Objective Assessment of Skin Flap Surgical Design for Simulation-Based Education in Facial Reconstruction

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Abstract

Introduction: Teaching and assessment of ideal surgical markings of local flaps required for optimal aesthetic and functional outcomes remains a challenge in the present era of competency-based surgical education. Simulation has gained recognition as a promising platform to complement the resource-intensive demands of competency-based education curricula. The present work provides a comprehensive overview of all biologic, prosthetic, and digital simulators proposed for training and assessment in facial local flaps, with an emphasis on each model's characteristics, costs, design/procedural skills, validation measures, and alignment with modern surgical educational paradigms. Given the lack of objective assessment tools, we utilized the bilobed flap for nasal reconstruction as a proof-of-concept for the development of an innovative objective assessment tool based on statistical shape analysis, with a focus on providing automated, evidence-based, objective, specific and practical feedback to the learner.

Methods: A systematic review of PUBMED and EMBASE databases were performed to identify all facial local flap simulators and assessment tools. Data regarding simulator design, costs, validation, learning outcomes and assessment tools was collected. Systematic reviews of the literature were performed to establish the essential cognitive processes required for optimal bilobed flap design and methods used for shape analysis. An objective assessment tool based on Procrustes statistical shape analysis was developed and performance boundaries were tested. A series of optimal and suboptimal designs generated in deliberate violation of the established ideals were then evaluated, and a four-component feedback score of *S*cale, *M*ism*a*tch, *R*otation, and *T*ranslation (SMaRT) was generated.

Results: Twenty-six facial simulators were identified including 13 benchtop, 5 animal, 5 digital and 3 alternative designs. Validation metrics were available for only 35% of simulators assessed, while no studies demonstrated skill transferability to clinical setting. Exact costs were reported for 30% of simulators. No objective assessment tools were available for the evaluation of geometric principles of local flap design. The proposed novel SMaRT assessment tool demonstrated the capacity to proportionally score a spectrum of designs (n=36) ranging from subtle to significant variations of optimal, with excellent computational and clinically reasonable performance boundaries. In terms of shape mismatch, changes in SMaRT score also correlated to intended violations in designs away from the ideal flap design.

Conclusion: A vast number of surgical simulators reported demonstrate notable educational potential; however, metrics-based validation efforts were often lacking given the absence of objective assessment tools for surgical marking. Future simulator development efforts should align simulation-based deliberate exercises with learning outcomes, and report consistently on validation measures, clinical transferability of skills and costs. This innovative educational approach could aid in incorporating objective feedback in simulation-based platforms in order to facilitate deliberate practice in flap design. Furthermore, the present assessment tool has the potential to be adapted to other fields of plastic surgery and to automatize assessment processes.

Résumé:

Introduction: L'enseignement et l'évaluation des marquages chirurgicaux pour lambeaux locaux requis pour des résultats esthétiques et fonctionnels optimaux demeurent un défi dans l'éducation et la formation chirurgicale. La simulation a gagné en reconnaissance en tant que plate-forme prometteuse pour contribuer à adresser les exigences des curriculums d'enseignement qui demandent beaucoup de ressources. La présente étude fournit un aperçu complet de tous les simulateurs numériques, biologiques et prothétiques chirurgicaux proposés pour la formation et l'évaluation des lambeaux de reconstruction faciale locaux tout en mettant l'accent sur les caractéristiques importantes de chaque modèle, des coûts, des compétences en conception/procédure, des mesures de validation ainsi que de l'alignement; le tout en harmonisation avec l'éducation chirurgicale moderne. Compte tenu du manque d'outils objectifs d'évaluation en matière d'éducation et de formation chirurgicale, nous avons utilisé le lambeau bilobé pour la reconstruction nasale comme preuve de concept afin de développer un outil d'évaluation innovateur basé sur une analyse statistique de la forme en portant une attention particulière sur la rétroaction spécifique et pratique à l'étudiant.

Méthodes: Une revue systématique des bases de données PUBMED et EMBASE a été réalisée afin d'identifier tous les simulateurs de lambeaux de reconstruction faciale ainsi que les différents outils d'évaluation. Les données concernant les coûts, la progression de l'apprentissage, la validation du fonctionnement du simulateur ainsi que les divers outils d'évaluation disponible ont été recueillies. Des revues systématiques de la littérature ont été effectuées afin d'établir les processus cognitifs essentiels requis pour une conception optimale des lambeaux bilobés et des méthodes utilisées pour l'analyse de la forme. Un outil objectif d'évaluation basé sur l'analyse statistiques de la forme de Procrustes a été développé et les limitations de la performance ont été

testées. Une série de conceptions considérées optimales et sous-optimales générées volontairement en violation de la méthode idéale ont ensuite été évaluées, puis un pointage de quatre composantes de magnitude, de discordance, de rotation et de translation (*S*cale, *M*ism*a*tch, *R*otation, and *T*ranslation - SMaRT) a été conçu.

Résultats: Vingt-six (26) simulateurs faciaux ont été identifiés, dont treize (13) de paillasse, cinq (5) animaux, cinq (5) numériques et trois (3) de conception alternative. Les paramètres de validation n'étaient disponibles que pour 35% des simulateurs évalués, alors qu'aucune étude n'a démontré la transférabilité des compétences en milieu clinique. Les coûts exacts ont été rapportés pour 30% des simulateurs. Aucun outil objectif d'évaluation n'était disponible pour l'appréciation des principes géométriques de la conception de lambeau local. Le nouvel outil d'évaluation SMaRT proposé a démontré la capacité de noter proportionnellement un spectre de conceptions (n = 36) allant de variations subtiles à significatives par rapport à la conception optimale, avec d’excellentes performances par rapport à l’analyse informatique et aux limites pratiques raisonnables. En termes d'inadéquation de la forme, les changements de pointage SMaRT étaient également corrélés aux violations intentionnelles dans les conceptions éloignées de la conception idéale du lambeau.

Conclusion

Un grand nombre de simulateurs chirurgicaux rapportés démontrent un potentiel éducatif non-négligeable. Toutefois, les efforts de validation basés sur des paramètres objectifs faisaient souvent défaut étant donné l'absence d'outils d'évaluation a l’égard du marquage chirurgical. Les futurs efforts de développement et\ou conception de simulateurs devraient se concentrer sur les exercices délibérés basés sur des résultats d'apprentissage afin de rendre compte de manière cohérente des mesures de validation, et de la transférabilité clinique des compétences et des coûts. Cette approche pédagogique innovante pourrait aider à intégrer une rétroaction objective par le biais des plates-formes de simulation visant à faciliter une pratique délibérée dans la conception de lambeaux. Par ailleurs, le présent mécanisme d'évaluation a le potentiel d'être adapté à d'autres domaines de la chirurgie plastique afin d’automatiser les processus d'évaluation.

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Contribution of Authors:

Mehrad Mojtahed Jaberi designed the project and developed the surgical design assessment tool. He was responsible for data collection and analysis. Finally, he was responsible for writing up and revising the manuscripts as well as the thesis.

Dino Zammit and **Becher Alhalabi** aided in concept development and editing of the manuscripts.

Yehuda Chocron, Hassan El-Hawary and **Jad Abi-Rafeh** aided in the literature review and in editing the manuscripts.

Dr. Mirko Gilardino supervised the project and aided in concept design, drafting and revision of manuscripts.

__Chapter 1__ - Introduction

Re-evaluating the Role of Simulation in Local Flap Education

Surgical education has experienced a major shift from the conventional apprenticeship-based model to an objective competency-based model. Plastic surgery is one of the fields pioneering simulation-based education, with the development of various simulators such as breast, cleft lip, cleft palate, rhinoplasty and craniosynostosis surgeries.[1] With increasing technological capacities, surgeons and educators are designing countless novel simulators ranging from high-fidelity bench top models to advanced virtual reality systems.[2,3] There remain advantages and disadvantages to each model regarding fidelity, reliability, feasibility, and validity, which would determine the characteristics of an ideal simulator. In order to justify cost effective implementation, simulators should be paired with validated assessment tools and demonstrate transferability of skills to clinical scenarios.[4,5] In this thesis, we critically reviewed the simulation efforts in the domain of design of local flaps in facial reconstruction and address the areas in need of improvement according to modern surgical educational standards.

A flap is tissue that is transferred from a donor site to a defect at recipient site while maintaining its own blood supply. Local flaps, as opposed to distant flaps, are transferred from an area adjacent to the defect. Facial reconstruction of cutaneous defects commonly resulting from cancer tumor excision is frequently performed using local flaps as they provide excellent colour and texture match[6]. Ideal surgical marking of local flaps is required for optimal aesthetic and functional outcomes. Teaching and assessment of the cognitive processes required for optimal design remains a challenge in the present era of competency-based surgical education.[7,8] Previously several facial local flap simulation models have been described in the plastic surgery, dermatology, and otolaryngology literature. However, as comprehensively reviewed in the following chapter, we have noted that reports primarily act as proof of principal concepts and lack in rigorous systematic validation; thus, their educational value has not been verified with objective data. Particularly, the degree of transferring the skills acquired by using the simulator to a clinical scenario regarding flap design has not been studied vigorously in the literature.

The overarching goal of this research is to critically assess our current understanding of education of local flaps and to advance the field by proposing an assessment tool which provides the groundwork for incorporation of objective feedback in simulation-based platforms to facilitate deliberate practice of surgical design. Such an approach has the potential to be adapted to other fields of plastic surgery to automatize surgical design assessment processes.

<u>Chapter 2</u> - *Manuscript 1*

Simulation-based Education of Local Facial Flaps: The Current State and Future Perspectives

Running Head: Local Facial Flaps Simulators Literature Review

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Abstract

BACKGROUND: Achieving competency in the selection, design, and execution of various local facial flaps remains a challenge for trainees. Simulation has gained recognition as a promising platform to complement the resource-intensive demands of competency-based education curricula. The present article provides a comprehensive overview of all biologic, prosthetic, and digital simulators proposed for training and assessment in facial local flaps, with an emphasis on each model's characteristics, costs, design/procedural skills, validation measures, and alignment with modern surgical educational paradigms.

METHODS: A systematic review of PUBMED and EMBASE databases were performed to identify all facial local flap simulators and assessment tools. Data regarding simulator design, costs, validation, learning outcomes and assessment tools was collected.

RESULTS: Twenty-six facial simulators were identified including 13 benchtop, 5 animal, 5 digital and 3 alternative designs. Validation metrics were available for only 35% of simulators assessed, while no studies demonstrated skill transferability to clinical setting. Exact costs were reported for 30% of simulators. No objective assessment tools were available for the evaluation of geometric principles of local flap design.

CONCLUSION: A vast number of surgical simulators reported demonstrate notable educational potential; however, metrics-based validation efforts were often lacking given the absence of objective assessment tools for surgical marking. Future simulator development efforts should align

simulation-based deliberate exercises with learning outcomes, and report consistently on validation measures, clinical transferability of skills, and costs. Adoption of objective assessment tools for local flap geometric designs is essential to realize the full potential of simulation-based education in facial reconstruction.

Introduction

The present state of surgical education allows residents to acquire knowledge of various local facial flap designs from a variety of sources, however, attaining expertise in the field of reconstructive plastic surgery remains a challenge due to numerous factors. Learning the intricacies for facial aesthetic unit reconstruction, within the complex three-dimensional (3D) anatomy of the face, based on traditionally two-dimensional (2D) resources such as textbook illustrations, requires a high level of spatial awareness and reasoning.[1] Although the geometrics of local flaps are easy to illustrate, the cognitive process required for optimal flap design is sophisticated and complex, and does not lend itself to being taught effortlessly.[2] Factors such as patient referral patterns for head and neck reconstruction shared among several subspecialties, as well as resident work hours restrictions, have limited residents' clinical exposure to facial reconstruction.[3,4] Furthermore, these procedures are routinely performed under local anesthesia on awake patients, which influences optimal teaching conditions for novice trainees.[5]

A well-planned and executed local flap can lead to excellent functional and cosmetic outcomes, with minimal distortion of surrounding facial anatomical landmarks, resulting in high patient satisfaction.[6] Facial cutaneous defects and scars can be tremendously disfiguring and impair function leading to significant psychosocial distress.[7,8] Education of local flap design for facial reconstruction thus remains a crucial, challenging portion of plastic surgery residency curriculums. Simulation-based education is now recognized as a promising platform to complement the resource intensive demands of the emerging competency-based education (CBE) curriculums progressively adopted in North American plastic surgery programs.[9,10] Simulation provides residents with the opportunity to familiarize themselves with essential steps of a specific surgical task of progressive complexity in a safe, structured manner.[11] Deliberate practice is defined as the purposeful and systematic exercise that requires focused attention and is conducted with the specific goal of improving performance.[12] Whereas traditional procedural simulators require the trainee to complete the simulation in its entirety, deliberate practice allows for repeatedly practicing a specific set of steps until trainees acquire competency, through constant assessment and feedback, which can then allow for immediate modification of surgical technique.[13] This approach has been proven effective for transferability of specific skills to the operating room.[13-15] In the context of facial reconstruction, essential tasks include procedural skills for flap elevation and suturing ,as well as, cognitive skills such as defect analysis, aesthetic subunit analysis, appropriate flap selection and optimal design according to geometric principles in relation to relaxed skin tension lines (RSTL), tissue laxity, aesthetic subunits and resultant scars.

