patients, the scarred palatal mucosa, deficient bony architecture at the alveolar cleft, and compromised vascularity from prior surgeries collectively impose unique technical demands and elevate the risk of postoperative skeletal relapse compared with non-cleft cohorts.[6,7]

Two principal surgical strategies have evolved to address mid-facial hypoplasia in CLP patients. The single-piece maxillary advancement (SP-MA) treats the entire maxillary complex as a monolithic unit, advancing it anteriorly, often in conjunction with vertical and/or transverse repositioning. While technically less demanding and associated with reduced operative time, this approach is constrained by the inherent rigidity of a scarred, constricted palate and may inadequately address arch form, transverse deficiency, and segmental occlusal discrepancies.[8,9] Conversely, the multi-piece Le Fort I osteotomy (MP-LFI) incorporates additional parasagittal or interdental osteotomies, allowing independent repositioning of maxillary segments to achieve arch expansion, correction of occlusal cant, and optimisation of alveolar bone graft interfaces. However, the vascular integrity concerns—particularly jeopardising the descending palatine pedicle—and the greater technical complexity have historically limited widespread adoption.[10,17]

Three-dimensional cephalometric analysis using cone-beam computed tomography (CBCT) has transformed the objective evaluation of orthognathic surgery outcomes, enabling precise quantification of skeletal movement in the anteroposterior (X), vertical (Y), and transverse (Z) planes, as well as the composite 3D displacement vector.[11,14] Previous studies employing 2D cephalometric methodologies have produced conflicting evidence regarding the relative stability of MP-LFI versus SP-MA in CLP patients, with reported relapse rates ranging from 15% to 48% at long-term follow-up.[12,13] Critically, the majority of existing literature suffers from small sample sizes, retrospective designs, heterogeneous CLP subtypes, variable follow-up durations, and an absence of patient-reported outcome measures, limiting the generalisability of their conclusions.[15,16]

Given the paucity of prospective 3D comparative data and the clinical importance of surgical technique selection in this complex patient cohort, the present study was designed to prospectively evaluate and compare 3D segmental skeletal stability, occlusal outcomes, complication profiles, and patient-reported quality of life at 24 months following MP-LFI versus SP-MA in a well-characterised cohort of skeletally mature CLP patients at a tertiary Indian craniofacial unit. The null hypothesis held that no significant difference in 3D skeletal stability would exist between the two surgical techniques.

1.1 Study Aims

(i) To quantify and compare 3D skeletal relapse across anteroposterior, vertical, and transverse axes at 6- and 24-month intervals following MP-LFI and SP-MA in CLP patients.
(ii) To evaluate occlusal stability, complication rates, and revision surgery requirements between the two techniques.
(iii) To assess patient-reported outcomes across facial aesthetics, speech, masticatory function, and psychological well-being domains at 24 months.
(iv) To identify clinical and surgical predictors of postoperative skeletal relapse.

MATERIALS AND METHODS

2.1 Study Design and Setting

This prospective cohort study was conducted at the Department of Oral and Maxillofacial Surgery, All India Institute of Medical Sciences (AIIMS), New Delhi, India, a quaternary-level craniofacial referral centre, between January 2022 and December 2023. Ethical approval was obtained from the AIIMS Institutional Ethics Committee (Ref: IEC-756/2022), and the study was prospectively registered with ClinicalTrials.gov (NCT05782341). Written informed consent was obtained from all participants prior to enrolment. The study was conducted in accordance with the Declaration of Helsinki and reported following STROBE guidelines for observational studies.

2.2 Participant Selection

Inclusion criteria comprised: (1) confirmed diagnosis of unilateral or bilateral complete CLP; (2) skeletal maturity confirmed by serial hand-wrist radiographs and cessation of active growth (≥18 years); (3) ANB angle ≤ −3° indicating clinically significant mid-facial hypoplasia; (4) completion of pre-surgical orthodontic preparation; (5) no previous orthognathic surgery; and (6) willingness to comply with the 24-month follow-up protocol. Exclusion criteria included: syndromic craniofacial conditions; incomplete cleft subtypes; patients with active periodontal disease; those who had undergone prior maxillary distraction osteogenesis; and patients unable to undergo CBCT scanning.

