JPRAS Open 43 (2025) 1–17

Contents lists available at ScienceDirect

JPRAS Open

journal homepage: www.elsevier.com/locate/jpra

Review Article

From Novel Facial Measurements to Facial Implantology: A Systematic Review[☆,☆☆]

Helena Baecher[a,*], Alexandra Scheiflinger[b], Katya Remy[c], Niklas Straub[d], Bhagvat Maheta[e], Khalil Sherwani[f], Can Deniz[g], Samuel Knoedler[h], Ali-Farid Safi[g,i], Martin Kauke-Navarro[h], Max Heiland[j], Leonard Knoedler[j]

[a] *Department of Cranio- and Maxillofacial Surgery, University Hospital Regensburg, Regensburg, Germany*
[b] *Department of Surgery, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, USA*
[c] *Division of Plastic and Reconstructive Surgery, Massachusetts General Hospital, Boston, MA, USA*
[d] *Department of Plastic Surgery, Medical Faculty Mannheim, Heidelberg University, Heidelberg, Germany*
[e] *Department of Surgery, California Northstate University College of Medicine, Elk Grove, CA, USA*
[f] *Department of Surgery, Medical University of Vienna, Vienna, Austria*
[g] *Craniologicum, Center for Cranio-Maxillo-Facial Surgery, Bern, Switzerland*
[h] *Department of Surgery, Division of Plastic Surgery, Yale School of Medicine, New Haven, CT, USA*
[i] *Faculty of Medicine, University of Bern, Bern, Switzerland*
[j] *Charité – Universitätsmedizin Berlin, corporate member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Department of Oral and Maxillofacial Surgery, Berlin, Germany*

ARTICLE INFO

Article history:
Received 11 September 2024
Accepted 6 October 2024
Available online 17 October 2024

ABSTRACT

Background: Facial implants have emerged as pivotal tools for both reconstructive and aesthetic skull bone augmentation. Contemporary manufacturing techniques, such as computer-aided design and manufacturing (CAD-CAM) systems, have revolutionized facial implants production, providing the advantages of high-level individualization. However, the absence of standardized facial measurements complicates the ability to accurately compare outcomes across various techniques. This systematic review investigates the strengths and limitations of various facial measurements employed

☆ Financial Disclosure Statement: The authors have no relevant financial disclosures.
☆☆ PROSPERO identifier: CRD42024512059

* Corresponding author. Helena Baecher, Department of Cranio- and Maxillofacial Surgery, University Hospital Regensburg, Regensburg, Germany.
E-mail address: helena.baecher25@gmail.com (H. Baecher).

https://doi.org/10.1016/j.jpra.2024.10.005

Key words:
Facial surgery
Facial implants
Alloplastic augmentation
Facial measurements
Anthropometric analysis

in facial implants, with a particular focus on their impact on aesthetic outcomes and potential complications.
Methods: We identified 13 studies in our comprehensive search across PubMed/MEDLINE, Web of Science, EMBASE, and CENTRAL databases.
Results: In total, 620 patients were included. The majority of the chosen studies focused on aesthetic purposes (69%). Primarily, mandibular (46%) or nasal regions (23%) were investigated, with porous polyethylene (31%), silicone (23%), and polyetheretherketone (23%) being the most utilized materials. Despite considerable heterogeneity in measurement approaches, including variations in reference points and angles, complications such as surgical site infections and nerve-related injuries were reported in the included studies.
Conclusion: Our review highlights the importance of standardized facial analysis for optimal implant planning. Future research should prioritize the development of uniform measurement concepts tailored to diverse implant applications to enhance outcomes and patient satisfaction in facial implantation.

Introduction

Facial plastic surgery has witnessed a significant surge at a global level. Specifically, facial bone contouring showed a remarkable increase, with a 40% rise observed in 2022 compared to 2018. Similarly, rhinoplasty procedures were performed more frequently, with a 30% increase during this period.[1]

Facial implants (FIs) stand out as essential tools for both reconstructive and aesthetic skull bone augmentation, enabling individual facial contouring and enhancement beyond soft tissue.[2]

Currently, computer-aided design and manufacturing (CAD-CAM) systems, leveraging computed tomography (CT) imaging, represent the state-of-the-art manufacturing process for custom-made FIs, resulting in reduced operative time and minimized intraoperative interventions.[3]

Patients' expectations have a significant influence on the facial design process in preparation for FI, with general facial features that are considered attractive forming the basic benchmark. Universal beauty attributes include averageness, youthfulness, and sexual dimorphism. Bilateral facial symmetry and proportional features are established anthropometric indicators of human attractiveness. In facial reconstructive surgery, mirroring the non-affected side to the affected side is considered the standard for design techniques. However, certain clinical scenarios, such as bilateral extended defects and reshaping facial contours in aesthetic surgery, preclude the use of anatomical mirroring. In such cases, facial features and anatomical measurements serve as indispensable tools for hands-free or AI-assisted implant design. Both methods require a variety of facial measurements.[4]

Anthropometric facial measurements involve both skeletal and soft tissue measurements, including frontal and lateral assessments. Established soft tissue and skeletal landmarks represent glabella (Gl), subnasale (Sn), menton (Me), pogonion (Pog), and pronasale (Pn). Key planes include the Frankfort horizontal plane (FH), which extends horizontally through the lowest orbital margin and the highest point of the skeletal auditory meatus (tragus point and orbitale in soft tissue analysis), and the coronal plane (CP), perpendicular to the FH and passing through the most protruding part of the pupils. These landmarks and planes facilitate angle and distance assessments, ensuring comparability and reproducibility of the measurements.

Despite the significance of FIs, there is a paucity of research that provides clear evidence-based guidelines on FI design. The majority of studies focus on implant design using the mirroring technique without referencing pertinent facial landmarks.[5,6] Moreover, the rapidly evolving concept of beauty requires updated information on facial measurements for FI.

Therefore, we conducted a systematic review to determine the advantages and drawbacks of various facial measurements in FIs, particularly focusing on aesthetic outcomes and complications. Ultimately, our research seeks to emphasize the necessity for evidence-based and updated guidelines on FI design and aims to stimulate future research endeavors in this area.

Methods

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines.[7] Additionally, it was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO identifier: CRD42024512059). Due to the heterogeneity observed in outcome measures and the small number of included studies, a narrative synthesis was conducted, as a meta-analysis was deemed inappropriate.