With validated assessment tools and appropriate simulator feedback, residents can perform deliberate practice, address specific shortcomings and ultimately achieve expert performance.[16] Achieving competency on simulators allows for the progression of residents on the learning curve in preparation for the next valuable yet limited clinical exposure. As many new simulators are being developed, educators remain critical of evidence supporting their validity and cost-effectiveness.[17] It therefore remains essential that simulator developers and surgical educators in plastic surgery be familiarized with the most recent developments and best practices in the domain of simulation-based surgical education. In the present study, the authors set to review the different types of facial flap simulators presently available in the literature, highlight strengths and limitations of each, and classify and contrast them according to type, cost, validation metrics, and learning outcomes measured. According to modern principles of simulation-based surgical education, the authors aim to highlight specific features that future simulators should ideally possess, with a focus on concepts such as proficiency-based, distributed deliberate practice, validation, formative feedback, objective assessment tools, and curriculum implementation.

Methods

The PubMed and EMBASE databases were queried to identify all publications relating to facial flap simulators from database inception until May 2020. This was done using variations of the search terms “facial surgery”, “local flap”, “simulation”, and “surgical education”. A combination of both MeSH terms and keywords were used. A separate search was conducted to evaluate for the presence of any objective assessment tools for evaluating trainee performance in local flap design, on facial local flap simulators or otherwise. This was performed using variations of the following search terms: (local flap*) AND (marking* OR design*) AND (skill* OR train* OR competenc* OR educat* OR simulat* OR assess*).

The search and screening process strictly adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[18] Inclusion criteria consisted of studies that reported on facial flap simulators for training purposes or assessment tools for any local flap design. Exclusion criteria consisted of articles written in a language other than English or French, as well as articles describing non-facial flap simulators, non-cutaneous flap simulators.

Results

The initial search strategy yielded 191 articles; citations were manually checked, and 40 relevant references were added. Following removal of duplicates, the search culminated in a total of 210 articles for evaluation. Titles and abstracts were screened initially for relevance by two independent evaluators, and 40 records were assessed by full-text review. A total of 23 articles were deemed eligible for inclusion, according to the specific inclusion and exclusion criteria (**Figure 1**).[19-41] Twenty-six different local facial flap simulators were identified; these were stratified and analyzed according to specific categories including bench-top (n=13), animal (n=5), digital (n=5), and alternative design models (n=3). (**Figure 2).**

Twenty models (77%) supported procedural skill simulation, such as flap raising and suturing; 18 models (69%) allowed for 3D design of local flaps, while 12 simulators (46%) allowed for ideal facial aesthetic subunit analysis. Of note, four simulators (15%) allowed for digital manipulation of flaps to visualize tissue movement. Validation metrics were available for 9/26 simulators evaluated (35%); seven simulators demonstrated content validity (78%), one face validity (10%), and one construct validity (10%). None of the simulators evaluated demonstrated predictive validity. Only one study evaluated specific learning outcomes on the simulator described,[31] and exact cost was reported on for eight simulators (30%).

Bench-top models

Thirteen (50%) bench top models for facial flap simulation were identified; 6 models (46%) were validated, including 5 that demonstrated content validity and one that demonstrated construct validity. Six models (46%) reported on costs ranging from less than $10, to $200; two additional simulators were described as "cheap". None of the studies evaluated learning outcomes following simulation-based training. All models supported procedural skill simulation; ten models (77%) supported 3D simulated flap design, and seven models (54%) allowed for simulated facial aesthetic subunit analysis (**Table 1**).

Animal models

Five (19%) animal models for facial flap simulation were identified; validation metrics were available for only one model, which demonstrated content validity. Cost was reported on for two models as less than $10, and "cheap". Learning outcomes were not assessed; all provided support for 3D design tasks and procedural skill simulation, however, none allowed for simulated facial aesthetic subunit analysis given anatomic differences. (**Table 2**).

Digital models

Five (19 %) digital facial flap simulators were identified. Validation metrics were not available for any of the models assessed. Cost was reported on for only one model as $2100. Learning outcomes were evaluated for only one simulator, in which trainees demonstrated significantly higher anatomical and procedural knowledge following simulator training, relative to control textbook learners.[31] Overall four simulators (80%) used finite element analysis to simulate skin manipulation during local flap surgery, but none provided simulation of procedural skills. Three studies (60%) allowed for 3D design of local facial flap, and all models supported facial aesthetic subunit analysis. (**Table 3**).

Alternative models

Three simulators (11.5%) identified did not fit within any of the aforementioned categories and thus classified as alternative designs. The first consisted of chilled, unrolled pastry rolls to allow trainees to excise creating 'defects' and preforming different forms of local facial flaps.[23] No assessments of validation metrics or learning outcomes were provided, and cost was reported on as 'cheap'. The second consisted of laminated pictures of real-life defects that were used to practice 2D flap design.[19] This simulator demonstrated content validity; cost was not specified nor were learning outcomes assessed. The third consisted of a hand-held projector, which projects outlined flap markings on human cadavers. This allowed trainees to perform 3D flap design, with overlay comparison with a reference design. This simulator supported aesthetic subunit analysis, and trainees were able to practice procedural skills. Face validity was established; however, exact cost was not reported (**Table 4**).

Objective Assessment Tools for Local Flap Design

The search strategy for the identification of objective assessment tools for local flap designs yielded 275 articles, of which, 14 were assessed by full-text review. (**Figure 2).** Only one study reported on flap geometric design principles, however, this was subjective, and performed according to an expert's evaluation and grading using a Likert scale. Two additional studies reported on flap design assessment but did not provide any elaboration on how this was performed. Overall, no objective assessment tools were available in the literature for local flap design (**Table 5**).

Discussion

With the advent of modern paradigm shifts in surgical education, it remains essential to critically assess and optimize educational strategies in plastic surgery. There has been a transition away from the traditional Halstedian approach of time-based apprenticeship, and the "see one, do one, teach one" model has given way to competency-based medical education (CBE)[42,43,44]. Residency programs continue to strive to align their training curricula with specific learning objectives in efficient and cost-effective manners. However, deployment of CBE within post-graduate education is expected to increase one-on-one time requirements with attending physicians, and potentially contribute to assessor burnout.[45] Simulation has gained notable recognition for its role as an effective training and assessment modality in the present era of CBE.[11] By leveraging emerging technologies and simulators of the highest educational standards, post-graduate curricula can come to truly capitalize on the benefits of milestones-based curricula.[46-49] The present study demonstrated that a vast number of surgical simulators continue to be developed for facial reconstruction, using different technologies and innovative approaches with notable educational potential, however, metrics-based validation efforts and assessment of learning outcomes were often lacking. Notably, there was a paucity of objective assessment tools for local flap design, which arguably remains the most challenging step to master. The absence of rigorous follow-up studies demonstrating the acquisition, retention and transferability of skills learned following simulation-based training also remain significant barriers for cost-effective wide-scale implementation.[50-52]

In simulation research, validation measures assess a simulator's functionality and effectiveness in teaching what it intends to teach, and, there exist both objective and subjective metrics.[53] Subjective measures of validation include face and content validities;[51] face validity refers to how realistic a simulator is to real life, while content validity refers to how well the simulator allows the trainee to reach his/her objective.[53] Construct, concurrent and predictive validity represent objective validation measures. Construct validity refers to the ability of a simulator to differentiate between performance of a novice and expert;[54] concurrent validity compares new simulators to previous 'gold standards', while predictive validity refers to a simulator's ability to predict future trainee performance based on performances on the simulator. Concurrent, predicative, and construct validity are widely believed to be three of the most important validity assessments for simulators.[53] However, as demonstrated in the present study, simulation-based literature remains often devoid of evidence-based validation efforts, limited to participant feedback regarding realism and confidence levels, survey tests of theoretical knowledge, and subjective evaluation by study members – all of which are legitimate, but not rigorous tools for concluding on the effectiveness of a simulator as an educational resource.[10,11] Additionally, across the plastic surgery specialty, there exists a need for systematic and standardized assessment tools to evaluate competency in particular procedures, with applicability in both simulated and true clinical settings.[55] In the context of simulation-based medical education, the latter has been deemed to be a significant barrier for the ubiquitous implementation of simulation-based training in post-graduate curricula.[56] In the context of facial local flaps, an added challenge represents identifying cut-offs for acceptable local flap designs, which, despite small degrees of variability, would still culminate in similar clinical outcomes.

In the present study, the most common type of facial flap simulators identified were bench-top models, representing 50% of simulators assessed. Bench-top simulators demonstrated marked versatility and different designs according to specific factors. These included the targeted learning objectives, education level of trainees, availability of materials used, as well as cost constraints. Optimal benchtop simulator design was found to represent a balance between complexity in design and cost limitations, with the goal of best fulfilling the learning objectives targeted for a specific group of trainees. Furthermore, an added advantage of bench-top prosthetic models is the potential for repeated use within reasonable additional cost.[57] This encourages deliberate practice among trainees until desired competencies are reached. However, none of the studies assessed discussed training schedules necessary to achieve competency, or highlighted potential use for deliberate practice.[13] With validation metrics only available for 46% of benchtop simulators evaluated, and absence of studies demonstrating transferability of acquired skills into clinical settings, the educational utility and cost-effectiveness of bench-top simulators relative to other available options remains elusive.

A recent systematic review of animal model simulators in plastic surgery suggested that the ideal animal model accurately mirrors the simulated clinical situation, is easily accessible, simple to set up, and the use of which remains humane and ethical to animals.[58] Indeed, it is widely accepted that live animal models tend to have higher fidelity relative to prosthetic or cadaveric simulators, potentially better-simulating real life clinical situations.[59] Although commonly considered the 'gold standard' in simulation, several ethical, financial, and accessibility issues persist with animal models use.[11] Furthermore, anatomical differences between human and animal skin that may affect engineering fidelity.[60] Given the facial morphologic differences between animals and humans, persistent ethical issues, cost of maintenance, and current lack of validation efforts, animal models evaluated in the present study may be less appealing for facial flaps education.

Digital simulators use innovative technology and software to create virtual environments and allow for the simulation of complex and intricate maneuvers, such as manipulating tissue in facial reconstruction.[60] Similar to bench-top models, digital models from other surgical domains have demonstrated notable skill acquisition and transferability to real clinical situations.[46,61,62] With rapid developments in Virtual Reality (VR) technology, it remains without a doubt that VR simulators have a growing role to play in surgical education with potential to provide extremely high-fidelity simulations that capture intricate anatomical details, and are completely reusable. However, one of the major challenges of VR models is modelling alteration of skin geometry and topology in response to force.[63] Another limitation is the costly component of providing realistic haptic feedback to the user, which remains an important component of engineering fidelity to consider. In the context of facial local flaps in particular, the relevance of haptic feedback may be insignificant for training of geometric design principles, but more beneficial for simulating procedural skills. Additional drawbacks include the high cost for development and maintenance[30,64]. Given that the clinical transferability of skills from VR remains to be established in facial local flap education, their utility may thus presently be limited for post-graduate training programs seeking to address educational gaps and complement clinical teaching for specific surgical skills in cost-effective manners. It could be argued that well-designed, low-fidelity, step-specific simulators could be more effective in terms of goal-directed learning and resource management than a fully immersive but costly VR experience.[65,66] Further research is warranted to establish whether 3D design tasks provide any added benefit relative to 2D design tasks in facial local flaps simulation.

To complement the ongoing transition away from traditional textbook-based learning resources, the present study demonstrated that simulators have rapidly evolved to allow for “hands on” experience and deliberate practice of principles learned both safely and effectively.[60,67,68] For local facial flaps, simulators assessed demonstrated marked potential for residents and medical trainees to develop the surgical judgement necessary to design optimal flaps and practice different techniques before preforming them on patients.[69] Additionally, simulators provide the opportunity for standardized, formative feedback with summative assessments, which could effectively complement new competency-based curricula.[10] Transferring the burden of providing formative feedback from the experts to simulators using objective, validated assessment tools could alleviate the need for extensive resources, reduce assessor burnout and allow the trainee to perform deliberate practice on one’s desired schedule.[70] However, as demonstrated in the present analysis, only three studies reported on assessment efforts, and the literature remains devoid of objective assessment tools for evaluation cognitive skill acquisition or retention in facial local flap design. Despite principles for optimal simulation-based education such as proficiency-based, distributed, and deliberate practice having been acknowledged, massed training with fixed time intervals is still extensively used.[71] To realize their full potential, local facial flap simulators should be ideally integrated alongside clinical practice and allow for independent learning via deliberate practice, with objective, formative feedback available in a non-judgmental environment without the need for supervisor involvement.