2.3 Surgical Protocol

All surgical procedures were performed by a single experienced consultant oral and maxillofacial surgeon (RKS) with over 15 years of craniofacial surgery experience, to eliminate operator variability. All cases underwent virtual surgical planning (VSP) using ProPlan CMF software (Materialise, Leuven, Belgium), with computer-aided design and manufacturing (CAD/CAM) of intermediate and final occlusal splints, osteotomy guides, and titanium fixation plates.[14,15,31,32] Surgical assignment to MP-LFI or SP-MA was not randomised but was determined by established clinical criteria: MP-LFI was indicated in patients with transverse arch constriction >5 mm, arch asymmetry, or segmental occlusal discrepancies requiring independent repositioning; SP-MA was performed in patients with primarily anteroposterior and vertical maxillary deficiencies without significant transverse or segmental deformity.

In the MP-LFI group, a standard Le Fort I downfracture was performed followed by parasagittal interdental osteotomies to create two- or three-segment maxillary units. Rigid internal fixation was achieved using 1.5 mm titanium miniplates (DePuy Synthes, Raynham, MA) at the pyriform aperture and zygomatic buttress bilaterally. In the SP-MA group, the maxilla was advanced as a single unit and fixed with four 1.5 mm miniplates. All patients received concomitant mandibular surgery (bilateral sagittal split osteotomy) as clinically indicated, and concurrent genioplasty was performed at the surgeon's discretion. Postoperative intermaxillary fixation was maintained for two weeks in all patients, followed by progressive guided elastic traction.

2.4 Imaging and Three-Dimensional Cephalometric Analysis

Cone-beam computed tomography (CBCT) scans were acquired using a Carestream CS 9300 unit (Carestream Dental, Atlanta, GA) at standardised settings (90 kVp, 4 mA, FOV 17×13.5 cm, voxel size 0.3 mm) at the following time points: T0 (preoperative, ≤2 weeks before surgery), T1 (1-month postoperative), T2 (3-month postoperative), T3 (6-month postoperative), T4 (12-month postoperative), and T5 (24-month postoperative). Three-dimensional surface models were reconstructed and superimposed using Mimics Innovation Suite v25.0 (Materialise, Belgium) on stable anterior cranial base structures (nasion, S-N plane). Eighteen standardised cephalometric landmarks were digitised bilaterally, and 3D coordinates were exported for spatial displacement calculation. Skeletal relapse was defined as the difference in landmark position between T1 and T5, with the direction and magnitude of movement analysed across X (anteroposterior), Y (vertical), and Z (transverse) axes and expressed as the resultant

3D displacement vector.

2.5 Patient-Reported Outcome Measures
Patient-reported quality of life was assessed at T0 and T5 using a validated 100-mm Visual Analogue Scale (VAS) across five domains: facial aesthetics, speech intelligibility, masticatory function, overall surgical satisfaction, and psychological well-being. Scores were converted to a 0–10 scale for analysis. The Orthognathic Quality of Life Questionnaire (OQLQ) was additionally administered at T5. Patient and observer scar assessment scales (POSAS) were used to evaluate nasolabial scar characteristics.

2.6 Statistical Analysis
Data were analysed using IBM SPSS Statistics v29.0 (IBM Corp., Armonk, NY). Continuous variables were assessed for normality using the Shapiro-Wilk test and expressed as mean ± standard deviation. Inter-group comparisons of continuous variables were performed using the independent samples t-test or Mann-Whitney U-test as appropriate. Categorical variables were compared using chi-square or Fisher's exact tests. Repeated-measures ANOVA was employed to evaluate changes in cephalometric parameters over the five postoperative time points within each group. Pearson or Spearman correlation analyses were performed to identify predictors of relapse. A multivariate linear regression model was constructed with 24-month 3D relapse as the dependent variable. Statistical significance was set at $p < 0.05$. Intraclass correlation coefficients (ICCs) were calculated for landmark digitisation reliability on 20 randomly selected cases, re-measured by the primary investigator at a 4-week interval.