Systematic search

We conducted a systematic review by screening the PubMed/MEDLINE, Web of Science, EMBASE, and CENTRAL databases up to December 14, 2023. A search term including 4 elements was built. Each of the elements was connected by “AND.” The search terms were (i) “facial” OR “face” OR “head” OR “frontal” OR “forehead” OR “periorbital” OR “glabellar” OR “canthal” OR “palpebra” OR “nasal” OR “nose” OR “nasolabial” OR “cheek” OR “cheekbones” OR “buccal” OR “malar” OR “zygomatic” OR “temporal” OR “ear” OR “maxillar” OR “mandibular” OR “mental” OR “chin” OR “jaw” OR “jawline” OR “forehead” OR “upper face” OR “middle face” OR “midface” OR “lower face” AND (ii) “aesthetic” OR “beauty” OR “attraction” OR “attractive” OR “pleasant” OR “aging” OR “golden ratio” OR “cosmetic” AND (iii) “measurement” OR “measure” OR “length” OR “width” OR “distance” OR “dimension” OR “proportion” OR “proportionality” OR “size” OR “analysis” OR “ratio” OR “symmetry” OR “asymmetry” OR structure” OR “shape” OR (“andmarks” OR “metrics” OR “volume” OR “profile” OR “balance” OR “ratio” OR “vertical” OR “horizontal” OR “thickness” OR “separation” OR “length to width” OR “width to length” OR “height” OR “diameter” AND (iv) “implant” OR “implantology” OR “modification” OR “design” OR “surgery” OR “operation” OR “plasty” OR “plastic” OR “correction” OR “maxillofacial” OR “maxillofacial surgery” OR “facelift” OR “rhytidectomy” OR “browlift” OR “mandibuloplasty” OR “maxilloplasty” OR “ostectomy” OR “genioplasty” OR “mentoplasty” OR “reshaping” OR “chin reshaping” OR “cheek reshaping” OR “jaw reshaping” OR “augmentation” OR “enhance” OR “balance” OR “blepharoplasty” OR “rhinoplasty” OR “cosmetic surgery” OR “liposuction” OR “fat removal” OR “filler.”

The search was limited by the time period of 2018 to 2023. The included articles were required to be accessible as full-text and authored in English, while animal trials, cadavers, and nonsurgical investigations were excluded.

Article titles and abstracts were evaluated independently by 2 reviewers (N.S. and H.B.). Subsequently, a thorough examination of the full texts was conducted manually for all abstracts meeting the eligibility criteria. The search strings used in the PubMed/MEDLINE, Web of Science, EMBASE, and CENTRAL databases are provided in Supplementary Digital Content 1. The PRISMA 2020 flowchart illustrates the selection process and details regarding the inclusion and exclusion criteria in Figure 1.

Quality assessments

To assess the quality of the chosen papers, Newcastle–Ottawa Scale (NOS) (Supplemental Digital Content 2) and the Level of Evidence (LOE) (Supplemental Digital Content 3) were used.

The NOS assigned a maximum of 9 stars to each study, evaluating 3 core domains: the selection of study cohorts (maximum of 4 stars), the comparability of groups (maximum of 2 stars), and the assessment of outcomes/exposures (maximum of 3 stars). A higher NOS score, indicative of a greater

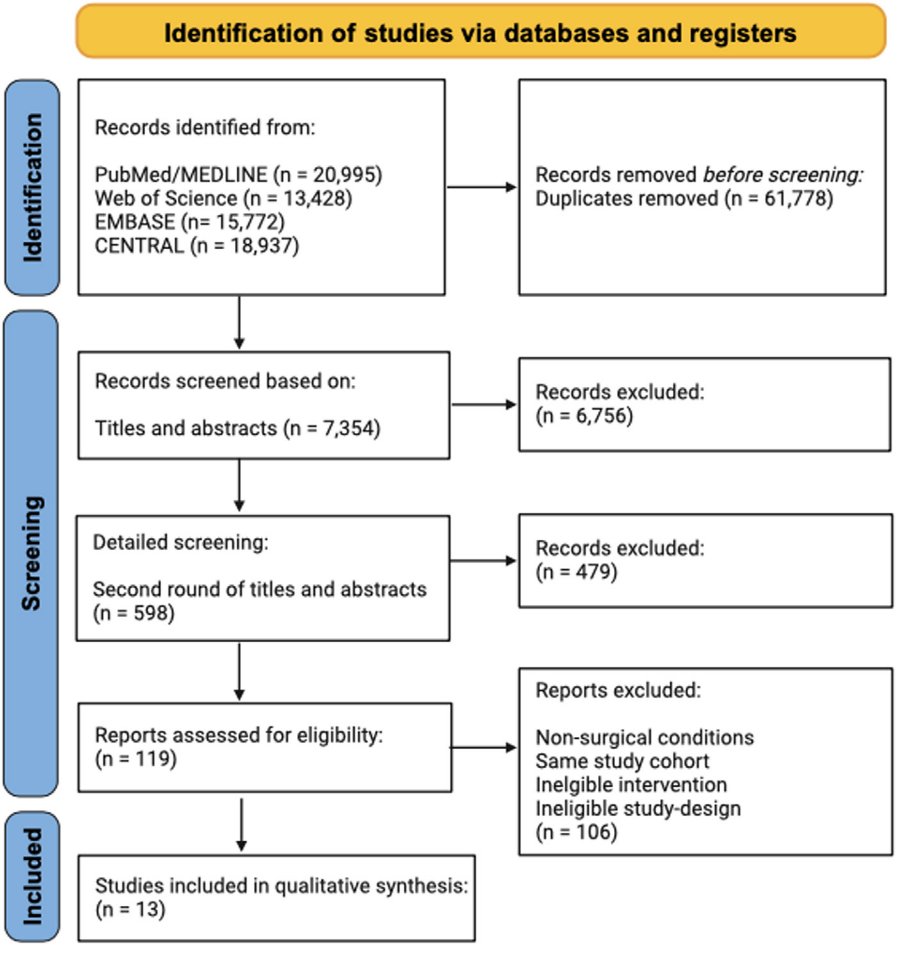

Figure 1. PRISMA 2020 flow diagram of the study identification process.

number of stars, was associated with an enhanced study quality and a diminished risk of bias in the conducted inquiries.[8]

The LOE established a hierarchical ranking of various study types based on their methodological preciseness and susceptibility to bias. For instance, LOE I denoted studies characterized by robust methodological rigor, such as systematic reviews or meta-analyses derived from well-conducted randomized controlled trials.[9]

Data extraction

The following data were extracted through a blinded dual review process for each article included in this review: Digital object identifier, PubMed identifier, first author, publication year, sample size, patient age, method of facial measurement, implant material, printing technology, implant design and imaging used, most commonly augmented/reconstructed area, reason for implantation (i.e., reconstruction, aesthetic facial contouring), length of follow-up, acute/longer-term complications, revision rate, implant acceptance, aesthetic outcome, patient satisfaction, time from implant design to implantation, implant measurements, and antibiotic/anti-infectious prophylaxis.