Future Directions

With recent advances in artificial intelligence, machine learning, and statistical shape analysis, development of objective assessment tools capable of providing unsupervised, timely feedback to trainees on local flap design principles for given defects would be ideal, in order to facilitate deliberate practice efforts and validate available simulators.[72] Indeed, the latter two points are of particular interest to our group and the subject of ongoing studies. As financial resources for education are increasingly scarce, reporting on one-time setup costs and recurring costs per use should become standard of practice when describing new simulators. Finally, it remains essential that rigorous follow-up studies are performed on all simulators developed in order to demonstrate the acquisition, retention and transferability of skills learned, to guide wide-scale implementation.

Conclusions

This article provides a comprehensive and critical overview of the current status of local facial flap education in plastic surgery. Different types of simulators have been developed, each with associated advantages and drawbacks; however, consistently, there existed a paucity of strict validation measures. Costs reporting remains poor, and no studies have demonstrated clinical transferability of skills learned, representing barriers to wide-scale adoption. The lack of high-level research in this domain is likely due to the fact that, currently, no validated assessment tools for surgical markings of local flaps exist. In order to effectively train the next generation of plastic surgery residents, future simulator developers and researchers should be familiarized with current developments and best practices in the domain of surgical education, including deliberate practice, aligning simulation exercises with learning outcomes, regardless of fidelity, and improving research practices to consistently report on costs, transferability of skills, and validity measures, for both simulators and assessment tools developed.

Figure 1 – Systematic search strategy to identify local flap simulators in facial reconstruction

PRISMA Flow Diagram

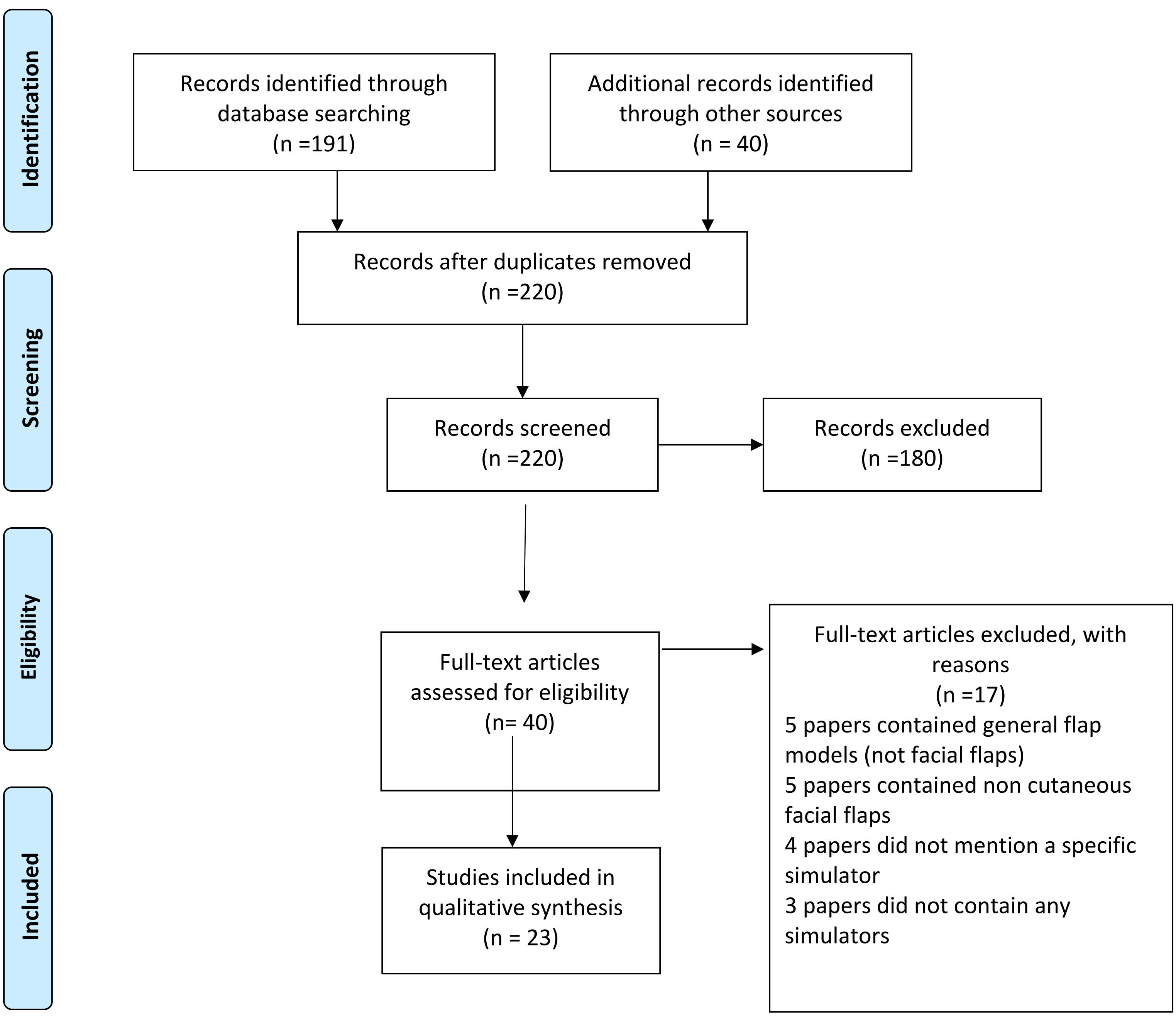
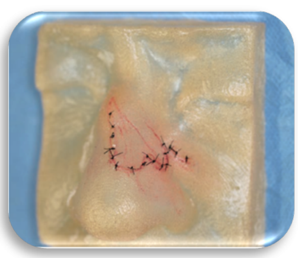


Figure 2: Types and frequency of facial flap simulators. (Courtesy of Ueda K, Shigemura Y, Otsuki Y, Fuse A, Mitsuno D. Three-Dimensional Computer-Assisted Two-Layer Elastic Models of the Face. *Plast Reconstr Surg.* 2017;140(5):983-986. Courtesy of Bauer F, Koerdt S, Rommel N, Wolff K-D, Kesting MR, Weitz J. Reconstruction of facial defects with local flaps – a training model for medical students? *Head & Face Medicine.* 2015;11:30. Courtesy of Mitchell NM, Cutting CB, King TW, Oliker A, Sifakis ED. A Real-Time Local Flaps Surgical Simulator Based on Advances in Computational Algorithms for Finite Element Models. *Plastic and Reconstructive Surgery.* 2016;137(2):445e-452e. Courtesy of Ali FR, Ghura V. PERFECT-ing technique prior to facial reconstructive surgery: a convenient, inexpensive aid to dermatologic surgical teaching. *Journal of the American Academy of Dermatology.* 2014;71(5):e203-204. Reproduced with permission)

Simulator Type	***Number***	***Example***
Benchtop	13	
Animal	5	

Digital	5	
Alternative	3	

Table 1: Bench top models' characteristics

Study	*Description of simulator*	*Support for:* Design Task Simulation	*Support for:* Aesthetic Subunit Analysis Simulation	*Support for:* Procedural Skills Simulation	*Validation*	*Cost*
Chipp et al., 2011, [24]	Plaster model of a face cover by layered dressings e.g. Mefix (periosteum), Microfoam (skeletal muscle), Allevyn (dermis epidermis)	3D	Fair	Yes	Content validity	Not reported
Davis et al., 2014, [25]	Foam positioned on a skull using Velcro pads	2D	No	Yes	None	"cheap"
Gurerrero-Gonzalez et al., 2016, [26]	A high-fidelity 3D model of a head bust model (IL Duomo, DermSurg Scientific) paired with head mounted video-camera (GoPro, Inc., San Mateo, CA, US) from expert surgeon's perspective for reference.	3D	Excellent	Yes	None	Not reported

Kite et al., 2018, [29]	Foam core base overlaid with multiple silicone layers to form a flat model of the skin	2D	No	Yes	Content validity	150 $
Kite et al., 2018, [29]	Foam core base overlaid with multiple silicone layers molded into a 3D shape of face	3D	Excellent	Yes	Content validity	200$
Nicolaou et al., 2006, [32]	Styrene mannequin head covered with cling film. Drawing pins are inserted onto to simulate raised lesions	3D	Excellent	Yes	None	“cheap”
Okamoto et al., 2018, [33]	3D printed 2 layered silicon and polyurethane model of the face that allows defect creation.	3D	Excellent	Yes	None	Not reported
Powell et al., 2019, [41]	3D printed layered silicone model of the face using 3D CT scan data. A 3mm depth of skin and 6 mm depth of fat.	3D	Excellent	Yes	Content validity	8.14$ for each flap used

Ross et al., 2003, [35]	Mannequin head covered with a disposable chamois cloth to simulate the skin on the face	3D	Poor	Yes	None	<10$
Sajan et al., 2013, [36]	3D organosilicate model of a human face	3D	Not reported	Yes	Construct validity	Not reported
Taylor et al., 2016, [38]	An expanded polystyrene foam head used as mold and covered with modeling clay. The clay was sculpted to include facial features. Gelatin and Mesh were added to the model to simulate the skin	3D	Excellent	Yes	Content validity	40$
Ueda et al., 2017, [39]	3D printed 2 layered silicon and polyurethane elastic model of the face that allows defect creation.	3D	Excellent	Yes	None	66$
Villafane et al., 1999, [40]	Patented material used as skin attached to a plastic box.	2D	No	Yes	None	Not reported

Table 2: Animal models' characteristics

Study	*Description of simulator*	*Support for*			*Validation*	*Cost*
		Design Task Simulation	*Aesthetic Subunit Analysis Simulation*	*Procedural Skills Simulation*		
Bauer et al., 2015, [20]	Pig head	3D	Poor	Yes	None	Not reported
Bretan et al., 2005, [21]	Dog head	3D	Poor	Yes	None	Not reported
Chan et al., 2010, [22]	Chicken skin draped over plastic mask secured with pins	3D	Poor	Yes	None	<10$
Hassan et al., 2014, [27]	Porcine skin draped over mannequin head secured with pins	3D	Poor	Yes	None	Not reported
Isaacson et al., 2014, [28]	Turkey thigh	3D	No	Yes	Content validity	"cheap"

Table 3: Digital models' characteristics

Study	*Description of simulator*	*Support for:*			*Validation*	*Cost*
		Design Task Simulation	*Aesthetic Subunit Analysis Simulation*	*Procedural Skills Simulation*		
Gurerrero-Gonzalez et al., 2016, [26]	Interactive touch screen white board with pictures of real faces with lesions.	2D	Excellent	No	None	Not reported
Mitchell et al., 2016, [30]	Finite-Element digital 3D figures of different heads with different lesions, Finite-Element	3D	Excellent	Digital manipulation of flap	None	2100$
Naveed et al., 2018, [31]	Online educational model on an iPad which shows defects on a mannequin face and the different markings for local flaps accompanied with educational module.	3D	Excellent	Digital manipulation of flap	None	Not reported

Pieper et al., 1995, [34]	Finite-Element digital 2D photos of patients' faces for Z-plasty	2D	Fair	Digital manipulation of flap	None	Not reported
Pieper et al., 1995, [34]	Finite-Element digital 3D face model created from CT and MRI data.	3D	Fair	Digital manipulation of flap	None	Not reported

Table 4: Alternative models' characteristics

Study	*Description of simulator*	*Support for skill*			*Validation*	*Cost*
		Design Task Simulation	*Aesthetic Subunit Analysis Simulation*	*Procedural Skills Simulation*		
Ali et al 2014, [19]	Pictures of real facial defects are taken and laminated (plasticized). Trainees draw surgical markings for the flaps	2D	Excellent	No	Content validity	Not reported

Chawdhary et al., 2014, [23]	Chilled pastry rolls are unrolled and used as skin. Defects are drawn on the rolls.	2D	No	Yes	None	“cheap”
Sayadi et al., 2018, [37]	A hand-held projector projects mathematically outlined flap markings on human cadavers.	3D	Excellent	Yes	Face validity	Not reported

Figure 3 – systematic search strategy to identify objective assessment tools in education of local flap designs