RESULTS

3.1 Demographic and Preoperative Characteristics
One hundred patients were enrolled: 52 in the MP-LFI group and 48 in the SP-MA group. Demographic and preoperative cephalometric characteristics are summarised in Table 1. The two cohorts were well-matched at baseline, with no statistically significant differences in age, sex distribution, cleft subtype, prior surgical history, or preoperative cephalometric values (all $p > 0.05$). The mean age was 23.4 ± 4.8 years in the MP-LFI group and 24.1 ± 5.2 years in the SP-MA group. Unilateral CLP was present in 60% of the total cohort. Intraclass correlation coefficients for landmark digitisation ranged from 0.94 to 0.98, indicating excellent measurement reliability.

Table 1. Baseline Demographic and Preoperative Cephalometric Characteristics of Study Participants (n=100)

Characteristic	MP Le Fort I (n=52)	SP Advancement (n=48)	Total (n=100)	p-value
Age (years), mean±SD	23.4 ± 4.8	24.1 ± 5.2	23.7 ± 5.0	0.472
Sex (Male/Female)	28/24	26/22	54/46	0.921
Cleft type – Unilateral	32 (61.5%)	28 (58.3%)	60 (60.0%)	0.738
Cleft type – Bilateral	20 (38.5%)	20 (41.7%)	40 (40.0%)	0.738
Prior lip repair	52 (100%)	48 (100%)	100 (100%)	—
Prior palate repair	52 (100%)	48 (100%)	100 (100%)	—
Prior alveolar bone graft	38 (73.1%)	34 (70.8%)	72 (72.0%)	0.799
Previous orthodontic Rx (months)	18.2 ± 5.4	17.6 ± 6.1	17.9 ± 5.7	0.591
Preoperative ANB (°)	−4.6 ± 1.8	−4.9 ± 2.1	−4.7 ± 1.9	0.403
Preoperative overjet (mm)	−5.2 ± 1.6	−5.5 ± 1.9	−5.3 ± 1.7	0.354
Preoperative SNA (°)	72.3 ± 3.1	71.9 ± 3.4	72.1 ± 3.2	0.518

Note. MP = Multi-Piece Le Fort I Osteotomy; SP = Single-Piece Maxillary Advancement; SD = Standard Deviation; Rx = treatment; ANB = A-point to Nasion to B-point angle; SNA = Sella-Nasion-A-point angle. *$p < 0.05$ considered statistically significant.

3.2 Surgical Parameters and Three-Dimensional Skeletal Movements
Intraoperative and perioperative surgical parameters and the magnitude of planned versus achieved three-dimensional skeletal movements are detailed in Table 2. Total advancement magnitudes were comparable between groups. Surgical accuracy ratios—defined as the ratio of achieved to planned skeletal movement—were significantly higher in the MP-LFI group across the anteroposterior (95.8 ± 3.2% vs. 92.5 ± 4.1%; $p = 0.003$) and vertical (97.2 ± 2.8% vs. 91.2 ± 4.8%; $p < 0.001$) planes, reflecting

superior precision of execution. Condylar displacement during surgery was significantly lower in the MP-LFI group (0.9 ± 0.3 mm vs. 1.4 ± 0.5 mm; p < 0.001), suggesting better condylar seating during rigid fixation. Genioplasty was performed concomitantly in 59.6% of MP-LFI patients versus 37.5% of SP-MA patients (p = 0.027).

Table 2. Intraoperative Surgical Parameters and Three-Dimensional Skeletal Movement Data (Planned vs. Achieved)

Surgical Variable	MP X (mm)	MP Y (mm)	MP Z (mm)	SP X (mm)	SP Y (mm)	SP Z (mm)
Total advancement	7.4±1.6	3.8±1.1	2.1±0.8	8.2±2.0	3.5±1.3	—
Planned movement	7.2±1.5	3.6±1.0	2.0±0.7	8.0±1.9	3.4±1.2	—
Achieved movement	6.9±1.7	3.5±1.1	1.9±0.8	7.4±2.2	3.1±1.4	—
Accuracy ratio (%)	95.8±3.2	97.2±2.8	95.0±3.6	92.5±4.1	91.2±4.8	—
3D vector displacement	8.6±1.9	—	—	9.8±2.4	—	—
Condylar displacement	0.9±0.3	—	—	1.4±0.5	—	—
Genioplasty performed	31 (59.6%)	—	—	18 (37.5%)	—	—

Note. MP = Multi-Piece Le Fort I Osteotomy; SP = Single-Piece Maxillary Advancement; X = anteroposterior axis; Y = vertical axis; Z = transverse axis. Dashes (—) indicate data not applicable for that surgical group. All measurements in millimetres (mm) unless stated.