Results

Literature research yielded a total of 69,132 articles, of which 13 were deemed eligible based on predetermined inclusion and exclusion criteria. The search was restricted by publication year, and all included studies were published between 2018 and 2023, ensuring the relevance of the topic of FIs. In 9 studies, accounting for 69% of the selected literature, LOE was predominantly classified as IV. The mean NOS score was 4.1±1.4. Detailed assessments of NOS and LOE can be found in Supplementary Digital Content 2 and 3. A total of 620 patients were evaluated in all included studies. We found no studies involving minors, and the average patient's age ranged from 23 to 34 years. Among the selected studies, 3 (23%) investigated facial measurements in FI as prospective studies, while 5 (38%) adopted a retrospective approach.

Nine articles (69%, n=284) elucidated FIs for aesthetic purposes, and one study (7.7%, n=1) investigated FI in reconstructive conditions. Three studies (23%, n=335) reported FI in both aesthetic and reconstructive procedures. Six studies (46%, n=271) investigated FIs in the mandibular or mental region, whereas 3 articles (23%, n=251) focused on FI of the nose. Two studies (15%, n=22) examined FI in the paranasal region. One study (7.7%) each assessed FI in the malar region (n=1) and the forehead/temporal region (n=75). Additionally, 7 articles (54%, n=188) reported computer-aided design/computer-aided manufacturing (CAD/CAM) or 3D printing as the manufacturing technology. Four studies (31%, n=58) investigated FI made of porous polyethylene (e.g., Medpor), and 3 studies (23%, n=205) included FI made of silicone. Three articles (23%, n=34) addressed polyetheretherketone (PEEK) use, while 2 articles provided FI made of polycaprolactone (PCL) (15%, n=45). One study each (7.7%) focused on polymethyl methacrylate (PMMA) implants (n=75) and polytetrafluoroethylene (PTFE) implants (n=206).

Mandibular and chin region

Findikcioglu et al. explored FIs for chin augmentation in a case report including 3 patients. The Riedel line, a vertical line drawn from the most projected portion of the upper lip to the most projected part of the lower lip, was applied by the authors in presurgical implant design. By definition, this line should meet the most protruding portion of the chin (i.e., menton). Among patients, 67% (2/3) required additional fat grafting to optimize facial symmetry and smooth the osteotomy line. In 33% (1/3) of cases, scar contracture of the lower labial mucosa resulted in increased incisor exposure. This was resolved by contracture release. Ultimately, all 3 patients expressed satisfaction with the final outcome.[10]

Al-Jandan et al. recruited 58 patients who underwent mandibular angle augmentation with solid silicone implants. Facial measurements involved analyzing the mandibular angle on a lateral cephalometric radiograph, which was considered ideal when it measured below 105°. Frontal examination included equal bitemporal and bigonal distances to ensure well-defined mandibular angles. Among patients without complications, 94% (47/50) expressed satisfaction with the end result, while 3 patients (6.0%) found their expectations misaligned with the postsurgical result. Notably, all dissatisfied patients had intact mandibular angles, as well as adequate facial symmetry. Additionally, implant infection occurred in 5.2% (3/58) of patients and implant displacement in 14% (8/58).[11]

A study conducted by Straughan et al. investigated 123 cases of mandibular recontouring making use of CAD/CAM FIs. The primary indication for surgery was to gain a more masculine appearance through a prominent and well-defined mandible. This was mostly achieved by increased ramus height along with posterior projection of the mandibular angle. Preoperatively, Fis were designed to achieve symmetric chin alignment relative to the dental midline and upper central midline structures, such as the nasal radix, nasal septum, and lip elements. Additionally, the width of each ramus was adjusted to be equidistant from the edge of the lateral orbital rim. 94% of patients were satisfied postoperatively. Dissatisfaction led to revisional procedures in 5 cases (4.1%, 5/123) and implant removal in 3 cases (2.4%, 3/123). During follow-up, acute implant infection occurred in 2.4% (3/123) cases.[12]

Straughan et al. focused on enhancing male mandible aesthetics. Again, CAD/CAM FIs made of PEEK were used for chin and mandible augmentation. Mandibular symmetry and cephalometric parameters, such as a mandibular angle projection of 130° and chin projection of 3°, were considered. The authors reported satisfactory aesthetic outcomes, and 100% (2/2) of the patients reported that they were pleased with the end result.[4]

In their investigation of silicone FIs in advancement genioplasty, Hwang et al. examined 79 cases. The authors defined an optimal labiomental angle of 119.4° for males and 117.6° for females. Postoperatively, patients were surveyed on their overall satisfaction. The majority (80%, 63/79) found the end result very satisfactory, while 10% (8/79) found it satisfactory, 7.6% (6/79) fair, and 2.5% (2/79) unsatisfactory. Both patients who expressed dissatisfaction with the end result experienced an infection. All patients were pleased with the aesthetic outcome. Incidence rates of 2.5% (2/79) were recorded for surgical site infection and wound dehiscence each.[13]

Research by Atef et al. focused on patient-specific FIs made of PEEK. For unilateral deficiencies, a mirror-image tool was applied to design the opposite mandibular contour. Additionally, cephalometric analysis of the pogonion, the midsagittal plane (MP), and the FH were methods used by the authors to customize implant design. While the FH is defined as a line through the tragus point and the inferior orbital rim, MP runs through the spina nasalis anterior, the nasion, and the sella turcica. The study reported universal patient satisfaction with the final outcomes, which included more harmonious facial profiles and more prominent labial folds. Transient complications, such as edema and mild ecchymosis occurred in 17% (1/6) of patients.[14]

Nasal region

Wei et al. conducted a study on nose elongation utilizing PTFE implants in a cohort of 206 patients. Reference values included nasal length (measured from the glabella to the subnasale), nasolabial angle, and angle of facial convexity. An increase in nasal length (4.4 mm) alongside reductions in the nasolabial angle (8.5°) and facial convexity (7.0°) was documented postoperatively. Throughout the follow-up period, infection manifested in 2.4% (5/206) of cases, implant migration occurred in 3.4% (5/206), and prominence of the implant was observed in 2.4% (5/206). In a patient survey conducted 6 months after surgery, 94% (193/206) reported that their nasal aesthetics and facial profile had definitely improved.[15]