PRISMA Flow Diagram

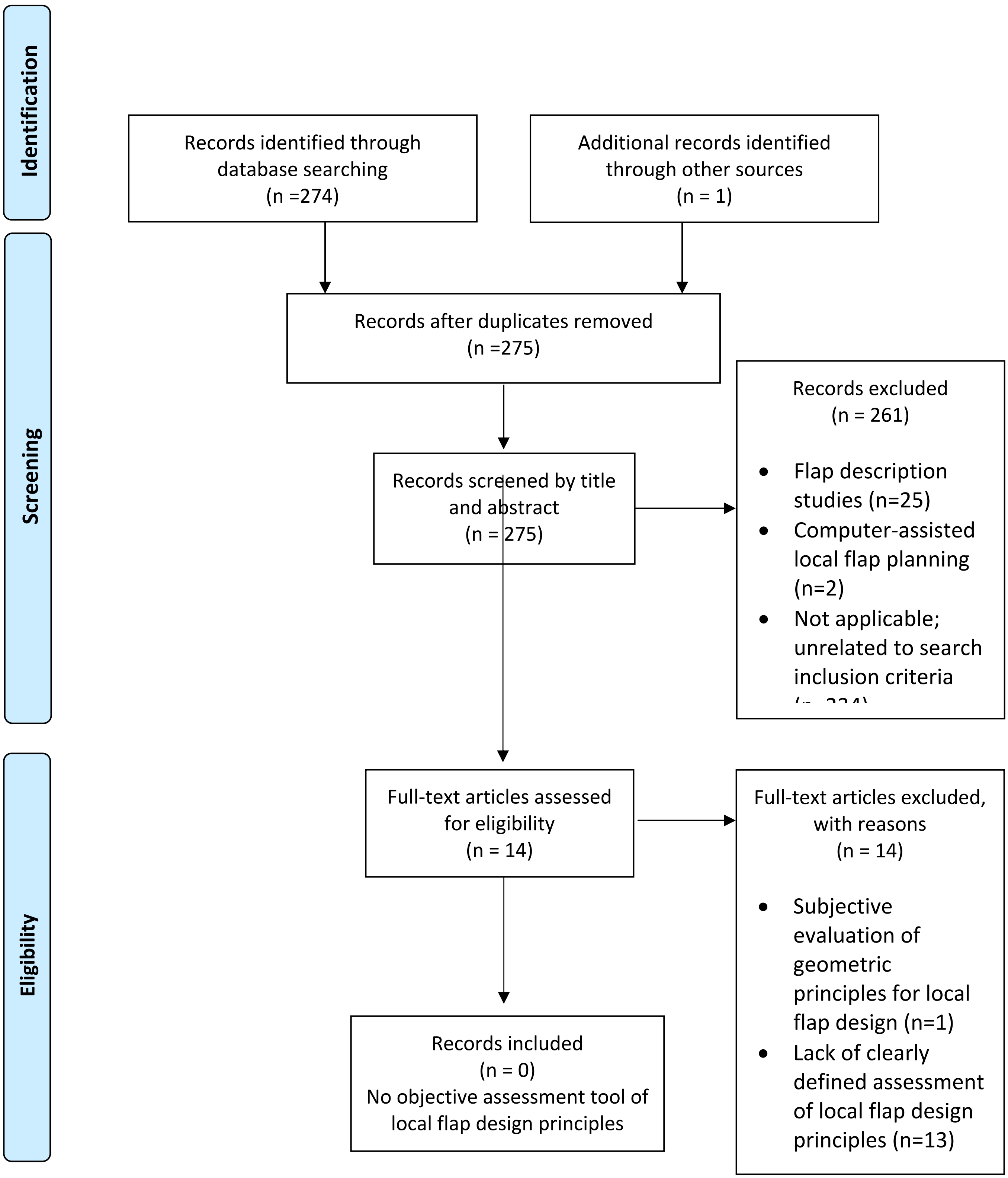


Table 5: Assessment Tools for Local Flap Design – No objective assessment tools for local flap design were identified in the literature.

Study	***Assessment Tool***	***Associated Training Tool***	***Trainees***	***Assessors***	**Objectivity**
Naveed et al., 2018, [31]	Subjective assessment of concepts geometric principles on a Likert scale (1-5) as an item in a Modified OSATS for assessment of local flap design and procedural skills: 1- Plans the flap inappropriately with no concept of geometry 3- Largely pertains to the geometry of rotational or advancement flaps	Online educational model on an iPad, which shows defects on a mannequin face and the different markings for different local flaps Explanation for each flap is included	Medical Students	Expert plastic surgeon	Subjective

	5- Exceptional local flap design with good understanding of applicable geometry				
Sayadi et al., 2018, [37]	Assessment tool unspecified in detail e.g. The hand-drawn bilobed flap had a 20 percent and 50 percent “deviation”, respectively, in the primary and secondary lobes when “compared” to published theoretical parameters	A hand-held projector projects mathematically outlined flap markings on cadavers. Trainees can these markings as guidelines to learn the flap markings	Expert plastic surgeon	Not specified	Not specified
Sajan et al., 2013, [36]	Assessment tool unspecified in detail e.g. reviewers "rated" two drawings and one scar revision per trainee.	A 3D organosilicate model of a human adult face, built with a	Residents	three blinded reviewers	Not specified

		corresponding 2D paper model			

References:

1. Shepherd L. Practical sculptural training for the plastic surgeon. Int J Surg 2005;3:93-7.

2. Croley JA, Malone CH, Goodwin BP, Phillips LG, Cole EL, Wagner RF. Mohs Surgical Reconstruction Educational Activity: a resident education tool. Adv Med Educ Pract 2017;8:143-7.

3. Ahmed N, Devitt KS, Keshet I, et al. A systematic review of the effects of resident duty hour restrictions in surgery: impact on resident wellness, training, and patient outcomes. Ann Surg 2014;259:1041-53.

4. Pattani R, Wu PE, Dhalla IA. Resident duty hours in Canada: past, present and future. CMAJ 2014;186:761-5.

5. Smith CS, Guyton K, Pariser JJ, Siegler M, Schindler N, Langerman A. Surgeon-patient communication during awake procedures. American journal of surgery 2017;213:996-1002 e1.

6. Chren MM, Sahay AP, Bertenthal DS, Sen S, Landefeld CS. Quality-of-life outcomes of treatments for cutaneous basal cell carcinoma and squamous cell carcinoma. J Invest Dermatol 2007;127:1351-7.

7. Essers BA, Nieman FH, Prins MH, Krekels GA, Smeets NW, Neumann HA. Determinants of satisfaction with the health state of the facial skin in patients undergoing surgery for facial basal cell carcinoma. Patient Educ Couns 2006;60:179-86.

8. Dobbs TD, Samarendra H, Hughes S, Hutchings HA, Whitaker I. Patient reported outcome measures for facial skin cancer: A systematic review and evaluation of the quality of their measurement properties. Br J Dermatol 2018.

9. Kazan R, Gilardino MS. Commentary on: Simulation: An Effective Method of Teaching Cosmetic Botulinum Toxin Injection Technique. Aesthetic surgery journal 2018;38:NP213-NP5.

10. Kazan R, Cyr S, Hemmerling TM, Lin SJ, Gilardino MS. The Evolution of Surgical Simulation: The Current State and Future Avenues for Plastic Surgery Education. Plast Reconstr Surg 2017;139:533e-43e.

11. Abi-Rafeh J, Zammit D, Mojtahed Jaberi M, Al-Halabi B, Thibaudeau S. Nonbiological Microsurgery Simulators in Plastic Surgery Training: A Systematic Review. Plast Reconstr Surg 2019;144:496e-507e.

12. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. Acad Med 2004;79:S70-81.

13. Zammit D, Safran T, Ponnudurai N, et al. Step-Specific Simulation: The Utility of 3D Printing for the Fabrication of a Low-Cost, Learning Needs-Based Rhinoplasty Simulator. Aesthet Surg J 2020;40:Np340-np5.

14. Kurashima Y, Feldman LS, Kaneva PA, et al. Simulation-based training improves the operative performance of totally extraperitoneal (TEP) laparoscopic inguinal hernia repair: a prospective randomized controlled trial. Surg Endosc 2014;28:783-8.

15. Fried GM, Feldman LS, Vassiliou MC, et al. Proving the value of simulation in laparoscopic surgery. Ann Surg 2004;240:518-25; discussion 25-8.

16. Ericsson KA. Deliberate practice and acquisition of expert performance: a general overview. Acad Emerg Med 2008;15:988-94.

17. Kneebone RL, Scott W, Darzi A, Horrocks M. Simulation and clinical practice: strengthening the relationship. Medical education 2004;38:1095-102.

18. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med 2009;6:e1000100.

19. Ali FR, Ghura V. PERFECT-ing technique prior to facial reconstructive surgery: a convenient, inexpensive aid to dermatologic surgical teaching. Journal of the American Academy of Dermatology 2014;71:e203-4.

20. Bauer F, Koerdt S, Rommel N, Wolff K-D, Kesting MR, Weitz J. Reconstruction of facial defects with local flaps – a training model for medical students? Head & Face Medicine 2015;11:30.

21. Bretan O, Nogueira EA, Silva EF, Trindade SH. Training the osteoplastic flap technique in dogs. Brazilian journal of otorhinolaryngology 2005;71:140-4.

22. Chan W-Y, Dalal M. Cost-effective plastic surgery skills training. Journal of Plastic, Reconstructive & Aesthetic Surgery 2010;63:e136-e7.

23. Chawdhary G, Herdman R. Pastry flaps for facial plastics. Clinical otolaryngology : official journal of ENT-UK ; official journal of Netherlands Society for Oto-Rhino-Laryngology & Cervico-Facial Surgery 2015;40:509-10.

24. Chipp E, Rayatt S. The stoke flap model for training in local flap surgery. Journal of plastic, reconstructive & aesthetic surgery : JPRAS 2011;64:836-7.

25. Davis CR, Fell M, Khan U. Facial reconstruction using a skull and foam training model. Journal of Plastic, Reconstructive & Aesthetic Surgery 2014;67:126-7.

26. Guerrero-Gonzalez GA, Ocampo-Garza J, Vazquez-Martinez O, Garza-Rodriguez V, Ocampo-Candiani J. Combined use of simulation and digital technologies for teaching dermatologic surgery. Journal of the European Academy of Dermatology and Venereology : JEADV 2016;30:e175-e6.

27. Hassan Z, Hogg F, Graham K. A 3-dimensional model for teaching local flaps using porcine skin. Annals of plastic surgery 2014;73:362-3.

28. Isaacson DS, Edmonds PR, Isaacson G. The galliform (Turkey thigh) model for resident training in facial plastic surgery. The Laryngoscope 2014;124:866-8.

29. Kite AC, Yacoe M, Rhodes JL. The Use of a Novel Local Flap Trainer in Plastic Surgery Education. Plastic and Reconstructive Surgery – Global Open 2018;6:e1786.

30. Mitchell NM, Cutting CB, King TW, Oliker A, Sifakis ED. A Real-Time Local Flaps Surgical Simulator Based on Advances in Computational Algorithms for Finite Element Models. Plastic and Reconstructive Surgery 2016;137:445e-52e.

31. Naveed H, Hudson R, Khatib M, Bello F. Basic skin surgery interactive simulation: system description and randomised educational trial. Advances in simulation (London, England) 2018;3:14-.

32. Nicolaou M, Yang G-Z, Darzi A, Butler PE. An inexpensive 3-D model for teaching local flap design on the face and head. The Annals of The Royal College of Surgeons of England 2006;88:320-.

33. Okamoto T, Hirota Y, Kimura Y, Senda E, Ueda K. 3D Separable 2-layered Elastic Models of the Face for Surgical Planning of Local Flaps. Plastic and reconstructive surgery Global open 2018;6:e1857.

34. Pieper SD, Laub DR, Jr., Rosen JM. A finite-element facial model for simulating plastic surgery. Plast Reconstr Surg 1995;96:1100-5.

35. Ross GL, Price RD, Fletcher-Williams G, McGrouther DA. Manoeuvring a-head in plastic surgery. British journal of plastic surgery 2003;56:812-4.

36. Sajan JA, Hilger PA, Sidman JD, et al. Validated Assessment Tools for Reconstructing Facial Defects in Simulation. Otolaryngology–Head and Neck Surgery 2013;149:P44-P5.

37. Sayadi LR, Chopan M, Maguire K, et al. A Novel Innovation for Surgical Flap Markings Using Projected Stencils. Plast Reconstr Surg 2018;142:827-30.

38. Taylor SR, Chang CW. Gelatin Facial Skin Simulator for Cutaneous Reconstruction. Otolaryngology--head and neck surgery : official journal of American Academy of Otolaryngology-Head and Neck Surgery 2016;154:279-81.

39. Ueda K, Shigemura Y, Otsuki Y, Fuse A, Mitsuno D. Three-Dimensional Computer-Assisted Two-Layer Elastic Models of the Face. Plast Reconstr Surg 2017;140:983-6.

40. Villafane O, Southern SJ, Foo IT. Simulated interactive local flaps: operating room models for surgeon and patient alike. British journal of plastic surgery 1999;52:241.