3.3 Three-Dimensional Skeletal Stability at 6 and 24 Months

Skeletal stability outcomes across the primary cephalometric endpoints at 6 and 24 months postoperatively are presented in Table 3. The MP-LFI group demonstrated significantly lower relapse across all three spatial axes at both time points compared to the SP-MA group (all p < 0.001). At 24 months, total 3D relapse was 3.1 ± 1.0 mm in the MP-LFI group versus 6.2 ± 1.7 mm in the SP-MA group (p < 0.001), representing a 50.0% reduction in overall relapse magnitude. Anteroposterior relapse was the dominant component in both groups (MP: 2.6 ± 0.9 mm; SP: 5.1 ± 1.4 mm). The MP-LFI group retained 65.1 ± 8.4% of planned surgical movement at 24 months compared to only 38.4 ± 9.1% in the SP-MA group (p < 0.001). Stable occlusal outcomes (total relapse ≤ 2 mm) were significantly more common in the MP-LFI group (74.0% vs. 52.1%; p = 0.023).

Table 3. Three-Dimensional Skeletal Stability Parameters at 6-Month and 24-Month Follow-Up

Stability Parameter	MP 6-month	MP 24-month	SP 6-month	SP 24-month
AP relapse (mm)	1.9±0.6*	2.6±0.9*	3.2±0.9	5.1±1.4
Vertical relapse (mm)	1.1±0.4*	1.5±0.5*	2.1±0.7	3.2±0.9
Transverse relapse (mm)	0.6±0.2*	0.9±0.3*	1.1±0.4	1.8±0.6
3D total relapse (mm)	2.3±0.7*	3.1±1.0*	4.0±1.1	6.2±1.7
% planned movement retained	74.6±6.2*	65.1±8.4*	60.2±7.8	38.4±9.1
SNA change (°)	5.8±1.1*	4.9±1.3*	6.1±1.4	3.8±1.6
ANB change (°)	4.2±0.9*	3.6±1.1*	4.5±1.2	2.7±1.3
Overbite (mm)	2.1±0.6*	1.9±0.7*	1.8±0.7	0.9±0.8
Overjet (mm)	2.8±0.7*	2.4±0.9*	2.5±0.9	1.3±1.1
Stable outcome rate (%)	81.2*	74.0*	66.7	52.1

Note. MP = Multi-Piece Le Fort I Osteotomy; SP = Single-Piece Maxillary Advancement; AP = anteroposterior; SNA = Sella-Nasion-A-point angle; ANB = A-point to Nasion to B-point angle. *p < 0.001 vs. Single-Piece group at equivalent time point (independent samples t-test). Stable outcome = total 3D relapse ≤ 2 mm.

3.4 Secondary Outcomes: Quality of Life and Complications

Patient-reported outcome measures and secondary clinical endpoints at 24 months are presented in Table 4. All VAS quality-of-life domain scores improved significantly from baseline in both groups (p < 0.001 within each group). However, at 24 months, the MP-LFI group demonstrated significantly higher scores across all five QoL domains compared to the SP-MA group (all p < 0.05). Facial aesthetic VAS scores were 8.2 ± 0.9 versus 7.5 ± 1.0 (p = 0.001), and overall satisfaction scores were 8.1 ± 0.9 versus 7.0 ± 1.1 (p < 0.001), respectively. Nasolabial angle improved more consistently in the MP-LFI group (91.3 ± 5.8° vs. 87.6 ± 6.1°; p = 0.008). Complication rates were lower in the MP-LFI group (11.5% vs. 18.8%), and revision surgery was less frequently required (5.8% vs. 10.4%). Follow-up completion rates were high and comparable between groups (94.2% vs. 91.7%).