Kim et al. introduced a novel technique for nasal tip augmentation employing 3D-printed PCL in their study. During implant shaping, the authors considered key parameters, including the nasolabial angle, the columellar lobular angle, and the nasal tip projection. Nasal tip projection was quantified by the distance from the alar base to the nasal tip. Aesthetic outcomes were evaluated by patients and 3 independent plastic surgeons. Patients rated satisfaction from 0 to 4 (0: lowest satisfaction, 4: highest satisfaction) in the rhinoplasty outcome evaluation questionnaire developed by AlHarethy et al.[16] Plastic surgeons used a scale from 1 to 5 (1: unsuccessful outcomes, 5: highly successful outcomes) to rate outcomes. Patient satisfaction was reported with a mean rating of 3.7 points, whereas plastic surgeons scored the outcomes at 4.5 points on average.[17]

In a study on PCL FIs, distinct shapes of ready-made implants (tip ball, drone ball, and dumbbell) were compared for their efficacy in nasal lobule correction. Facial measurements were based on the nasolabial angle and the tip projection. The nasolabial angle was targeted within the range of 93.4–98.5° in males and 95.5–100.1° in females. Tip projection was defined as the distance along the perpendicular line from the vertical facial plane to the most anterior projecting point of the nasal tip. Instances of hypertrophic scarring and implant exposure were documented in 8.7% (2/23) of cases. Notably, all 23 patients expressed satisfaction with their postoperative nose shape.[18]

Paranasal region and midface augmentation

Yen et al. investigated the impact of paranasal augmentation on nasal measurements, analyzing 10 patients. The researchers assessed parameters including alar width, alar base width, tip projection (defined as the distance between the nose tip and the CP), nasolabial angle, columellar inclination, and the CP. A comparative analysis with a control group undergoing malar reduction was conducted. The study revealed a significantly greater postoperative increase in alar width, alar base width, and nasolabial angle among the augmented group. Patient satisfaction was evaluated by using a questionnaire with 3 questions about outcome satisfaction. Scores ranged from 0 to 5 (0: lowest satisfaction, 5: highest satisfaction). Satisfaction levels regarding the aesthetic outcome and soft tissue changes in the nasal and paranasal regions remained consistently high, averaging at 4.5. Minor complications were observed, as 10% (1/10) of patients experienced partial intraoral wound dehiscence.[19]

Zhang et al. analyzed the efficacy of patient-specific implants in paranasal augmentation. Preoperative implant design was informed by facial analysis, which included the nasolabial angle and the distance between NA (the most posterior point of nasal insertion) and NP (intersection of the P-line and the L-line). The NA-NP distance was categorized as light (2–3 mm), moderate (1–2 mm), or high (<1 mm). Surgical outcomes were assessed using the Wrinkle Severity Rating Scale for nasolabial folds (WSTS-NLF), which ranged from 0 to 3 (0: no wrinkle, 3: deep wrinkle). Postoperatively, lower mean scores on the WSTS-NLF, along with increased nasolabial angles and NA-NP distances, were observed. The patient satisfaction rate was 100% (12/12).[20]

Malar region

In a case report, Wong et al. described a combined approach of using a patient-specific implant along with malar reduction to address midfacial asymmetry. The ideal zygoma shape was determined by considering the optimal ratio between the widest part of the midface (WM) and the widest part of the lower face (WL). The target ratio of WM/WL was 1.3±0.1, derived from previous research findings. Subsequent evaluation of postoperative photogrammetry and CT images revealed postoperative enhancement of midfacial symmetry, achieving the desired WM/WL ratio of 1.3.[21]

Forehead and temporal region

Hirohi et al. conducted a retrospective study involving 75 patients to compare integrated forehead and temporal augmentation with conventional forehead augmentation (i.e., expansion of the lateral boundaries of the implants to the temporal fusion lines). Presurgical facial measurements included forehead height, forehead width, nasal dorsal line, and the profile of the forehead, which was segmented into thirds. By definition, the lower two-thirds were expected to be relatively vertical, while the upper third should slope toward the anterior hairline. On average, the aesthetic outcomes of integrated forehead and temporal augmentation received a rating of 3.7 points on a scale ranging from 1 to 4 (1: dissatisfaction, 4: very high satisfaction) from 2 blinded plastic surgeons. Notably, the frequencies of implant removal (2.4% (1/41) vs. 18% (6/34)) and filler injections for touch-up (2.4% (1/41) vs. 18% (6/34)) were significantly lower following integrated augmentation compared to conventional forehead augmentation.[22]

Table 1 presents a summary of study characteristics, while detailed descriptions of all mentioned facial measurement methods are listed in Table 2. The most relevant anatomical points are defined in Table 3. All facial measurements of the chosen studies are illustrated in Figures 2–4.

Discussion

FI has found wide application across various fields, from the correction of congenital anomalies to post-traumatic reconstruction and aesthetic augmentation. In-depth preoperative analysis of the face is pivotal to ensure successful implant adaptation and requires strategies for accurate assessment and interpretation of facial proportions.[23,24] Therefore, various strategies for facial measurements were developed to facilitate implant design and allow comparisons of facial contours pre- and postoperatively.[25]

In this systematic review, we investigated facial measurements in FI regarding cosmetic outcomes, patient satisfaction, as well as acute and long-term complications. Based on the analysis of 13 studies including 620 patients, the following findings may warrant further discussion.

Inhomogeneity of anthropometric measurements

Across different approaches to FI, our analysis revealed significant inhomogeneity in the methods of facial measurements.

Table 1
Summary of study characteristics.

Year	First author	PMID	Study design	Number of patients	Mean patient age [years]	Reason for surgery	Anatomical region	Material	Imaging	Planning technology	Facial analysis	Patient satisfaction	Complications	Mean length of follow-up [months]
2023	Wong	37643059	CR	1	23	R	Malar	-	3D	-	Ratio widest part of the midface - widest part of the lower face (WM/WL=1.3)	-	-	-
2022	Straughan	35367034	CR	2	27	A	Chin, mandible	Polyethylene	3D	PSI	Chin symmetry, mandibular angle projection (130°), chin projection (3°)	100%	-	18
2022	Zhang	35968952	PS	12	28	A	Paranasal	PEEK	3D	PSI	Distance of NA - NP, nasolabial angle	100%	0%	13
2021	Hwang	34842399	RS	79	27	A	Chin, Labiomental groove	Silicone	2D	OTS	Labiomental angle: 119.4° (males), 117.6° (females)	90%	surgical site infection (3%), wound dehiscence (3%)	12
2021	Atef	34328575	PS	6	27	A/R	Chin, Mandible	PEEK	3D	PSI	Pogonion analysis, midsagittal plane, FH	100%	temporary edema and mild ecchymosis (17%)	12
2021	Straughan	33884405	RS	123	31	A/R	Mandible	PEEK, Silicone, Polyethylene	3D	PSI	Chin symmetry, distance ramus - lateral orbital rim	94%	infection (2%), dissatisfaction (7%)	26
2021	Wee	34292245	PS	23	34	A	Nose	PCL	3D	PSI	Nasolabial angle: 93.4–98.5° (males), 95.5 to 100.1° (females), tip projection	100%	hypertrophic scarring (4%), exposure (4%)	10