41. Powell AR, Srinivasan S, Green G, Kim J, Zopf DA. Computer-Aided Design, 3-D-Printed Manufacturing, and Expert Validation of a High-fidelity Facial Flap Surgical Simulator. JAMA Facial Plast Surg 2019;21:327-31.

42. Polavarapu HV, Kulaylat AN, Sun S, Hamed OH. 100 years of surgical education: the past, present, and future. Bulletin of the American College of Surgeons 2013;98:22-7.

43. Kotsis SV, Chung KC. Application of See One, Do One, Teach One Concept in Surgical Training. Plastic and reconstructive surgery 2013;131:1194-201.

44. Rohrich RJ. "See one, do one, teach one": an old adage with a new twist. Plast Reconstr Surg 2006;118:257-8.

45. Holmboe ES, Sherbino J, Long DM, Swing SR, Frank JR. The role of assessment in competency-based medical education. Medical teacher 2010;32:676-82.

46. Ahlberg G, Enochsson L, Gallagher AG, et al. Proficiency-based virtual reality training significantly reduces the error rate for residents during their first 10 laparoscopic cholecystectomies. American journal of surgery 2007;193:797-804.

47. Belyea DA, Brown SE, Rajjoub LZ. Influence of surgery simulator training on ophthalmology resident phacoemulsification performance. Journal of Cataract & Refractive Surgery 2011;37:1756-61.

48. Daly MK, Gonzalez E, Siracuse-Lee D, Legutko PA. Efficacy of surgical simulator training versus traditional wet-lab training on operating room performance of ophthalmology residents during the capsulorhexis in cataract surgery. Journal of cataract and refractive surgery 2013;39:1734-41.

49. Ferlitsch A, Schoefl R, Puespoek A, et al. Effect of virtual endoscopy simulator training on performance of upper gastrointestinal endoscopy in patients: a randomized controlled trial. Endoscopy 2010;42:1049-56.

50. Kneebone R. Simulation in surgical training: educational issues and practical implications. Medical education 2003;37:267-77.

51. Schout BMA, Hendrikx AJM, Scheele F, Bemelmans BLH, Scherpbier AJJA. Validation and implementation of surgical simulators: a critical review of present, past, and future. Surgical Endoscopy 2010;24:536-46.

52. Gallagher AG, Ritter EM, Satava RM. Fundamental principles of validation, and reliability: rigorous science for the assessment of surgical education and training. Surg Endosc 2003;17:1525-9.

53. McDougall EM. Validation of surgical simulators. Journal of endourology 2007;21:244-7.

54. Evgeniou E, Walker H, Gujral S. The Role of Simulation in Microsurgical Training. Journal of surgical education 2018;75:171-81.

55. Knox AD, Gilardino MS, Kasten SJ, Warren RJ, Anastakis DJ. Competency-based medical education for plastic surgery: where do we begin? Plast Reconstr Surg 2014;133:702e-10e.

56. Plana NM, Rifkin WJ, Kantar RS, et al. A Prospective Randomized Blinded Trial Comparing Digital Simulation to Textbook for Cleft Surgery Education. Plast Reconstr Surg 2018.

57. de Montbrun SL, MacRae H. Simulation in Surgical Education. Clinics in Colon and Rectal Surgery 2012;25:156-65.

58. Loh CYY, Wang AYL, Tiong VTY, et al. Animal models in plastic and reconstructive surgery simulation—a review. Journal of Surgical Research 2018;221:232-45.

59. Lewis R, Strachan A, Smith MM. Is high fidelity simulation the most effective method for the development of non-technical skills in nursing? A review of the current evidence. The open nursing journal 2012;6:82-9.

60. Badash I, Burtt K, Solorzano CA, Carey JN. Innovations in surgery simulation: a review of past, current and future techniques. Annals of Translational Medicine 2016;4:453.

61. Cosman PH, Hugh TJ, Shearer CJ, Merrett ND, Biankin AV, Cartmill JA. Skills acquired on virtual reality laparoscopic simulators transfer into the operating room in a blinded, randomised, controlled trial. Studies in health technology and informatics 2007;125:76-81.

62. Seymour NE, Gallagher AG, Roman SA, et al. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. Ann Surg 2002;236:458-63; discussion 63-4.

63. Sifakis E, Hellrung J, Teran J, Oliker A, Cutting C. Local flaps: a real-time finite element based solution to the plastic surgery defect puzzle. Studies in health technology and informatics 2009;142:313-8.

64. Kanevsky J, Safran T, Zammit D, Lin SJ, Gilardino M. Making Augmented and Virtual Reality Work for the Plastic Surgeon. Annals of plastic surgery 2018.

65. Tan SC, Marlow N, Field J, et al. A randomized crossover trial examining low- versus high-fidelity simulation in basic laparoscopic skills training. Surg Endosc 2012;26:3207-14.

66. Zammit D, Ponnudurai N, Safran T, Gilardino M. Reevaluating the Current Model of Rhinoplasty Training and Future Directions: A Role for Focused, Maneuver-Specific Simulation. Plast Reconstr Surg 2019;144:597e-605e.

67. Khunger N, Kathuria S. Mastering Surgical Skills Through Simulation-Based Learning: Practice Makes One Perfect. Journal of Cutaneous and Aesthetic Surgery 2016;9:27-31.

68. Salas E, Burke CS. Simulation for training is effective when …. Quality and Safety in Health Care 2002;11:119-20.

69. Agha RA, Fowler AJ. The Role and Validity of Surgical Simulation. International Surgery 2015;100:350-7.

70. McKinnon VE, Kalun P, McRae MH, Sonnadara RR, Fahim C. A Shift on the Horizon: A Systematic Review of Assessment Tools for Plastic Surgery Trainees. Plast Reconstr Surg 2018;142:217e-31e.

71. Bjerrum F, Thomsen ASS, Nayahangan LJ, Konge L. Surgical simulation: Current practices and future perspectives for technical skills training. Medical teacher 2018;40:668-75.

72. Sewell C, Morris D, Blevins NH, et al. Providing metrics and performance feedback in a surgical simulator. Comput Aided Surg 2008;13:63-81.

Chapter 3 - Bridging Text

The information gathered in the previous manuscript through a systematic review of literature, confirmed that the lack of high-level research in the domain of local flap design for facial reconstruction is likely due to the fact that, currently, no validated objective assessment tools for surgical markings of local flaps exist. Having this in mind, in the following manuscript, we set out to develop an innovative objective assessment tool which is in our view the single most important barrier for advancement of simulation-based surgical education in this field. In order to compare shape similarity between optimal and suboptimal designs, the authors utilized mathematical concepts of shape dissimilarity, commonly used in the field of statistical shape analysis.[9] We aimed to develop this assessment tool with a focus on providing automated, evidence-based, objective, specific, and practical feedback to the learner. Serving as an innovative approach to improve post-graduate education of surgical markings, to the authors' knowledge, this approach is first of its kind and has immense potential to automatize surgical design assessment.

Chapter 4 -*Manuscript 2*

SMaRT Assessment Tool: An Innovative Approach for Objective Assessment of Flap Designs

Running Head: Local Facial Flaps Design Assessment

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Key Words: Assessment Tool, Surgical Marking, Local Flaps, Surgical Education, Statistical Shape Analysis

Abstract

Introduction: Teaching and assessment of ideal surgical markings of local flaps required for optimal aesthetic and functional outcomes remains a challenge in the present era of competency-based surgical education. We utilized the bilobed flap for nasal reconstruction as a proof-of-concept for the development of an innovative objective assessment tool based on statistical shape analysis, with a focus on providing automated, evidence-based, objective, specific, and practical feedback to the learner.

Methods: Systematic reviews of the literature were performed to establish the essential cognitive processes required for optimal bilobed flap design and methods used for shape analysis. An objective assessment tool based on Procrustes statistical shape analysis was developed and performance boundaries were tested. A series of optimal and suboptimal designs generated in deliberate violation of the established ideals were then evaluated, and a four-component feedback score of *S*cale, *M*ism*a*tch, *R*otation, and *T*ranslation (SMaRT) was generated.

Results: The SMaRT assessment tool demonstrated the capacity to proportionally score a spectrum of designs (n=36) ranging from subtle to significant variations of optimal, with excellent computational and clinically reasonable performance boundaries. In terms of shape mismatch, changes in SMaRT score also correlated to intended violations in designs away from the ideal flap design.

Conclusion: This innovative educational approach could aid in incorporating objective feedback in simulation-based platforms in order to facilitate deliberate practice in flap design. Furthermore, the present assessment tool has the potential to be adapted to other fields of plastic surgery and to automatize assessment processes.

Introduction

Local flaps are classically used for reconstruction of facial defects, commonly secondary to skin cancer excision.[1] Considering the specific defect's dimensions, the complex three-dimensional anatomy of facial aesthetic subunits, appropriate local flap selection and optimal design require complex cognitive processes by the reconstructive plastic surgeon.[2] Given the endless possibilities of defects based on location and size, it remains critical for plastic surgery residents to develop proper spatial reasoning and awareness based on general design principles, while concurrently taking into account accompanying clinical pearls and pitfalls applicable to any scenario.[2-4] The age-old wisdom of "measure twice, cut once" alludes to the importance of precise pre-operative planning, which remains critical in the field of plastic surgery to achieve optimal functional and aesthetic outcomes.[5]

Due to the geometric nature of surgical designs, preoperative surgical marking remains a challenging domain in surgical education.[5] The feedback process to learners, while being evaluated by an assessor, often remains subjective, non-specific, variable, and untimely.[6] Moreover, involving assessors in deliberate practice exercises for real-time feedback is impractical and resource-intensive.[7] Opportunities to perform deliberate practice with the aim of mastering the design of a specific local flap,[8-10] while simultaneously receiving objective, specific, and practical feedback, remains extremely limited in the clinical setting and in post-graduate training programs.[11] Ideally, prior to the occasional and infrequent patient encounters, residents should strive to reach competency in surgical design using educational resources presently available.[12] Traditional resources include two-dimensional textbook illustrations highlighting geometric principles with accompanying markings indicated on specific defects. The transition towards competency-based education has culminated in a surge in popularity of simulation-based training platforms in plastic surgery,[13-15] with local flap design remaining notably amenable to simulation. However, consistently, there remains a paucity of rigorous validation efforts for local flap simulators, which stems from the lack of objective assessment tools available for surgical designs. Using an objective assessment tool is thus critical to quantitively assess design principles and identify improvements necessary in trainees. Moreover, objective data can be documented and assessed in a serial fashion, allowing for the monitoring of progression through structured training curricula.[16]

Given that no objective assessment tools exist for the evaluation of local flap design, the authors sought to develop such a tool using bilobed nasal flaps design as a proof-of-concept.[17-19] The bilobed flap for nasal reconstruction was deemed an appropriate choice given that it has been previously deemed an essential procedure for plastic surgery residents to demonstrate competence in during training, with limited clinical exposure.[11,20] However, before an objective assessment tool may be developed, essential procedural steps that the assessment tool must evaluate should first be established.[21] The objectives of the present study were to develop an objective assessment tool for local flap design based on statistical shape analysis,[22] with a focus on the capacity to provide feedback to learners, that remains objective, specific, and practical for design improvement. By implementing a four-component score assessment tool, the authors aim to provide evidence for its capacity to assess suboptimal local flap designs, in comparison to previously established principles and concepts of optimal designs.

Methods

Identification of Essential Concepts in Bilobed Flap Design

A systematic search of the U.S. National Library of Medicine (MEDLINE), Excerpta Medica Database (EMBASE), PubMed, and Cochrane databases was performed using variations of the following search terms: ("Bilobed") AND ("Face*" OR "Nose*"). Additionally, a survey was administered to plastic surgery residents at our university (n=15) to identify the 5 most frequented textbook references for learning principles of bilobed flap design. References were queried by two independent evaluators in accordance with the PRISMA guidelines[23]. Essential principles in bilobed flap design were compiled and grouped into one of three major categories: defect analysis, aesthetic subunit analysis, and geometric principles. Qualitative text analysis was subsequently performed and a cognitive demand table[24] generated based on coded statements, in order to identify specific concepts deemed essential in each category. The final shortlist was approved by an expert academic craniofacial plastic surgeon (MG, senior author), and in consideration of the essential geometric principles established, a reference standard for bilobed flap designed was generated, for a virtual defect drawn on a sketched image of a lateral view of a nose. The final design of the senior author was also subsequently assessed for suitability by two independent academic plastic surgeons in order to validate its use as the reference standard for the present study.