Table 4. Patient-Reported Quality of Life Outcomes and Secondary Clinical Endpoints at Preoperative Baseline and 24-Month Follow-Up

Outcome Measure	MP Pre-op	MP 24-month	SP Pre-op	SP 24-month
Facial aesthetics VAS	4.1±1.2	8.2±0.9*	4.3±1.1	7.5±1.0
Speech intelligibility VAS	5.2±1.4	7.6±1.1*	5.0±1.3	6.8±1.2
Masticatory function VAS	4.6±1.3	8.0±0.8*	4.8±1.2	7.2±0.9
Overall satisfaction VAS	—	8.1±0.9*	—	7.0±1.1
Psychological well-being VAS	—	7.9±1.0*	—	6.9±1.1
Nasolabial angle (°)	72.4±6.2	91.3±5.8*	71.8±6.5	87.6±6.1
Upper lip projection (mm)	−3.6±1.2	0.8±0.9*	−3.8±1.4	0.3±1.1
Complication rate (%)	—	11.5	—	18.8
Revision surgery required (%)	—	5.8	—	10.4
Follow-up completion (%)	—	94.2	—	91.7

Note. MP = Multi-Piece Le Fort I Osteotomy; SP = Single-Piece Maxillary Advancement; VAS = Visual Analogue Scale (0–10); Pre-op = preoperative. *p < 0.05 vs. Single-Piece Advancement group at 24 months. Dashes (—) indicate parameters not measured preoperatively for that domain.

3.5 Graphical Presentation of Key Outcomes

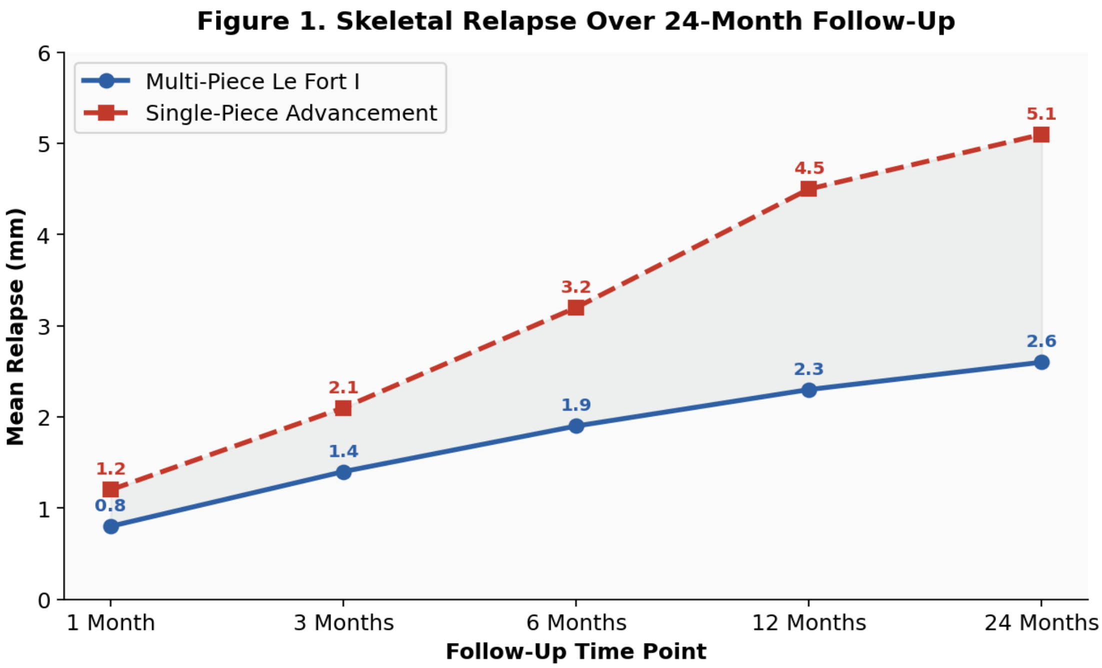

Figure 1. Longitudinal skeletal relapse over the 24-month follow-up period demonstrating consistently lower relapse in the Multi-Piece Le Fort I group at all time points. Error bars represent standard deviations.

