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A Proposed Method for Measuring the Aesthetic Outcome of Head Surgery

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Abstract. Objective quantification of facial asymmetry is important for evaluating postoperative aesthetic outcomes in head and neck surgery. This paper presents a semi-automatic, low-cost framework for three-dimensional facial symmetry analysis based on consumer-grade 3D facial scanning. The proposed workflow consists of facial model preprocessing and normalization, anatomical landmark-based mid-plane construction, and quantitative symmetry assessment. Both global facial symmetry and local symmetry within a surgically affected Region of Interest (ROI) are evaluated, enabling targeted analysis of surgery-related contour changes.

The framework was designed as an accessible alternative to specialized 3D scanning systems and commercial post-processing solutions. Three-dimensional facial scans were acquired using an iPhone 16 Pro Max under standardized conditions. The method was preliminarily evaluated on a pilot dataset comprising four parotidectomy patients and one control subject.

The results demonstrate that the proposed approach is capable of detecting and quantifying localized asymmetry associated with surgical intervention, even when using low-cost acquisition devices and low-quality scans. Although the present study is limited by the small sample size, the findings support the feasibility of consumer-grade 3D facial scanning for objective postoperative symmetry assessment and provide a foundation for future validation on larger and more diverse patient cohorts.

Keywords: facial asymmetry analysis, parotidectomy, 3D facial scanning, medical image processing

2020 *Mathematics Subject Classification:* 68U10, 68T45, 62P10

1. Introduction

Parotid gland surgery constitutes a specialized branch of head and neck surgical interventions. The surgeon performing such procedures must possess a high level of practical experience and theoretical knowledge to ensure confidence and appropriate intraoperative decision-making. The significance of these operations lies primarily in their postoperative aesthetic and functional consequences. The aesthetic impact arises not only from the fact that the facial nerve – responsible for innervating the muscles governing facial expression, eyelid closure, and the retention of liquids in the oral cavity during eating – traverses the parotid gland, but also from the postoperative scar and the facial asymmetry caused by tissue removal. These changes occur in a highly visible region of the body, which patients must carry in plain sight and which plays a decisive role in interpersonal interactions [1].

The treatment of salivary gland tumors is primarily surgical. The extent of surgery must be determined on an individual basis; as the radicality of the procedure increases, so does the volume of resected tissue and, consequently, the degree of contour deficiency. Conversely, insufficiently extensive intervention or inadequate surgical technique markedly increases the risk of tumor recurrence in both benign and malignant cases. For certain benign tumors, the risk of malignant transformation is also elevated under these circumstances. Reoperation requires substantially greater surgical expertise, and during such procedures the risk of facial nerve injury increases by orders of magnitude. Beyond its functional consequences, impairment of facial nerve function represents a tragic outcome following salivary gland surgery, associated with severe psychosocial sequelae. In recent years, advances in technology have led to the use of intraoperative nerve monitoring in an effort to mitigate this risk [8].

Over the past decades, increasing emphasis has been placed on the long-term aesthetic outcomes of surgical interventions. This trend is observable across all surgical disciplines, but is particularly pronounced in highly visible regions such as the face and neck. Aesthetic considerations are of even greater importance in the management of benign lesions, as in such cases a disfiguring scar can hardly be justified as an acceptable sacrifice in the interest of life-saving treatment or recovery. During each intervention, surgical decision-making is guided not only by adherence to professional guidelines but also by ethical and moral responsibility. Especially in young female patients, the skin incision is not merely a technical aspect of surgery; rather, it becomes a lifelong factor that may influence self-image, social relationships, and the patient's future life trajectory.

For a long time, the most widely used skin incision in salivary gland surgery was the so-called Modified Blair Incision, which provides excellent exposure and a high degree of surgical safety. It has withstood the test of time and remains the most frequently applied approach for the removal of salivary gland tumors [3, 5]. However, the scar resulting from this incision – extending anterior to the auricle and into the cervical region – is located in a conspicuous area and may therefore be aesthetically unfavorable, particularly in younger patients or those with heightened aesthetic expectations (see Figure 1a). To mitigate this issue, alternative incision types have gained prominence, such as the Modified Facelift Incision (see Figure 1b), which has proven effective in aesthetic surgery. This approach relocates scars into natural skin creases and the hair-bearing scalp behind the ear, while still providing adequate surgical access to both the tumor and the facial nerve [2].