Development of an Objective Assessment Tool for Local Flap Design

Objective assessment of surgical designs is fundamentally a shape analysis exercise, comparing one shape's similarity to a reference standard. This allows for the use of a well-established mathematical principle from the field of statistical shape analysis termed Procrustes analysis,[25] previously implemented for objective assessment of facial symmetry in plastic surgery.[26] The essential components of such an analysis comprise, initially, mathematical Euclidean similarity transformations of a given design, including translation, rotation, and scale, in order to maximize the fit of one shape to a reference standard, and attain the minimally-achievable dissimilarity possible. Additionally, the degree of this minimally-achievable dissimilarity or mismatch can then be computed using the root mean square deviation between the two shapes.[25,26]

In order to collect suitable data for model generation and testing, Procreate® (Savage Interactive, North Hobart, Australia) image processing application was used on an iPad tablet (Apple Inc, Paolo Alto, California). The authors were able to extract surgical designs drawn using touch-screen technology over a 400x550 pixels background, representing a sketched image of a nasal lesion. The image file was transformed from Portable Network Graphics (PNG) into Scalable Vector Graphics (SVG), and subsequently, into a 100-point XY coordinates dataset representing the design outline using open source software (Image Convertor®, QaamGo Media GmbH, Cologne, Germany) (Coordinator® Spotify AB, Stockholm, Sweden). The Procrustes analysis was subsequently performed using the open-source programming language Python™ (Python Software Foundation, Delaware, USA) in order to compare design similarity to the proposed reference standard. Finally, a four-component score of the four variables (scale, mismatch, rotation, and translation, referred to as SMaRT) was provided for each tested design against the reference design**. (Figure 1)**

The Sensitivity of the SMaRT Assessment Tool for Discerning Variations in Local Flap Designs

In order to assess the performance boundaries of the SMRT assessment tool, the reference bilobed design was first compared to itself in order to establish the minimum possible computed mismatch, as it pertains to computational limits. Subsequently, in order to establish a more practical minimum achievable mismatch score, taking into account human error, equipment used, as well as analytical settings employed, two authors repeatedly attempted to redraw an overlay of the reference bilobed design (n=9), while having the original reference design in the background. The 95% confidence intervals for each parameter of the SMaRT score were then calculated.

In order to evaluate this model's sensitivity at discerning specific design manipulations, as it pertains to the essential principles of bilobed flap design established, various permutations of bilobed-flap designs were then fed into this model. Computed SMaRT scores, based on the statistical shape analysis employed, were then compared to expected SMaRT scores, as it pertained to purposeful modifications to the reference design using Euclidean similarity transformations. Sample bilobed designs (n=12) purposefully rotated at various degrees, scaled at different scales, and translated by various millimetres in the XY coordinates, were tested. Moreover, using image processing, two authors purposely distorted the shape of the reference bilobed flap in order to analyze the computed SMaRT score for a spectrum of bilobed flap designs (n=15) purposefully violating each sub-category of the identified essential principles.

Results

Of the 153 articles identified through literature search, 18 were included in the final analysis, with adequate, detailed descriptions of bilobed local flap design principles in facial reconstruction.[19,27-43] In addition, 5 of the most frequented textbook references identified by survey administrated to plastic surgery residents (n=15) were assessed **(Figure 2).** [44-48] The text regarding bilobed flap design was extracted from both sources, and a qualitative text analysis subsequently performed to synthesize the essential principles of bilobed flap design, as presented in **Table 1.** Notable concepts were further stratified into three major categories, including defect analysis, aesthetic subunit analysis, and geometric design principles. We further subcategorized geometric principles into pivot point identification, axis identification, arcs of rotation, and lobe dimensions, in order to guide the subsequent design exercises, and facilitate the deliberate violation of each subcategory during model testing. Accordingly, the reference standard for bilobed flap design was generated for a virtual defect drawn on an illustration of a lateral view of a nose and deemed suitable for use as a reference standard in this study **(Figure 3).**

In order to establish computational performance boundaries, the reference image was compared to itself. The computed SMaRT score (S 1.00X, M 2.406 x 10^{-16}mm, R 3.18° x 10^{-15}, T 0mm, 0mm) output showed excellent level of precision relative to expected SMaRT score (S 1X, M 0mm, R 0°, T 0mm, 0mm). Next, to establish practical performance boundaries, 95% confidence intervals were established for each component, when the reference image was compared to nine hand-drawn overlay designs. In this exercise, the SMaRT assessment tool showed reasonable approximation relative to expected scores, as S 1.003X [0.995 – 1.011] , M 0.0867mm [0.0750 – 0.0981] , R 0.69° [0.31 – 1.07], T(x) 0.083mm [0.045 – 0.122], T(y) 0.132mm [0.058 – 0.205] **(Figure 3).**

When the reference design underwent purposeful modifications to produce a spectrum of designs **(n=12)** in each category of scale, rotation and translation, the SMaRT scores showed consistency across expected and computed SMaRT scores, within a clinically acceptable margin of error relative to the deliberate transformation **(Figure 4).** Additionally, when the reference design underwent purposeful modifications to produce a spectrum of designs (n=15), each deliberately violating specific sub-categories of the essential geometric principles, the SMaRT assessment tool was demonstrated capable of identifying poor designs arising from incorrect cognitive processes **(Figure 5)**. In order to visually represent the spectrum of mismatch scores attributed to designs investigated in this study, **Figure 6** provides a logarithmic mismatch ruler to demonstrate the performance boundaries of the assessment tool and the extent of mismatch for multiple sample designs ranging from subtle to significant variations from the optimal design.

Discussion

The plastic surgery literature remains devoid of objective tools for assessment of surgical markings for local flap design, which remain critical in order to provide specific and constructive feedback to trainees during deliberate practice. In this study, the authors aimed to develop an innovative approach towards the training and assessment of local flaps in facial reconstruction that incorporates objective statistical shape analysis to guide educational and assessment efforts in this domain. The proposed SMaRT assessment tool compares novice surgical designs to an expert design in real-time. The authors demonstrate that this tool is sensitive to Euclidean transformations including translation, rotation and scale, and is able to compute an objective measure of mismatch with excellent computational and clinically reasonable practical performance boundaries. By analyzing various examples of suboptimal or incorrect designs, the authors further demonstrate that the extent of violation of the evidence-based principles of flap design can be easily conveyed to the learner given the four-components feedback score**.** This provides potential for the quantitative assessment of improvements in trainee designs, in a serial fashion, tracking progression through structured training curricula.

The bilobed flap for nasal reconstruction was chosen as a proof-of-concept,[17,18] given that it was deemed to be an essential plastic surgery procedure for resident training in a recent educational study.[20] A follow-up study by the same group demonstrated that, through retrospective review of case log procedure data of graduating residents, trainees continue to have limited clinical exposure to facial local flaps, being involved in an average of 2.6 cases during post-graduate training.[11] Moreover, the bilobed flap design has complex cognitive processes, attesting to its suitability to achieve the objectives of this study. The question of how plastic surgery educators may teach and assess the required surgical judgement of optimal local flap design was then systematically approached. Cognitive processes pertaining to what elements of a surgical design render it suboptimal for its intended purpose were established through a comprehensive systematic review of the literature. Utilizing classic descriptions of local flap principles available in the literature and published textbooks, the spatial reasoning and clinical judgement necessary was highlighted in an evidence-based fashion. Intuitively, violation of these essential steps established for bilobed flap design by a novice learner would lead to suboptimal designs. An ideal assessment tool would thus be sensitive to identifying and objectively reporting on the extent of such design errors, providing learners accordingly with specific, objective, and personalized feedback in order to guide improvement during independent deliberate practice.

In order to compare shape similarity between optimal and suboptimal designs, the authors utilized mathematical concepts of shape dissimilarity, commonly used in the field of statistical shape analysis.[25] The authors postulated that the availability of detailed productive feedback to a learner in this context would be most useful if it includes components of Euclidean transformations necessary to minimize mismatch, as well as a measure of overall resulting mismatch using root mean square deviation. To measure mismatch objectively, the authors utilized the Procrustes technique[25] that takes into account translation, rotation, and scale transformations necessary to achieve minimum dissimilarity between two shapes, providing an overall assessment of shape dissimilarity accordingly. The Procrustes analysis has been previously used in plastic surgery for the objective and quantitative assessment of dissimilarity, for example, for facial asymmetry analysis between two hemiface outlines.[26,49] Moreover, as an objective approach, this statistical analysis removes the need for subjective evaluation and feedback by an assessor, which remains both resource-intensive and inherently prone to human error and variability. This approach continues to have marked potential for 3-dimensional applications, which remains a noteworthy consideration to simulate the complex topology of the face in future works.[26]

Although theoretically, achieving 0mm of mismatch between novice and expert design would mean the surgical designs are precisely similar, this remains an unrealistic goal for learners given both computational and practical performance boundaries of our model, arising from equipment limitations, computational settings, data processing, transformations, and human error. Therefore, for the bilobed flap design task, we established the computational performance boundaries by comparing the reference standard design against itself, as well as practical performance boundaries, by comparing multiple hand-drawn overlaid designs against the reference standard. The average mismatch computed in the latter case represents the minimal mismatch achievable within the computational and practical boundaries of our model, and should thus serve as the target for trainees to achieve in design training exercises. However, there additionally remains another important threshold to consider, namely, a range of what may constitute clinically acceptable designs, which would, within reasonable variation, still be considered optimal and sufficient for demonstrating competence in this procedure. For instance, minor design differences in each category of scale, rotation, translation, or overall mismatch, may still all lead to clinically acceptable designs. These thresholds would however remain somewhat subjective, based on expert opinion, and cumbersome to establish for all possible defects of varying sizes and locations and the corresponding local flap reconstructive options.

The proposed assessment tool may be generalized for use in other surgical design tasks, notwithstanding local flaps, and on any background images of different facial lesions, specific patient views, or using any reference design standard that is fed into the model. However, in organizing any specific design task, it would be imperative to establish the limits acceptable for mismatch by using overlaid repeated designs generated by the educator as described in this study or pooled from multiple experts in a form of visual-script concordance test.[50-52] This threshold of mismatch could realistically represent the target for a novice learner to achieve while performing deliberate practice, and demonstrate competence within the current setting. The direction of improvement towards a pre-established threshold rather than an actual number is likely more comprehensible and practical for the learner. Learners' perspective on the SMaRT assessment tool, nature of the feedback provided, and its validation remain the subject of ongoing studies by our group.

Serving as an innovative approach to improve post-graduate education of surgical markings, to the authors' knowledge, this study is first of its kind in proposing an assessment tool with a focus on providing learners with independent, objective feedback. One limitation remains that the analysis was performed on 2D surgical designs, which may fail to take into account the complex 3D topological features of the nose or other anatomic areas for future application. While similar statistical shape analysis techniques can be applied to 3D datasets as well, 2D analysis is performed more easily, using portable electronic devices, is easily comprehensible, and amenable to the application of necessary corrections and improvements. The criterion validity, defined as the extent to which a measure is related to the outcome of interest, namely competence in the procedure, can be achieved through multiple methods, such as text analysis as utilized here or other expert-based methods in cognitive research such as cognitive task analysis.[21,53-59] In terms of feedback, the clinical interpretability and the utility of the SMaRT score is yet to be examined. Finally, implementation strategies of such an approach in a residency training need to be explored following evidence for validation, educational potential, and economic utility. Particularly, this tool needs to be validated for its ability to distinguish the expert from novice performance for the design task at hand and evaluated for its potential in enabling the acquisition and retention of surgical marking design skills over time. While limitations of the present study, these points are indeed the subject of on-going studies by our group.

Conclusions

By using the bilobed local flap for facial defect reconstruction as an example of a core essential learning outcome with low clinical exposure for residents, the authors propose an objective assessment tool based on statistical shape analysis and provide evidence for its capacity to score suboptimal designs according to published concepts of bilobed flap design. This educational tool could aid in incorporating unsupervised objective feedback in simulation-based platforms, facilitating deliberate practice, with the end goal of complementing the resource-intensive demands of emerging competency-based training curricula. The innovative approach proposed herein could have significant implications in other fields of plastic surgery, where surgical designs remain of paramount importance for successful functional and aesthetic outcomes, including cleft lip and palate repair, burn contracture release, and breast reduction/reconstruction. With technological advancements in the fields of artificial intelligence, augmented reality and surgical simulation,[13,60] the authors hope that the present study provides the foundational steps necessary for the objective, automated, and personalized evaluation of skin flap design and contribute to the advancement of the field of surgical education.