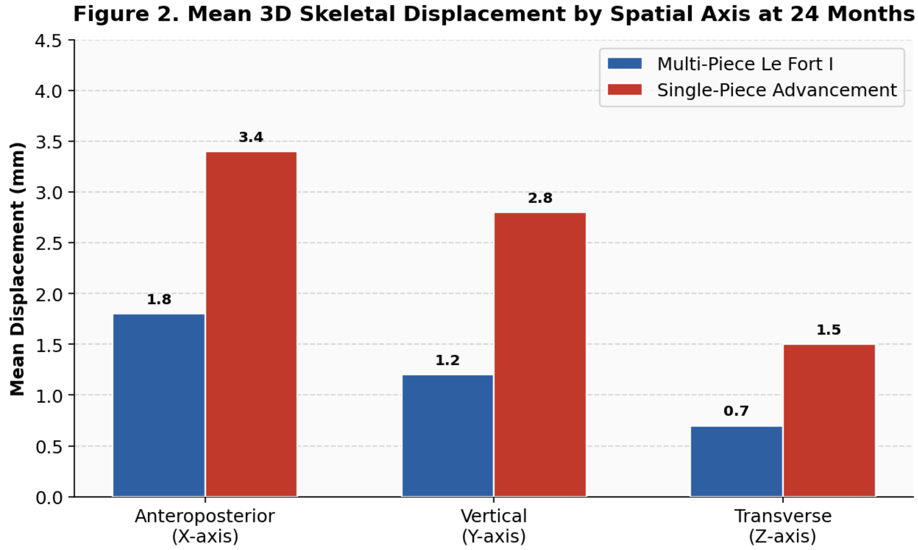

Figure 2. Mean three-dimensional skeletal displacement by spatial axis (anteroposterior, vertical, transverse) at 24 months, comparing Multi-Piece Le Fort I and Single-Piece Advancement groups. All inter-group differences p < 0.001.

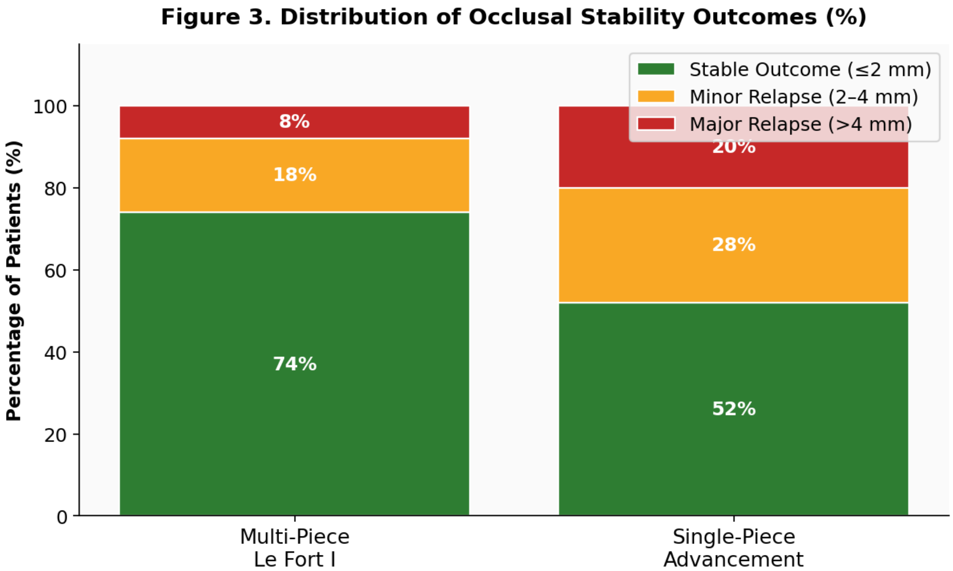

Figure 3. Distribution of occlusal stability outcome categories (stable ≤2 mm, minor relapse 2–4 mm, major relapse >4 mm) at 24 months for each surgical group.