(a) Modified Blair **(b)** Modified Facelift

Figure 1. Surgical incision types considered in this study: (a) Modified Blair incision and (b) Modified Facelift incision.

Following salivary gland surgery, in addition to the visibility of the incision scar, changes in facial contour must also be considered. These are influenced by numerous factors, including the course of the skin incision, the amount of subcutaneous adipose tissue, the extent of soft tissue involvement during surgery, the volume loss of the salivary gland, and the degree of scarring. This implies that although the most striking facial deformity arises from damage to facial nerve function, even in cases of completely preserved nerve integrity, subtle asymmetries and contour deformities may develop. These changes are often underestimated in clinical practice, yet they may impose a substantial burden on patients [10].

Despite the fact that aesthetic benefits constitute the primary rationale for adopting alternative incision techniques in place of the classical Modified Blair Incision, objective and quantitative evaluation of aesthetic outcomes is not yet a routine component of clinical follow-up. Traditionally, postoperative aesthetic assessment has relied on subjective scoring systems, quality-of-life questionnaires, and two-dimensional photographic documentation. While these approaches provide valuable clinical information, they are limited in their ability to capture subtle three-dimensional contour changes and to provide objective and reproducible measurements.

More recently, three-dimensional facial scanning technologies have been introduced to support objective postoperative evaluation. Brzoska et al. [6] demonstrated the feasibility of quantitative three-dimensional facial analysis after parotidectomy using dedicated facial scanning systems and specialized post-processing tools. Their work confirmed the clinical value of objective symmetry-based assessment. However, the widespread adoption of such approaches may be limited by the cost of dedicated hardware and software as well as the technical expertise required for their operation.

The quantitative assessment of facial asymmetry has been investigated for several decades. A foundational contribution was provided by Ferrario et al. [7], who introduced a three-dimensional distance-from-symmetry approach for evaluating facial asymmetry using geometric measurements. Their work demonstrated the potential of three-dimensional analysis for objective characterization of craniofacial morphology.

In parallel with methodological developments, recent advances in mobile sensing technologies have significantly increased the accessibility of three-dimensional facial acquisition. Rudy et al. [11] evaluated the accuracy and precision of the iPhone-based TrueDepth scanner and demonstrated that consumer-grade mobile devices can provide clinically useful three-dimensional facial data. A systematic review and meta-analysis by Mai and Lee [9] further confirmed that mobile-device-compatible 3D scanners can achieve sufficient accuracy for a wide range of facial digitization applications.

Building upon these developments, the present work combines consumer-grade smartphone-based acquisition with landmark-driven mid-plane estimation and ROI-oriented symmetry analysis. The objective is not to replace high-end scanning systems in terms of geometric accuracy, but rather to provide a practical, low-cost, and easily deployable framework for routine postoperative assessment of facial asymmetry after parotidectomy.

The present work addresses this need by investigating a workflow based on consumer-grade three-dimensional acquisition, anatomical landmark-based mid-plane construction, and region-oriented symmetry analysis.

The main contributions of this work can be summarized as follows:

- We propose a semi-automatic framework for three-dimensional facial symmetry assessment using consumer-grade 3D facial scanning.
- We introduce a landmark-based mid-plane construction procedure that enables anatomically meaningful and reproducible symmetry analysis.
- We evaluate both global facial symmetry and local symmetry within surgically affected Regions of Interest (ROIs), allowing localized assessment of surgery-related contour changes.

- We demonstrate the feasibility of the proposed approach on a pilot dataset of parotidectomy patients acquired using a widely available smartphone device.

The present study should be regarded as a proof-of-concept investigation intended to evaluate the feasibility of low-cost three-dimensional facial asymmetry assessment rather than to provide statistically generalizable clinical conclusions. Nevertheless, the preliminary results indicate that the proposed framework can support objective postoperative evaluation and justify further investigation on larger patient cohorts.

The remainder of this paper is organized as follows. Section 2 presents the proposed methodology, Section 3 describes the dataset and acquisition protocol, Section 4 reports the experimental results, and Section 5 concludes the paper and outlines directions for future work.