(*continued on next page*)

Table 1 (*continued*)

Year	First author	PMID	Study design	Number of patients	Mean patient age [years]	Reason for surgery	Anatomical region	Material	Imaging	Planning technology	Facial analysis	Patient satisfaction	Complic ations	Mean length of follow-up [months]
2020	Kim	31661758	RS	22	-	A	Nose tip	PCL	3D	PSI	Nasolabial angle, columellar lobular angle, nasal tip projection	mean score of 3.67/4	-	36
2018	Yen	29401214	RS	10	33	A	Midface, paranasal	Polyeth ylene	2D	OTS	Alar width, tip projection, nasolabial angle, columellar inclination, CP	mean score of 4.5/5	partial intraoral wound dehiscence (10%)	13
2018	Findik cioglu	29261517	CR	3	27	A	Chin	Medpor	2D	OTS	Riedel line	100%	mental neuropraxia (100%), mucosal contracture (33%)	24
2018	Wei	29762452	RS	206	29	A/R	Nose elong ation	ePTFE	3D	OTS	nasal length, nasolabial profile, nasolabial angle, angle of facial convexity	94%	infection (2%), implant migration or deviation (3%), reddening of nasal skin (2%), visible or prominent implant (2%)	13
2018	Hirohi	29596570	RS	75	31	A	Forehead, Temporal	Methyl methacry-late cement	3D	PSI	Forehead height, forehead width, forehead profile	-	acne-like rash (5%), facial nerve injury (2%), scalp numbness (2%), seroma (2%)	12
2018	Al-Jandan	30648361	PS	58	-	A	Mandibular Angle	Silicone	3D	OTS	Angle of the jaw (<105°)	94%	infection (4%), displacement (14%)	6

Reasons for surgery included reconstructive (R) and aesthetic (A) reasons. CR: Case Report, RS: a retrospective study, PS: a prospective study, PEEK: polyetheretherketone, PCL: polycaprolactone, ePTFE: expanded polytetrafluorethylene, PSI: patient-specific implant, OTS: off-the-shelf implant.

Table 2
Summary of all facial measurements and their corresponding descriptions analyzed in this study.

Point of view	Augmented area	Measurement	Explanation	Studies
Profile	Forehead	Forehead thirds	Relatively vertical in the lower two-thirds, upper third declined toward the anterior hairline	22
	Nose	Angle of facial convexity	Glabella, subnasale, pogonion	15
		Columellar lobular angle Nasolabial angle	Angle of columella-subnasale-labrale superius	15,19,20
			Line drawn through anterior and posterior ends of the nostril and vertical facial plane	17
			angle between a line drawn through the midpoint of the nostril aperture and a line drawn perpendicular to the FH while intersecting the subnasale males: 93.4–98.5°, females: 95.5–100.1°	18
		Nasal length	Distance glabella–subnasale	15
		Nasal dorsal line	Distance glabella–radix–dorsum–tip	
		Tip projection	Distance between tip and CP/alar base	19,17,18
	Paranasal	Distance NA—NP	NA: most posterior point of the nasal insertion NP: intersection of the P-line and the L-line I: horizontal plane through a point 1 cm below the lower lid margin S: horizontal plane on the columellar insertion and the subnasale B: midline between I-line and S-line L: midline between B-line and S-ine light 2-3mm, moderate 1-2mm, high <1mm	20
		Columellar inclination	Angle of CP – columella - subnasale	19
	Mandible/chin	Frankfort horizontal plane	Right and left orbitale and the right porion	14
		Coronal plane	Plane perpendicular to FH passing the most protruding part of the pupils	19
		Labiomental angle	Sublabiale–labrale inferius–soft tissue pogonion 119.4° (males), 117.6° (females)	13
		Mandibular angle	Long and low in profile, <105° when measuring the slope of the lower border and the ascending ramus on a lateral cephalometric radiograph 130°	11,4

(*continued on next page*)

Table 2 (*continued*)

Point of view	Augmented area	Measurement	Explanation	Studies
		Chin projection	3°, to a point behind a perpendicular line drawn straight down from the glabella	4
		Pogonion analysis	Analysis of the most anterior chin midpoint	14
		Riedel line	Line between the most projected part of the upper lip to the most projected part of the lower lip, should intersect with the pogonion	10
Frontal	Forehead	Forehead height	Distance supraorbital rim–frontal hairline	22
		Forehead width	Distance bilateral temporal hairlines	
		Bitemporal distance	Equal bitemporal distance	11
		Alar width	Distance between the most lateral parts of the bilateral alar wings	19
		Alar base width	Distance between the bilateral alar bases	
	Nose	Ideal ratio—widest part of the midface (WM) and widest part of the lower face (WL)	WM/WL=1.27±0.1	21
	Malar	Midsagittal plane	Nasion, anterior nasal spine, center of the sella turcica	14
	Mandible/chin	Chin symmetry	Relative to mental foramen to mental foramen	12,4
			Relative to the upper central midline structures: nasal radix, nasal septum, incisors, and lip elements,	
		Bigonial distance	Equal bigonial distance	11
		Distance lateral orbital rim–mandibular ramus	Width of each ramus similar distance from edge of lateral orbital rim	4,12

FH: Frankfort horizontal plane, CP: coronal plane.

Table 3
Definition of anatomical points used in facial analysis.

Soft tissue points	Anatomical landmark
Trichion (Tr)	Most anterior point of the hairline
Glabella (Gl)	Midpoint between the eyebrows
Subnasale (Sn)	Intersection between the columella and the upper lip
Soft tissue Menton (Me')	Lowest point of the chin, as measured on the soft tissue
Soft tissue Pogonion (Pog')	Most anterior point of the chin, as measured on the soft tissue
Pronasale (Pn)	Tip of the nose
Columella (Cm)	Most anterior point of the columella of the nose
Labrale superius (Ls)	Most anterior point of the upper lip
Labrale inferius (Li)	Most anterior point of the lower lip
Sublabiale (Sl)	Most posterior point on the labiomental soft tissue contour
Tragus (T)	Cartilaginous projection anterior to the external auditory meatus
Orbitale (O)	Most inferior point of the infraorbital ridge
Skeletal points	**Anatomical landmarks**
Nasion (N)	Most anterior point of the nasofrontal suture
Spina nasalis anterior (Spa)	Anterior nasal spine
Sella (S)	Midpoint of the sella turcica
Articulare (Ar)	Intersection between the posterior border of the mandibular ramus and lower border of the cranial base
Skeletal Gonion (Go)	Midpoint between the most posterior and inferior points of the mandibular angle
Skeletal Menton (Me)	Lowest point on the mandibular symphysis
Skeletal Pogonion (Pog)	Most anterior point of the skeletal chin