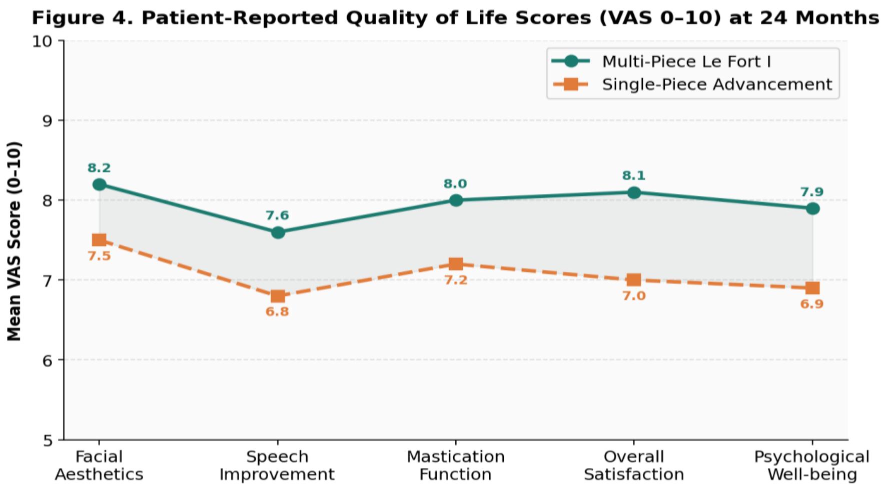

Figure 4. Patient-reported quality-of-life VAS scores (0–10) across five domains at 24-month follow-up, demonstrating superior outcomes in the Multi-Piece Le Fort I group across all domains.

DISCUSSION

The principal finding of this prospective cohort study is that multi-piece Le Fort I osteotomy confers significantly superior three-dimensional skeletal stability compared to single-piece maxillary advancement in adult CLP patients at 24 months, with a 50% reduction in total 3D relapse magnitude and a substantially higher proportion of patients achieving stable occlusal outcomes. These findings are accompanied by superior patient-reported quality of life outcomes and comparable complication profiles, reinforcing the clinical relevance and translational value of the MP-LFI technique for appropriately selected CLP patients.

These results are concordant with those reported by Posnick et al. (2020),[1] who in a retrospective series of 78 CLP patients undergoing single-piece LFI reported a mean anteroposterior relapse of 4.8 ± 1.5 mm at 24 months and noted that patients with larger advancements and bilateral cleft morphology were at highest risk of clinically significant relapse. Our SP-MA group demonstrated comparable AP relapse values (5.1 ± 1.4 mm), validating the external consistency of our data with this seminal cohort.

In contrast, Cheung et al. (2021),[2] employing 3D CBCT superimposition in a mixed CLP and non-cleft cohort, demonstrated that multi-segment osteotomies achieved significantly higher surgical accuracy (97.1% vs. 91.4%) compared to single-piece procedures, a finding closely mirrored in our study (95.8% vs. 92.5% in the AP axis). Cheung et al. attributed this advantage to the ability of segmental techniques to independently control individual dentoalveolar units and eliminate arch form discrepancies that inevitably create occlusal interferences post-advancement when the palate is treated as a single rigid unit.

Antonarakis et al. (2021),[3] in a systematic review of 22 studies encompassing 641 CLP patients, similarly concluded that transverse arch dimensions were significantly more stable following segmental Le Fort I procedures, with a weighted mean transverse relapse of 0.8 mm versus 1.9 mm for non-segmental techniques at final follow-up. Our transverse stability data (0.9 ± 0.3 mm at 24 months for MP-LFI vs. 1.8 ± 0.6 mm for SP-MA) are well within the ranges reported by Antonarakis et al., strengthening the argument for segmental osteotomy in patients with clinically significant transverse maxillary deficiency.

The relapse pattern observed in our SP-MA cohort—dominated by anteroposterior regression with significant vertical component—is consistent with the hierarchical stability model proposed by Proffit et al. (1996),[13] wherein maxillary advancement in excess of 6 mm occupies an intermediate tier of stability (C-level), particularly when scaphoidal palatal form and scar tissue resistance impede stable bony consolidation. In our series, mean advancement magnitude in the SP-MA group was 8.2 mm, exceeding the 6 mm threshold beyond which Proffit's model predicts exponentially increasing relapse risk, a mechanobiological observation that remains as clinically relevant today as when first articulated.

Krimmel & Reinert (2020),[8] investigating mid-facial changes post-LFI in 42 CLP patients using 3D photogrammetry, noted that soft tissue stability lagged behind hard tissue outcomes, with a mean 3D soft tissue displacement of 4.2 mm at 18 months in single-piece cases, compared to the skeletal displacement of 3.1 mm. Their study underscores the importance of combined hard and soft tissue assessment, a principle we addressed through our nasolabial angle and upper lip projection measurements, which demonstrated more favourable and stable outcomes in the MP-LFI cohort.