2. Proposed Method

The logical structure of the proposed framework is illustrated in Figure 2.

Figure 2. The main logical components of our proposed method.

The workflow consists of three major processing stages: preprocessing and normalization of the acquired 3D facial model, anatomical landmark-based mid-plane construction, and quantitative symmetry analysis.

2.1. Preprocessing

After loading the `.glb` file containing the three-dimensional facial scan, the model is normalized such that the head is positioned within a unit cube. Points outside this volume are discarded in order to eliminate irrelevant data and acquisition artifacts.

Although the acquisition protocol provides relatively consistent head positioning, minor variations inevitably occur during scanning. Therefore, the orientation of the head is further refined using information obtained during the mid-plane estimation stage. This normalization process ensures that all scans are represented within a common coordinate system, thereby enabling meaningful comparison between different subjects.

2.2. Mid-plane Construction

The purpose of this stage is to estimate the sagittal mid-plane of the head, which serves as the reference plane for all subsequent symmetry measurements.

The detected landmarks are used to define the coronal reference plane of the face. The normal vector of this plane determines the orientation of the sagittal mid-plane. Furthermore, the estimated mid-plane is constrained to pass through both the midpoint of the line segment connecting the eyes and the tip of the nose, thereby ensuring anatomically meaningful alignment.

To achieve this, a set of anatomically identifiable facial landmarks is detected automatically. These landmarks include the centers of the eyes, the tip of the nose, and, when reliably visible, the corners of the mouth. Landmark detection is performed using a previously developed object-detection-based method described by Bertók et al. [4], which provides robust localization of these facial reference points and supports accurate estimation of the three-dimensional orientation of the head.

2.3. Symmetry Calculation

The proposed symmetry analysis is based on the estimated mid-plane obtained in the previous stage.

Let x denote a point on the facial surface. The corresponding point x' is determined along the line perpendicular to the estimated mid-plane passing through x. Starting from x, this line is extended across the mid-plane until it intersects the facial surface on the opposite side of the head. The resulting intersection point is denoted by x'. Consequently, the point pair (x, x') represents anatomically corresponding locations with respect to the estimated symmetry plane.

The distances are measured from the two surface intersection points to the estimated mid-plane along the same normal direction.

Let $d(x)$ and $d(x')$ denote the perpendicular distances of x and x' from the mid-plane. The asymmetry associated with the point pair (x, x') is defined as

$$A(x, x') = |d(x) - d(x')|.$$

For a perfectly symmetric facial surface, the distances are equal and therefore $A(x, x') = 0$. Larger values indicate increasing local asymmetry.

The overall symmetry of the head, referred to as Global Symmetry (GS), is computed as the average asymmetry over all corresponding point pairs:

$$GS = \frac{1}{N} \sum_{i=1}^{N} A(x_i, x_i'),$$

where N denotes the total number of point pairs considered during the analysis.

To evaluate surgery-related contour changes, a Region of Interest (ROI) is defined on the facial surface. In the current pilot study, ROIs were manually delineated by experienced head-and-neck surgeons. The selected regions correspond to the anatomical area directly affected by the surgical intervention while excluding unrelated facial regions. The same clinical criteria were applied consistently across all subjects. Representative ROI definitions are shown in Figure 3(b).

Local symmetry within the ROI, referred to as ROI Symmetry (RS), is computed analogously:

$$RS = \frac{1}{M}\sum_{j=1}^{M} A(r_j, r'_j),$$

where M denotes the number of point pairs belonging to the ROI.

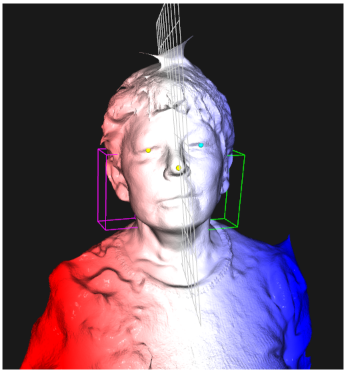
Finally, the overall surgery-related asymmetry measure, referred to as Total Symmetry (TS), is defined as the absolute difference between the global and local symmetry values:

$$TS = |GS - RS|.$$

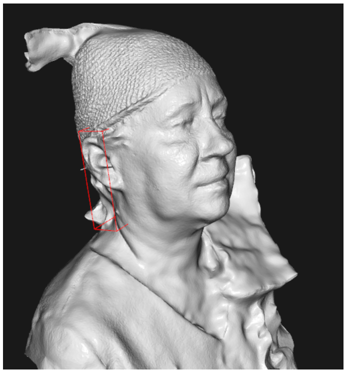
A larger value of TS indicates a greater discrepancy between overall facial symmetry and symmetry within the surgically affected region, suggesting a stronger localized effect of the surgical intervention.