Acknowledgements

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Figure 1: Overview of local flap design exercise, data collection and analysis. An image processing software on a smart tablet is used to extract surgical designs. Data is transformed, and Procrustes analysis subsequently conducted. A four-component SMaRT score of Scale (ratio), Mismatch (mm), Rotation (degrees), and Translation XY (mm) is provided for each tested design**.**

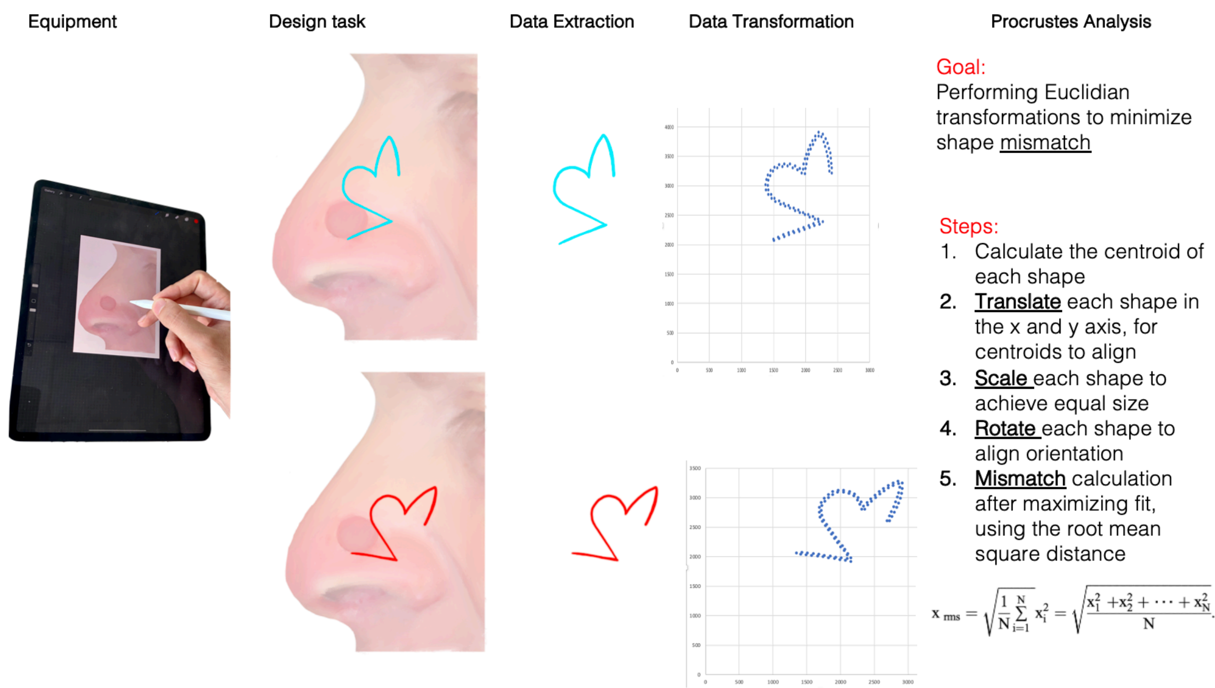


Figure 2: Overview of systematic search strategy to identify essential principles in bilobed flap design, conducted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Figure 2.

PRISMA 2009 Flow Diagram

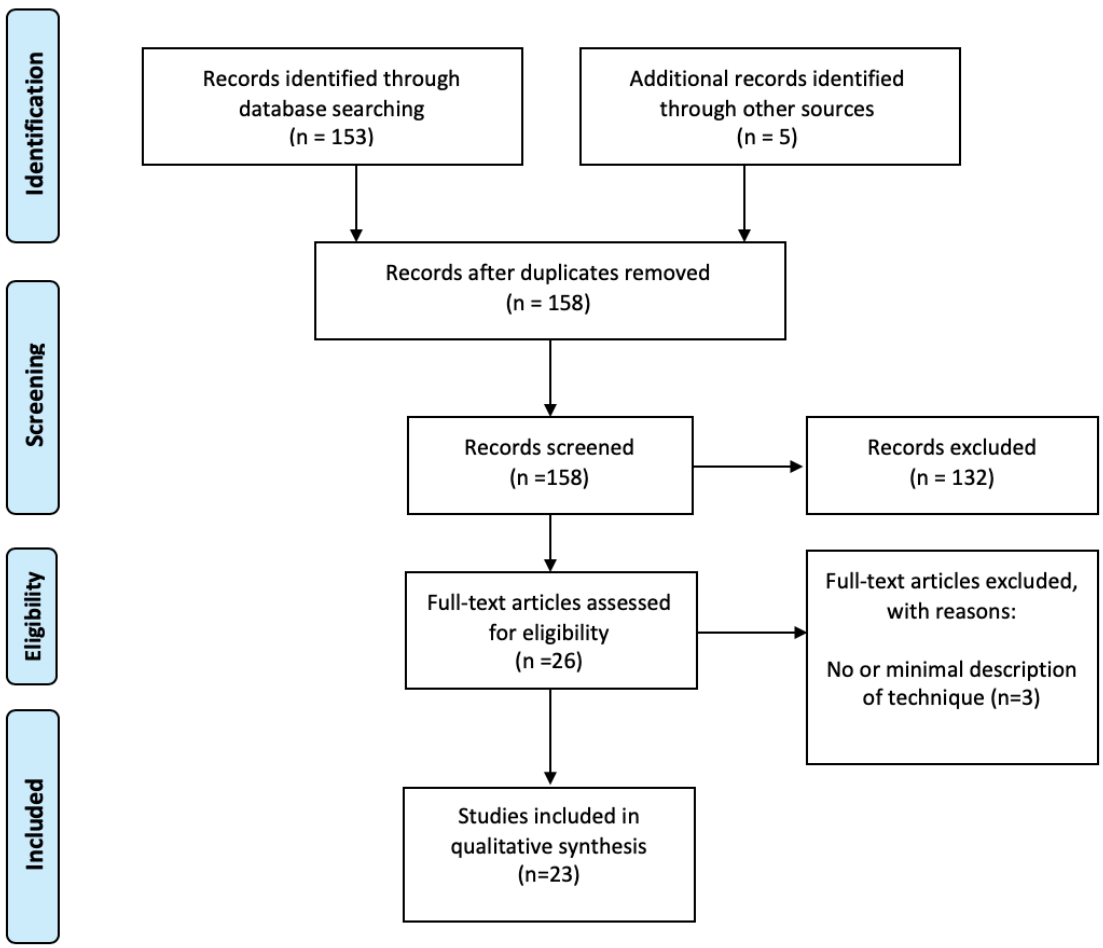


Figure 3: Bilobed flap design reference standard for the given sketched nasal defect of interest; the computed SMaRT assessment tool metrics are compared to those expected to establish the model's computational boundaries. Overlay drawings of the same reference design are tested to establish the model's practical boundaries. A four-component SMaRT score of Scale (ratio), Mismatch (mm), Rotation (degrees), and Translation X,Y (mm, mm) is provided.

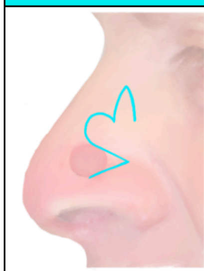
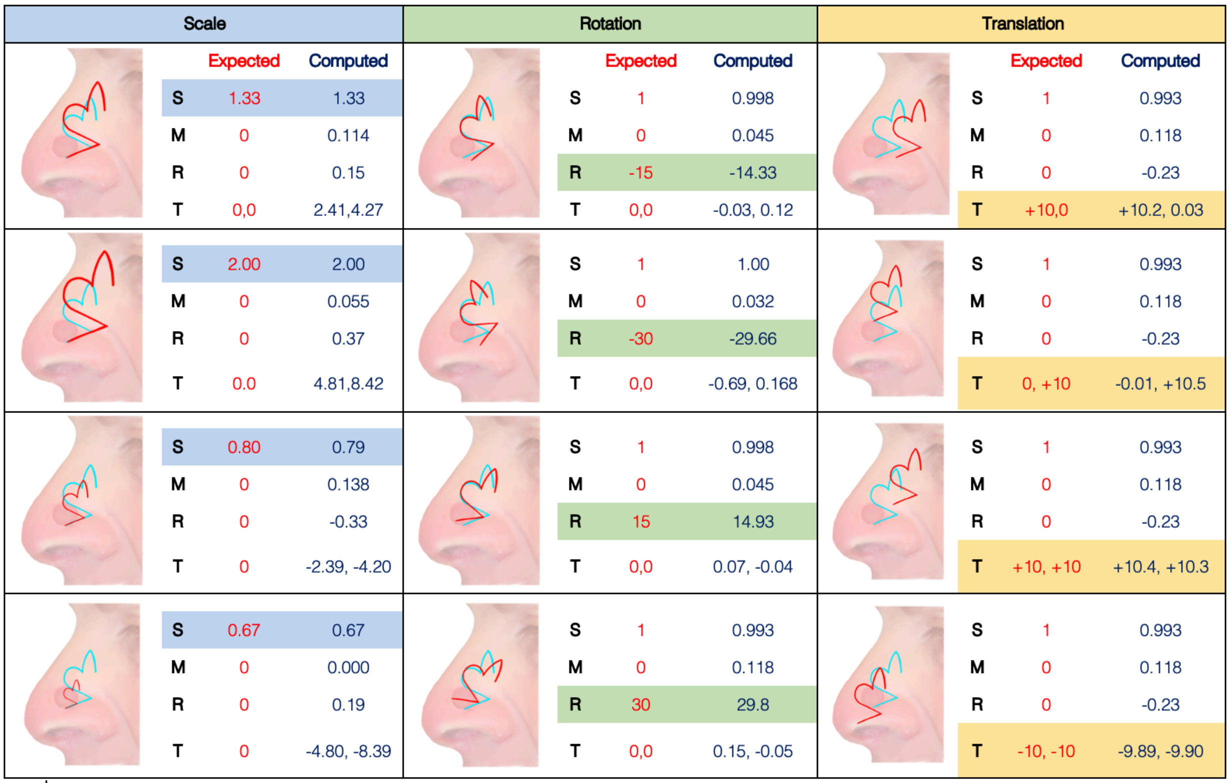
Reference			
		Expected	Computed
	S	1	1
	M	0	2.406×10^{-16}
	R	0	3.18×10^{-15}
	T(x)	0	0.0
	T(y)	0	0.0
Reference Overlay Hand Drawn (n=9)			
		Expected	Computed Mean [95% Confidence Interval]
	S	1	1.003 [0.995 – 1.011]
	M	0	0.0867 [0.0750 – 0.0981]
	R	0	0.69 [0.31 – 1.07]
	T(x)	0	0.083 [0.045 – 0.122]
	T(y)	0	0.132 [0.058 – 0.205]

Figure 4: Sensitivity for discerning specific design manipulations demonstrated by comparing computed SMaRT scores to expected SMaRT scores following purposeful modifications to the reference design using Euclidean similarity transformations. The SMaRT assessment tool demonstrated consistency across expected and computed scores within a clinically acceptable margin of error. A four-component SMRT score of Scale (ratio), Mismatch (mm), Rotation (degrees), and Translation X,Y (mm, mm) is provided.



Scale	Expected	Computed	Rotation	Expected	Computed	Translation	Expected	Computed
S	1.33	1.33	S	1	0.998	S	1	0.993
M	0	0.114	M	0	0.045	M	0	0.118
R	0	0.15	R	-15	-14.33	R	0	-0.23
T	0,0	2.41,4.27	T	0,0	-0.03, 0.12	T	+10,0	+10.2, 0.03
S	2.00	2.00	S	1	1.00	S	1	0.993
M	0	0.055	M	0	0.032	M	0	0.118
R	0	0.37	R	-30	-29.66	R	0	-0.23
T	0.0	4.81,8.42	T	0,0	-0.69, 0.168	T	0, +10	-0.01, +10.5
S	0.80	0.79	S	1	0.998	S	1	0.993
M	0	0.138	M	0	0.045	M	0	0.118
R	0	-0.33	R	15	14.93	R	0	-0.23
T	0	-2.39, -4.20	T	0,0	0.07, -0.04	T	+10, +10	+10.4, +10.3
S	0.67	0.67	S	1	0.993	S	1	0.993
M	0	0.000	M	0	0.118	M	0	0.118
R	0	0.19	R	30	29.8	R	0	-0.23
T	0	-4.80, -8.39	T	0,0	0.15, -0.05	T	-10, -10	-9.89, -9.90

Figure 5: Ability to identify poor designs arising from incorrect cognitive processes in bilobed flap design demonstrated by purposeful modifications to the reference design and SMRT scores computed. The model proved effective at proportionally scoring a spectrum of designs ranging from subtle to significant variations off optimal, with excellent computational and clinically reasonable performance boundaries. A four-component SMRT score of Scale (ratio), Mismatch (mm), Rotation (degrees), and Translation X,Y (mm, mm) is provided.