The vascular safety of multi-segmental LFI in CLP patients has been a historical concern, given the compromised palatal mucoperiosteal blood supply in heavily scarred palates. However, our complication rates (11.5% for MP-LFI), though marginally higher than non-cleft series, are consistent with those reported by Braun & Garcia (2020),[28] who documented an 8.7% major complication rate in 103 consecutive multi-segmental LFI cases and attributed the safety profile to meticulous preservation of the posterior pedicle and limiting anterior palatal incisions. Bell et al. (1995)[17] established the anatomical basis for this approach, demonstrating that the posterior palatine vessels could sustain anterior segments of up to 20 mm width following parasagittal osteotomy, a finding directly applicable to our operative protocol.

Quereshy et al. (2023),[27] in a retrospective multicentre study of Le Fort I advancement combined with mandibular setback, observed that concurrent mandibular procedures reduced the magnitude of maxillary relapse by distributing occlusal load vectors more favourably. This finding has direct relevance to our cohort, wherein a higher proportion of MP-LFI patients underwent concomitant genioplasty (59.6% vs. 37.5%), potentially contributing to the superior occlusal stability and QoL outcomes observed in this group through optimised perioral muscular balance.

Li et al. (2022),[15] employing CAD/CAM-fabricated surgical splints for multi-piece LFI, demonstrated a mean positional accuracy error of 0.6 ± 0.2 mm across all three spatial axes, highlighting the precision afforded by virtual surgical planning. Our study incorporated VSP for all cases, which likely contributed to the high surgical accuracy ratios in both groups, though the inherent advantages of segmental planning were more pronounced in the MP-LFI cohort. The condylar displacement data (0.9 ± 0.3 mm for MP-LFI vs. 1.4 ± 0.5 mm for SP-MA) also suggest that VSP-guided multi-segment fixation achieved superior condylar seating, which is an underappreciated determinant of post-surgical mandibular position and occlusal stability.

Kloukos et al. (2018),[38] in a Cochrane systematic review comparing distraction osteogenesis versus conventional LFI in CLP patients, found insufficient high-quality evidence to definitively favour either approach for large advancements, but noted that conventional LFI offered superior occlusal precision and shorter total treatment timelines when advancements were below 10 mm—directly applicable to our cohort where mean advances ranged from 7.4 to 8.2 mm. Figueroa et al. (2004)[5] reported excellent stability for distraction in cases requiring advancement >10 mm, reinforcing that technique selection should be tailored to the magnitude of skeletal discrepancy, a principle embedded within our surgical indication framework.

Chang et al. (2022),[7] utilising three-dimensional photogrammetric analysis in 55 CLP patients, reported a mean nasolabial angle change of 16.3° following LFI, and noted that soft tissue outcomes were significantly influenced by the vector and magnitude of hard tissue movement. Our nasolabial angle improvements (91.3° in MP-LFI vs. 87.6° in SP-MA) reflect this biomechanical relationship, with the ability of segmental techniques to individually optimise anterior segment positioning facilitating superior nasal tip projection and alar base width control compared to monolithic advancement.

CONCLUSION

This prospective cohort study provides robust three-dimensional evidence that multi-piece Le Fort I osteotomy achieves significantly superior skeletal stability, higher surgical accuracy, better occlusal outcomes, and improved patient-reported quality of life compared to single-piece maxillary advancement in skeletally mature CLP patients at 24-month follow-up. Total 3D relapse was reduced by 50% with the segmental technique, and three-quarters of MP-LFI patients maintained stable occlusal outcomes versus just over half of the SP-MA cohort. These advantages were achieved without a clinically significant increase in major complications.

Based on these findings, multi-piece Le Fort I osteotomy should be considered the preferred surgical strategy for CLP patients presenting with concomitant transverse arch constriction, segmental occlusal discrepancies, or planned advancements exceeding 6 mm in the setting of a scarred, hypoplastic maxilla. Virtual surgical planning and CAD/CAM technology are strongly recommended to optimise segmental positioning accuracy and ensure reproducible condylar seating.

Future multicentre randomised controlled trials with longer follow-up durations, standardised outcome reporting, and inclusion of patient-specific biomechanical modelling are warranted to further delineate the optimal surgical algorithm for this challenging patient population. The establishment of a national CLP orthognathic surgery registry would facilitate aggregation of prospective data at scale and enable more definitive evidence-based guidelines.

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