Because all facial models are normalized to a unit cube during preprocessing, the reported symmetry measures are dimensionless normalized quantities.

Although ROI delineation is currently performed manually, future work will investigate partially automated ROI definition procedures based on anatomical landmarks and geometric surface analysis. Such extensions are expected to improve reproducibility and further reduce user intervention.



(a)



(b)

Figure 3. (a) The colored points represent the facial landmarks used for estimating the mid-plane. The heat map visualizes the distances of surface points from the estimated mid-plane. (b) The manually delineated Regions of Interest (ROIs) used for local symmetry analysis are highlighted in red.

3. Materials and Methods

For the initial evaluation of the proposed method, we constructed a database comprising four patients who underwent parotidectomy at Jósa András Teaching Hospital between 2013 and 2017. For each patient, the details of the surgical procedure are summarized in Table 1. In addition, a control subject with no history of facial surgery was included in the database.

For one patient, the standard Modified Blair incision had to be extended beyond its conventional extent in order to provide adequate surgical access to a larger tumor and the affected anatomical region. To distinguish this case from the standard procedure, it is denoted as "Modified Blair+" throughout the paper.

Written informed consent was obtained from all participants prior to data acquisition. Three-dimensional facial scans were acquired using the built-in TrueDepth-based scanning capabilities of an iPhone 16 Pro Max. The use of a widely available consumer-grade device was motivated by the goal of developing a practical and low-cost assessment workflow that can be deployed in routine clinical environments without requiring dedicated scanning hardware or specialized technical expertise.

To improve consistency across acquisitions, all scans were performed according to a standardized protocol. Participants were seated during scanning, and the acquisition distance, lighting conditions, and illumination direction were kept as constant as possible. Participants removed their glasses before scanning, and the hair was covered in order to minimize scanning artifacts and reduce the influence of non-facial structures on the subsequent symmetry analysis.

The head position was not mechanically constrained during acquisition. Instead, the proposed framework automatically estimates and normalizes head orientation based on the detected facial landmarks described in Section 2. This design choice reflects realistic clinical conditions and allows the method to remain practical for routine use.

Figure 4. Representative three-dimensional facial scan acquired using the proposed acquisition protocol. Hair was covered during scanning to reduce scanning artifacts, and the resulting surface mesh was used for the subsequent symmetry analysis.

Representative scans obtained during data collection are shown in Figure 4. Although the scans were acquired under controlled conditions, the resulting models intentionally contain minor acquisition artifacts and geometric imperfections. This was considered beneficial for evaluating the robustness of the proposed method under realistic, non-ideal circumstances that are likely to occur in everyday clinical practice.

4. Experimental Results

The primary objective of the experimental evaluation was to investigate whether the proposed symmetry-based framework is capable of detecting and quantifying facial asymmetry associated with parotidectomy-related contour changes. Particular attention was paid to the ability of the method to operate on consumer-grade 3D scans containing realistic acquisition artifacts.

For the evaluation, a pilot dataset consisting of four parotidectomy patients and one control subject was analyzed. The dataset included patients treated using different surgical approaches, thereby providing an opportunity to explore the potential of the proposed framework for objective postoperative assessment. The acquired scans were intentionally retained at a relatively low quality level in order to evaluate the robustness of the method under realistic clinical conditions.

Table 1 summarizes the Global Symmetry (GS), ROI Symmetry (RS), and Total Symmetry (TS) values computed for each subject. As described in Section 2, GS characterizes the overall facial symmetry, RS characterizes symmetry within the surgically affected region, and TS represents the absolute difference between these two quantities.

Table 1. For the patients included in the study, the symmetry metrics determined by our method and the corresponding rankings based on these metrics.