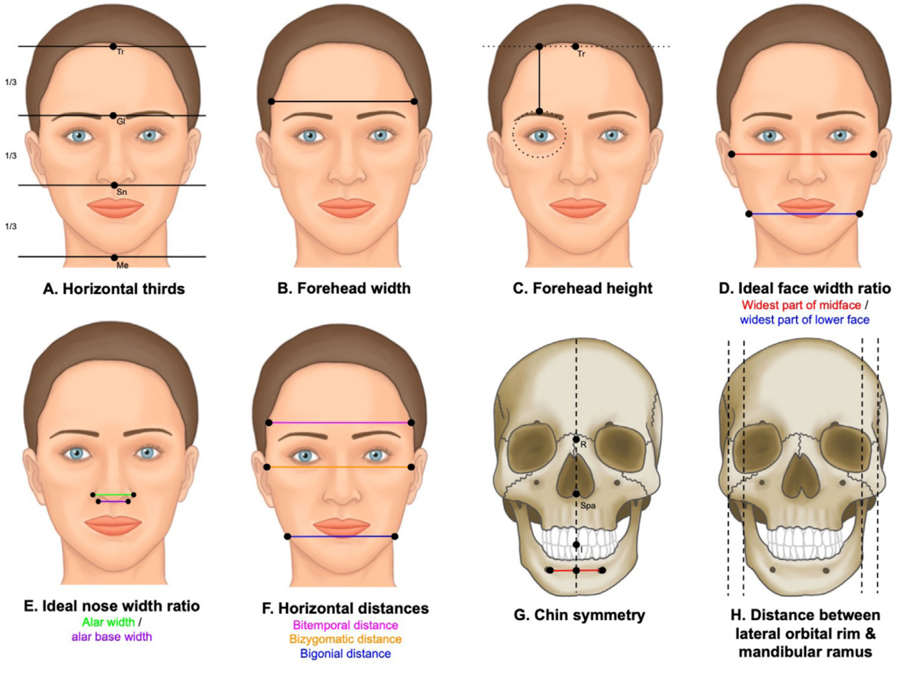

Figure 2. Frontal facial measurements for forehead and mental FI. Anatomical points are defined in Table 3. Tr, Trichion; Gl, Glabella; Sn, Subnasale; Me, Menton; R, Radix; Spa, Spina nasalis anterior.

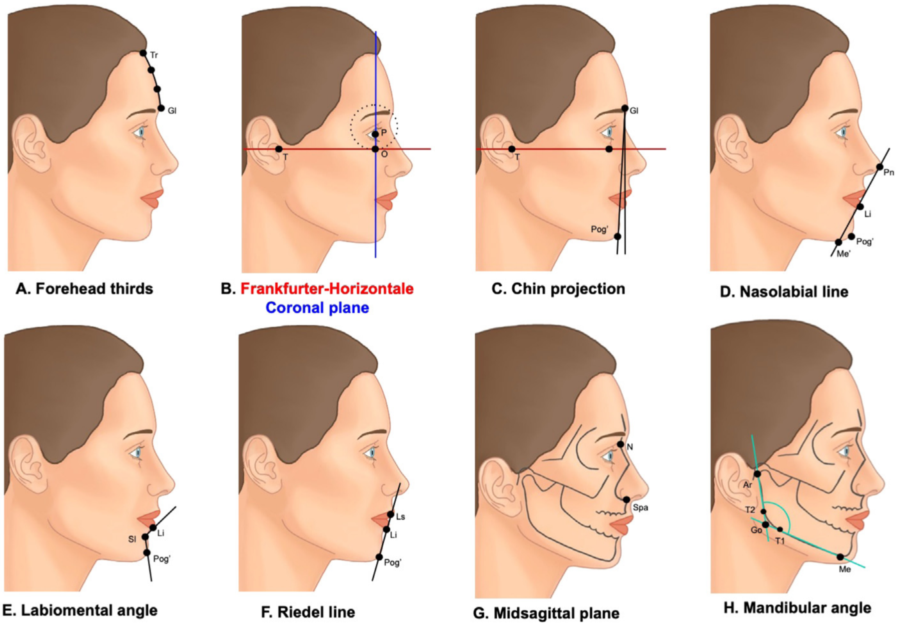

Figure 3. Lateral facial measurements for forehead, mandibular, and mental FI. Anatomical points are defined in Table 3. Tr, Trichion; Gl, Glabella; T, Tragus; O, Orbitale; P, Pupil; Pog', soft tissue Pogonion; Me', soft tissue Menton; Pn, Pronasale; Li, Labrale inferius; Ls, Labrale superius; Sl, Sublabiale; Me, Menton; Spa, Spina nasalis anterior; N, Nasion; Ar, Articulare; Go, Gonion.

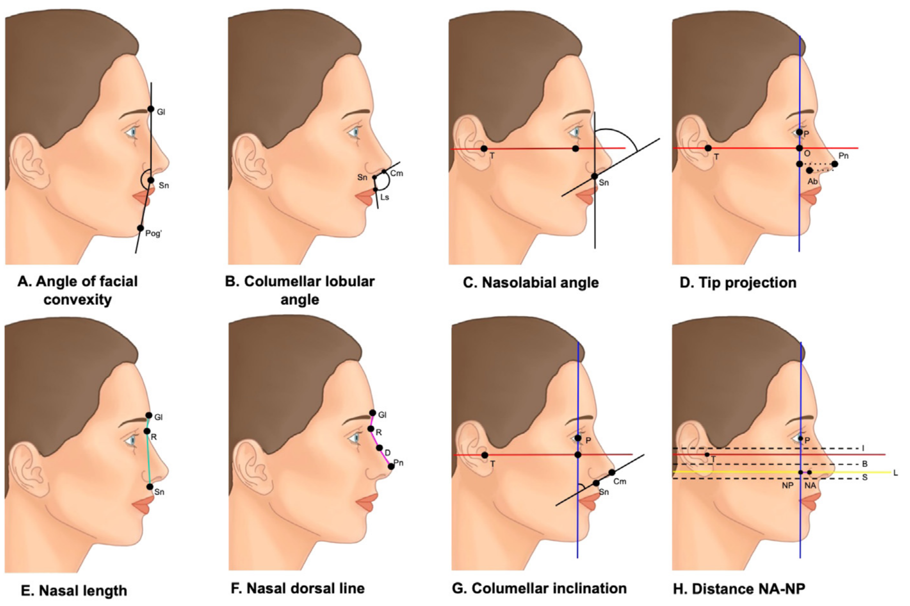

Figure 4. Lateral facial measurements for nasal and paranasal FI. Anatomical points are defined in Table 3. Gl, Glabella; T, Tragus; O, Orbitale; P, Pupil; Pog', soft tissue Pogonion; Sn, Subnasale; Cm, Columella; Pn, Pronasale; Ab, Alar base; Ls, Labrale superius; R, Radix; D, Dorsum.

Inconsistencies were found in the specific measurement methods, including variations in reference points, distances, and angles for the same augmentation areas. In studies examining FI in the chin region, 7 different measurement approaches were identified from a lateral viewpoint (i.e., FH, mandibular angle, CP, Riedel line, labiomental angle, chin projection, and pogonion analysis).[4,10,11,13,14] Similarly, lateral measurements for nasal augmentation entailed 5 distinct measurement methods, contingent on the specific augmentation area, such as the dorsum, nose tip, or paranasal region (i.e., nasolabial angle, nasal length, nasal dorsal line, angle of facial convexity, and tip projection).[15,17-20] Particularly noteworthy, in the reviewed studies, is the nasolabial angle defined in 3 different ways: i) as the angle of columella-subnasale-labrale superius, ii) as the angle between a line drawn through the anterior and posterior ends of the nostril and the vertical facial plane, and iii) as the angle between a line drawn through the midpoint of the nostril aperture and a line drawn perpendicular to the FH while intersecting the subnasale.[15,17,18] Comparison of the cosmetic outcomes is particularly challenging as there is no standard for nasal analysis in FI.

A study on anthropometric principles for facial aesthetic surgery by Armengou et al. describes a variety of different measurements for each facial region and full-face analysis. When analyzing the nose, the authors mentioned the nasolabial angle, a parameter that is also mentioned in our review, as well as the nasofrontal angle and the nasomental angle. In addition, the authors emphasized the importance of ethnic background in facial measurements.[25]

Considering that patients of various ethnicities present with diverse facial features, such as the shape of the face, eyes, noses, and lips, ethnic diversity particularly influences preoperative planning for FI. Given the interindividual differences in craniofacial characteristics observed in the global population, patients from geographically diverse regions have different cosmetic ideals and expectations for the esthetic outcome after FI. For example, in some Asian regions, the aim of nasal dorsum augmentation is often to enlarge the nasal bridge, whereas in the USA, procedures to narrow the nasal width or remove the dorsal hump are frequently performed in cosmetic rhinoplasty.[26,27] Surgical outcomes can also be heavily influenced by genetic factors. Some ethnicities may present with thicker skin around the nose, resulting in fewer occurrences of implant extrusion or skin redness.[27] Therefore, adapting facial measurements to consider ethnic differences should be a fundamental principle in FI to improve and personalize cosmetic outcomes. This approach was not observed in the investigated studies.

The proven variability of definitions for the same measurement concept complicates the comparison of various facial augmentation techniques and leads to inconsistent FI results and variability in patient satisfaction. The absence of consideration of ethnic background in facial measurements limits the customization of implant design. We, therefore, suggest the implementation of standardized facial measurements in FI tailored to factors such as gender, ethnic background, shapes of facial features (e.g., nose, lips, and chin), and individual patient concerns.

Patient satisfaction

In mandibular implants, studies using the Riedel line and pogonion analysis for anthropometric analysis aimed for significantly higher patient satisfaction than the study using a labiomental angle of 119.4° for males and 117.6° for females (100 vs. 89.9%).[10,13,14] Further literature review reveals that the labiomental angle is considered most attractive when measuring between 107° and 118°, which is similar to the findings of Hwang et al.[13,28] In contrast to other mandibular measurements, the labiomental angle addresses only a minor part of the lower face, while evaluation of the pogonion and the Riedel line concerns larger areas. As a result, measurement methods pertaining to the face as a whole may achieve higher levels of satisfaction compared to analysis of minor facial regions. This is also emphasized in a study by Li et al. using facial thirds in anthropometric analysis.[29] Hence, we recommend prioritizing measurements that capture broader facial areas or incorporating comprehensive full-face measurements into facial analysis within FI.

Complications

Complications were reported in 9 out of 13 studies. The most prevalent complication was surgical site infection, with the highest incidence observed in mandibular angle augmentation. This may be attributed to the use of silicone implant materials. Another important adverse event associated with silicone implants is implant displacement.[30] Al-Jandan et al. support these findings in their study, which reported implant displacement in 14% of cases.[11]

Nerve-related injuries were only reported in cases of frontal and mandibular augmentation. Hirohi et al. opted for a temporal approach in forehead augmentation, where sensory fibers of the temporal branch of the facial nerve traverse the subcutaneous tissue in this region, and then, above the zygomatic arch, through the subgaleal space.[31] Once more, sensory fibers of the mental nerve were in proximity to the surgical site, resulting in mental neuropraxia as a frequent adverse event in chin augmentation. A review of iatrogenic facial nerve injuries demonstrates that the majority of facial nerve injuries stem from oral and maxillofacial procedures, thus confirming our findings.[32]

In a clinical context, FI of the frontal and mandibular regions necessitates particular caution, leading to measures such as carefully selected surgical approaches, preoperative nerve evaluation, and perioperative nerve monitoring. Based on these insights, customizing presurgical implant design methodologies is emphasized, including facial analysis, choice of implant material, and surgical approach, to effectively achieve the desired cosmetic and functional outcomes.

Limitations

The conclusions drawn from this systematic review must be interpreted in the consideration of the following limitations. The retrospective nature of 5 studies and the small patient cohorts may introduce bias and may put the conclusions on preoperative facial measurements in FI into perspective. Notably, the included studies were of very low quality based on the LOE classification, with 9 studies rated as Level IV and one classified as Level V. Additionally, the relatively small number of included articles (13 out of 69,132 screened) could limit the applicability of the results.

Conclusion

This systematic review of facial measurements for FI revealed significant discrepancies in measurement methods, highlighting the necessity for standardized facial analysis in each facial region. The evaluation of the methodological quality of the incorporated studies, using LOE and NOS, revealed relatively low standards among the current studies on facial measurements for FIs. Consequently, there is a need for large-scale studies and prospective investigations to establish solid evidence across various measurement methods. Finally, further research is warranted to develop consistent measurement protocols for diverse implant applications, including masculinization, feminization, ethnic adaptation, and facial harmonization.