ID	Type of Surgery	Global Symmetry	ROI Symmetry	Total Symmetry	Doctor's Ranking	Method's Ranking
Patient #1	Modified Facelift	4.29	4.72	0.43	1	1
Patient #2	Modified Blair	0.44	3.92	3.48	2	2
Patient #3	Modified Blair+	0.69	6.05	5.36	3	4
Patient #4	Modified Blair	0.84	4.77	3.93	4	3
Patient #5	None	1.55	0.00	1.55		

The results indicate that the proposed method successfully differentiates between subjects exhibiting different levels of localized asymmetry. The control subject demonstrates the expected behavior, namely the absence of surgery-related asymmetry within the selected ROI. In contrast, the operated patients exhibit varying degrees of discrepancy between global and local symmetry measures, reflecting differences in postoperative contour changes.

To facilitate interpretation, the patients were ranked according to the Total Symmetry measure. The resulting ranking was compared with the independent aesthetic ranking provided by the surgeon responsible for the operations and postoperative follow-up. As shown in Table 1, the proposed method produced rankings that are broadly consistent with the clinical evaluation. In particular, Patient #1 was identified as having the most favorable aesthetic outcome by both the surgeon and the proposed method, while Patient #2 occupied the same position in both rankings.

A discrepancy can be observed for Patients #3 and #4. According to the surgeon's assessment, Patient #3 achieved a more favorable aesthetic outcome than Patient #4, whereas the proposed method assigned a higher symmetry score to Patient #4. This difference may be explained by the fact that the proposed framework evaluates primarily geometric symmetry within the selected ROI, while the surgeon's assessment incorporates additional qualitative factors that are difficult to capture using symmetry measurements alone, including scar visibility, tissue texture, and the overall visual impression of the face. Consequently, the disagreement does not necessarily indicate an error of the proposed method, but rather highlights the difference between objective geometric measurements and comprehensive clinical aesthetic judgement.

These preliminary findings suggest that the proposed framework is capable of providing meaningful and reproducible quantitative information regarding postoperative facial asymmetry. At the same time, the observed ranking discrepancy emphasizes the importance of combining objective measurements with expert clinical evaluation when assessing aesthetic outcomes.

The present study has several limitations. Most notably, the pilot dataset contains only four operated patients and one control subject, which precludes statistically significant conclusions. Furthermore, ROI delineation was performed manually, and the scans intentionally contained acquisition artifacts. Nevertheless, these conditions provide a realistic assessment scenario and demonstrate the feasibility of the proposed low-cost approach. Larger-scale validation studies will be required to establish the clinical reliability and generalizability of the method.

5. Conclusion

In this paper, we presented a semi-automatic, low-cost framework for the objective three-dimensional assessment of facial asymmetry following parotid gland surgery. By combining consumer-grade 3D facial scanning, anatomical landmark-based midplane estimation, and ROI-oriented symmetry analysis, the proposed method provides quantitative measures describing both global and localized postoperative facial asymmetry.

The presented framework was designed as an accessible alternative to approaches that rely on dedicated scanning systems and specialized post-processing software. The preliminary results obtained from the pilot dataset demonstrate that the method is capable of detecting and quantifying localized asymmetry associated with surgical intervention, even when using low-cost acquisition devices and scans containing realistic acquisition artifacts.

Comparison with the surgeon's aesthetic assessment revealed a generally consistent relationship between the computed symmetry measures and expert clinical judgement. At the same time, the observed disagreement in one case highlights the fact that facial symmetry represents only one component of overall aesthetic outcome and should be interpreted together with additional clinical factors such as scar visibility, tissue characteristics, and subjective patient perception.

The present study should be regarded as a proof-of-concept investigation. Owing to the limited number of subjects, no statistically generalizable clinical conclusions can be drawn regarding the relative aesthetic performance of the investigated surgical techniques. Nevertheless, the results demonstrate the feasibility of the proposed framework and support further investigation of consumer-grade three-dimensional facial scanning for objective postoperative assessment.

Future work will focus on automated ROI definition, improved robustness against acquisition artifacts, and validation on larger and more diverse patient cohorts. Such studies will enable statistically grounded evaluation of aesthetic outcomes and provide a stronger basis for comparing alternative surgical approaches in terms of their long-term visual impact.

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