Author Contributions

Conceptualization: L.K., H.B., A.S., A.-F.S., and M.K.-N.; Methodology: L.K., H.B., A.-F.S., M.K.-N., and M.H.; Writing – original draft: L.K., H.B., and S.K.; Writing – review & editing: A.S., B.M., A.-F.S., and M.K.-N.; Data curation: H.B., N.S., B.M., K.S., and C.D.; Project administration: L.K., K.R., N.S.; Supervision: L.K., H.B., M.K.-N., and M.H.

Funding

This research received no external funding.

Standardized Reporting Guidelines

The authors adhered to the PRISMA guidelines to ensure a standardized report of this systematic review. The review protocol can be accessed at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42024512059

Informed Consent Statement

Based on a retrospective analysis, a fully anonymized set of clinical data and in agreement with the decision of the Ethics Committee, signing an informed consent was not required.

Data Available Statement

Derived data supporting the findings of this study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi: 10.1016/j.jpra.2024.10.005.

References

1. Campiglio G. International Society of Aesthetic Plastic Surgery. ISAPS International survey on aesthetic/cosmetic procedures performed in 2022. 2023.
2. Yaremchuk MJ. *Atlas of facial implants*. Elsevier Health Sciences; 2019.
3. Alonso-Rodriguez E, Cebrián JL, Nieto MJ, et al. Polyetheretherketone custom-made implants for craniofacial defects: Report of 14 cases and review of the literature. *J Cranio-maxillofacial Surg*. 2015;43:1232–1238.
4. Straughan DM, Yaremchuk MJ. Improving male chin and mandible eesthetics. *Clin Plast Surg*. 2022;49:275–283.
5. Lutz JC, Assouline Vitale LS, Graillon N, Foletti JM, Schouman T. Standard and customized alloplastic facial implants refining orthognathic surgery: Outcome evaluation. *J Oral Maxillofac Surg*. 2020;78 1832.e1-32.e12.
6. Onică N, Onică CA, Budală DG, et al. The use of 3D technology in the management of residual asymmetry following orthognathic surgery: A case report. *Healthcare (Basel)*. 2023:11.
7. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Syst Rev*. 2021;10:89.
8. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*. 2010;25:603–605.
9. examination The periodic health. Canadian Task Force on the Periodic Health Examination. *Can Med Assoc J*. 1979;121:1193–1254.
10. Findikcioglu K, Sibar S, Gulsen A. Treatment approach to severe microgenia cases: Combined use of osseous and implant genioplasty. *J Craniofac Surg*. 2018;29:e175–e179.
11. Al-Jandan B, Marei HF. Mandibular angle augmentation using solid silicone implants. *Dent Med Probl*. 2018;55:367–370.
12. Straughan DM, Yaremchuk MJ. Changing mandible contour using computer designed/computer manufactured alloplastic implants. *Aesthet Surg J*. 2021;41 Np1265-np75.
13. Hwang J, Park B. Correction of the deepened labiomental groove using silicone implants in advancement genioplasty. *J Craniofac Surg*. 2021;32:e389–e392.
14. Atef M, Mounir M, Shawky M, Mounir S, Gibaly A. Polyetheretherketone patient-specific implants (PPSI) for the reconstruction of two different mandibular contour deformities. *Oral Maxillofac Surg*. 2022;26:299–309.
15. Wei J, Herrler T, Deng N, et al. The use of expanded polytetrafluoroethylene in short nose elongation: Fourteen years of clinical experience. *Ann Plast Surg*. 2018;81:7–11.
16. AlHarethy S, Al-Angari SS, Syouri F, Islam T, Jang YJ. Assessment of satisfaction based on age and gender in functional and aesthetic rhinoplasty. *Eur Arch Otorhinolaryngology*. 2017;274:2809–2812.
17. Kim JH, Kim GW, Kang WK. Nasal tip plasty using three-dimensional printed polycaprolactone (Smart Ball®). *Yeungnam Univ J Med*. 2020;37:32–39.
18. Wee SY, Kim TH, Kang HY, Park ES. Aesthetic nasal lobule correction using a three-dimensional printed polycaprolactone implant. *J Craniofac Surg*. 2021;32:e808–e812.
19. Yen C-I, Chen R-F, Zelken J, et al. The influence of paranasal augmentation on the measurement of the nose for the treatment of midfacial concavity. *Aesthet Surg J*. 2018;38:241–251.
20. Zhang J, Li D, Liu Y, et al. Application of patient-specific PEEK implant for aesthetic considerations in paranasal augmentation. *J Craniofac Surg*. 2022;33:e877–e880.
21. Wong KI, Zhong Y, Yu Z, Jiang T, Wei M. Combining patient-specific implant with malar reduction to repair mid-facial asymmetry caused by craniofacial fractures in Asians. *J Craniofac Surg*. 2024;35:241–242.
22. Hirohi T, Nagai K, Ng D, Harii K. Integrated forehead and temporal augmentation using 3D printing-assisted methyl methacrylate implants. *Aesthet Surg J*. 2018;38:1157–1168.
23. Binder WJ. Custom-designed facial implants. *Facial Plast Surg Clin North Am*. 2008;16:133–146 vii.
24. Oliver JD, Eells AC, Saba ES, et al. Alloplastic facial implants: A systematic review and meta-analysis on outcomes and uses in aesthetic and reconstructive plastic surgery. *Aesthet Plast Surg*. 2019;43:625–636.

25. Armengou X, Frank K, Kaye K, et al. Facial anthropometric measurements and principles—overview and implications for aesthetic treatments. *Facial Plast Surg*. 2023;40:348–362.
26. Ponsky D, Eshraghi Y, Guyuron B. The frequency of surgical maneuvers during open rhinoplasty. *Plast Reconstr Surg*. 2010;126:240–244.
27. Suh M-K. Cosmetic augmentation rhinoplasty for East Asians. *Facial Plast Surg Clin North Am*. 2021;29:589–609.
28. Naini FB, Cobourne MT, Garagiola U, McDonald F, Wertheim D. Mentolabial angle and aesthetics: a quantitative investigation of idealized and normative values. *Maxillofac Plast Reconstr Surg*. 2017;39:4.
29. Li M, Lin X, Xu Y. The application of rapid prototyping technique in chin augmentation. *Aesthetic Plast Surg*. 2010;34:172–178.
30. Rojas YA, Sinnott C, Colasante C, Samas J, Reish RG. Facial implants: Controversies and criticism. a comprehensive review of the current literature. *Plast Reconstr Surg*. 2018;142:991–999.
31. Ammirati M, Spallone A, Ma J, Cheatham M, Becker D. An anatomicosurgical study of the temporal branch of the facial nerve. *Neurosurgery*. 1993;33:1038–1044.
32. Hohman MH, Bhama PK, Hadlock TA. Epidemiology of iatrogenic facial nerve injury: A decade of experience. *Laryngoscope*. 2014;124:260–265.