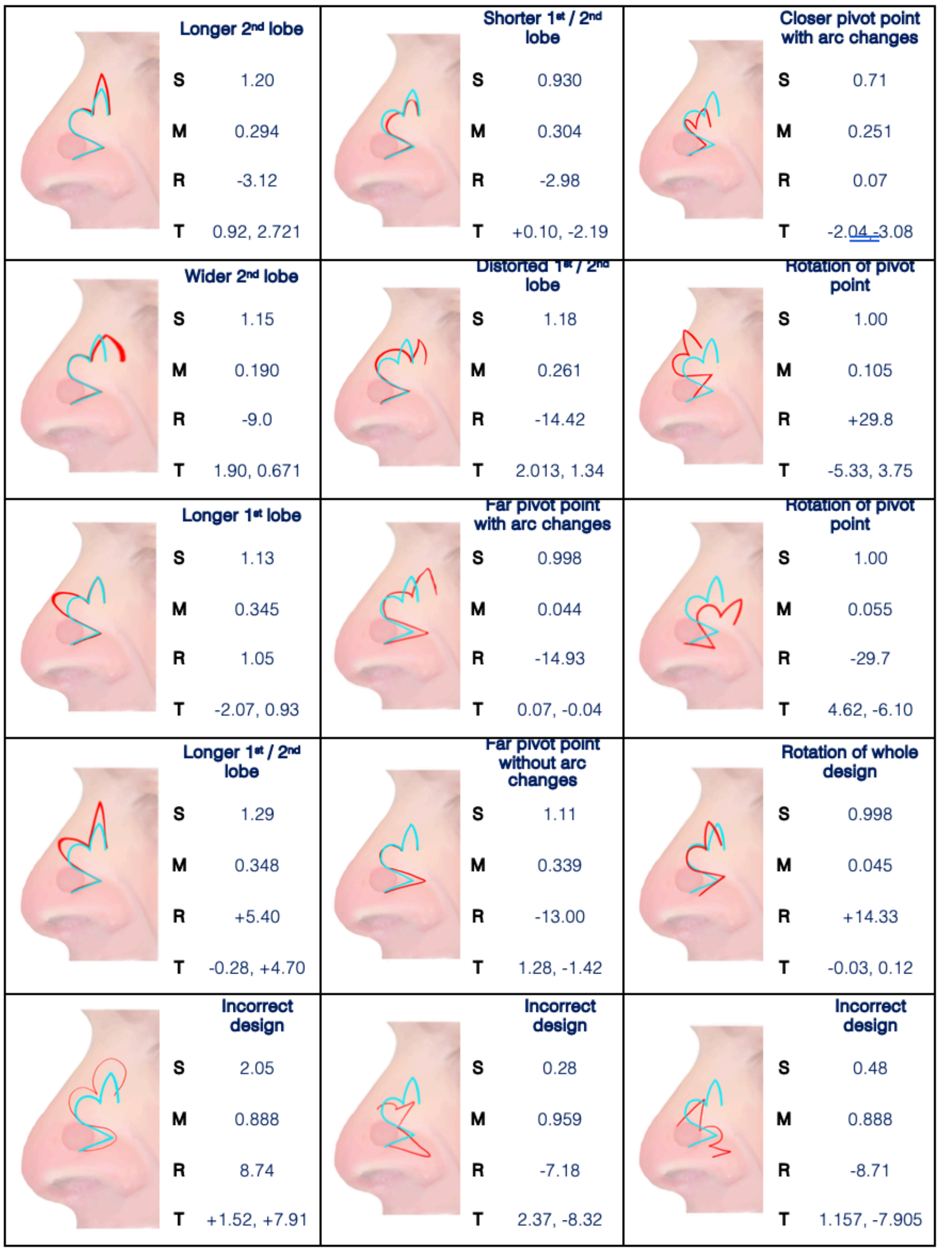


Figure 6: Logarithmic mismatch ruler to demonstrate performance boundaries of the proposed assessment tool proposed using sample designs evaluated.

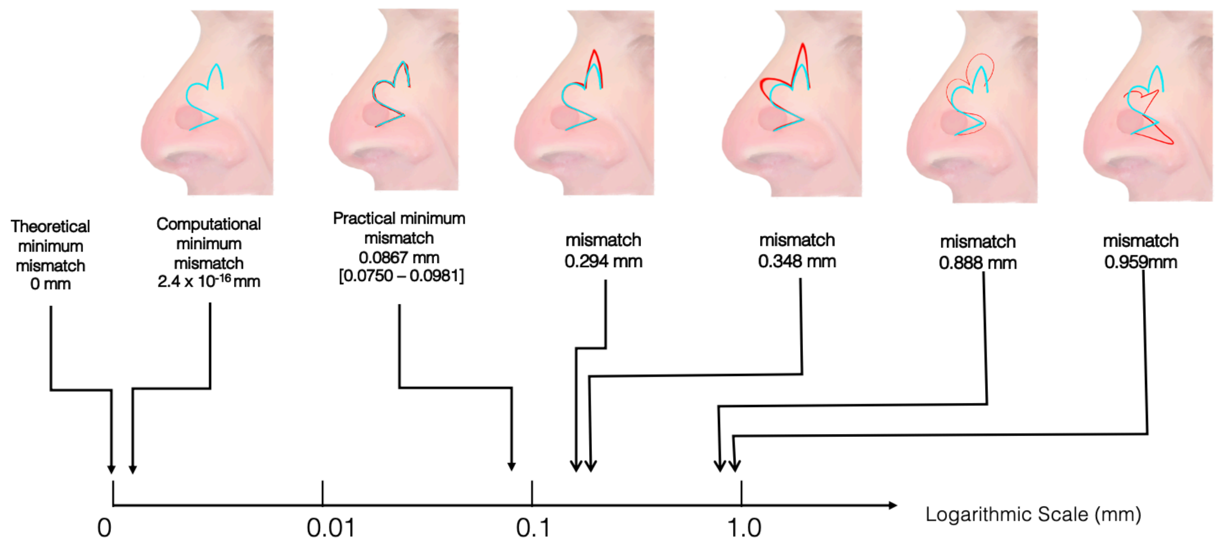


Table 1

Defect Analysis		
Concept	**Comments**	**Reference**
Defect size	0.5-1.5cm	[44],[45]
	1-1.5cm	[46]
	<1.5cm	[19], [27], [31], [32], [33] [36], [37],
Defect location	Caudal 1/3 of the nose; (tip and ala)	[19], [44], [47], [46], [45], [28],[29], [30],[32], [35], [36], [37], [40], [41]
	Cephalic 1/3 not suitable unless size is <0.5cm	[46]
	Location dictates orientation of flap: lateral vs. medial	[27], [32], [36], [38], [41] [46], [44], [45]
Defect shape	Ideally circular shape	[46]
Defect depth / layers	Ideal for cutaneous only defects	[44], [46]
	Superior to skin graft for nasal defects extending beyond subcutaneous layer	[19], [32]

Skin laxity surrounding the defect	Assess using pinch test to ensure tension-free closure	[47], [46], [39]

Aesthetic Subunit Analysis		
Concept	**Comments**	**References**
Nasal aesthetic subunits	Avoid designing incisions close to the alar inferior margin; ideally at least 0.5cm-1cm caudal to nostril (scarring will lead to nostril elevation)	[44], [45], [46], [32]
	Medially based bilobed flaps will lead to scars in the nasal tip that cannot be camouflaged between aesthetic subunits. Defects of the Nasal ala are best treated with medially based bilobed flaps whereas defects of the tip are best treated with laterally based flaps.	[46] [33]
Neighbouring aesthetic subunits	Avoid designing incisions close to the lower eyelid (scaring will lead to ectropion)	[44], [45]
	Avoid extending pattern to cheek to preserve cheek/nose junction	[26], [44], [45]
	Defects in cephalic 1/3 must be small (less than 0.5 cm) given that it necessitates use of medial canthus skin which is thin and immobile	[46]

Resultant Scars	Scars should ideally be camouflaged in between aesthetic subunits of the nose and neighboring structures Scars should be located parallel to relaxed skin tension lines of the dorsum	[46] [34]
	Patients with thick sebaceous skin have a higher risk of developing flap necrosis, trapdoor deformity, and depressed scars	[46], [33], [39]

Geometric Design Principles		
Concept	**Comments**	**Reference**
Pivot point identification	Identify center point of defect Measure defect radius (r)	[19], [46], [32], [29], [33], [41]
	Decision for flap orientation - laterally based for tip defects - medially based for lobule defects	[46], [44],[45],[31], [36], [32]
	Distance: Pivot point should be placed one radius away from the defect margin Location: Scar placement ideally in aesthetic subunit border e.g. laterally based bilobed flaps require burrow triangle of tissue to be excised such that the resultant scars are hidden in the alar groove e.g. medially based bilobed flaps scaring will extend to the nasal tip which is difficult to camouflage	[46], [44],[47], [45], [29], [32] , [26], [31], [41]
Axes identification	- Defect axis (from pivot point to the center of the defect)	[46], [44], [47], [45], [29], [33], [36], [38]

	- Second lobe axis (90-100 degrees to the defect axis, passing through the pivot point) - First lobe axis (bisects defect axis and second lobe axis, passing through the pivot point)	
Arcs of Rotation	Two arcs centered at pivot point may be drawn to guide the dimensions of the lobes: - 2r arc: passing through center of defect - 3r arc: tangential to distal border of defect	[19], [46],[44], [47], [45], [29], [32], [40]
Lobe dimensions	Height of first lobe extends to 3r arc, originating from 2r arc Height of second lobe is twice the height of first lobe, tapering to a point.	[46], [44], [47], [45], [29]
	Width of the first lobe equals width of the defect Width of second lobe may be 25% less than width of first lobe Diameter of first lobe=90-100% of defect Diameter of second lobe=80-85 % of first lobe	[19], [27], [29], [31], [32], [33], [35], [36], [38], [39], [40]. [46], [44], [47], [45] [41]
	Final placement of second lobe should be in the loose skin of the side wall (in laterally based) or upper dorsum of the nose (medially based)	[19], [44], [47]

Other / miscellaneous

Reference	Text
[19], [44], [47], [46], [26], [33], [39], [41]	Undermine widely above perichondrium on both sides of incision to avoid trap door deformity and ensure tension free closure.
[46], [45], [31], [32], [35], [36], [38], [19]	Dissection plane between periosteum, perichondrium and SMAS layers (nasal muscles)
[46], [29]	First closes defect, second closes first, second closed primarily, then burrow triangle / redundancy is excised / standing cutaneous deformity as marked by burrows triangle by design
[19], [44], [47], [28], [36], [39]	First excise standing cutaneous deformity as marked by burrows triangle by design. Subsequently, first closes defect, second closes first, second closed primarily.
[46]	Trim the tip of the second lobe to adjust the height
[46], [45]	Correct mismatch in thickness to avoid closed door deformity
[46], [45]	Use a suture anchored at the pivot point, or bent paper ruler, to make measurements, as an alternative to calipers or straight rulers because of the topography of the nose width.
[46]	For smaller defects, lobes of the flap may be designed in rhombic shapes.

References

1. Johnson AR, Egeler SA, Wu WW, Bucknor A, Ibrahim AMS, Lin SJ. Facial Reconstruction After Mohs Surgery: A Critical Review of Defects Involving the Cheek, Forehead, and Perioral Region. *J Craniofac Surg.* 2019;30(2):400-407.
2. Kaufman AJ. Tips to Avoid Complications Following Mohs Reconstruction. *Facial Plast Surg Clin North Am.* 2019;27(4):571-579.
3. Shepherd L. Practical sculptural training for the plastic surgeon. *Int J Surg.* 2005;3(1):93-97.
4. Croley JA, Malone CH, Goodwin BP, Phillips LG, Cole EL, Wagner RF. Mohs Surgical Reconstruction Educational Activity: a resident education tool. *Adv Med Educ Pract.* 2017;8:143-147.
5. Sayadi LR, Chopan M, Maguire K, et al. A Novel Innovation for Surgical Flap Markings Using Projected Stencils. *Plast Reconstr Surg.* 2018;142(3):827-830.
6. Kempton SJ, Bentz ML. Making Master Surgeons Out of Trainees: Part I. Teaching Surgical Judgment. *Plast Reconstr Surg.* 2016;137(5):1646-1653.
7. Verrier ED. The Surgeon as Educator. *Thorac Surg Clin.* 2019;29(3):227-232.
8. Bjerrum F, Thomsen ASS, Nayahangan LJ, Konge L. Surgical simulation: Current practices and future perspectives for technical skills training. *Med Teach.* 2018;40(7):668-675.
9. Ericsson KA. Deliberate practice and acquisition of expert performance: a general overview. *Acad Emerg Med.* 2008;15(11):988-994.

10. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med.* 2004;79(10 Suppl):S70-81.
11. Shih JG, Knox ADC, Zhygan N, Courtemanche DJ, Fish JS, Brown MH. Toward the Assessment of Core Procedural Competencies among Canadian Plastic Surgery Residents. *Plast Reconstr Surg.* 2018;142(6):958e-967e.
12. Kneebone RL, Scott W, Darzi A, Horrocks M. Simulation and clinical practice: strengthening the relationship. *Med Educ.* 2004;38(10):1095-1102.
13. Kazan R, Cyr S, Hemmerling TM, Lin SJ, Gilardino MS. The Evolution of Surgical Simulation: The Current State and Future Avenues for Plastic Surgery Education. *Plast Reconstr Surg.* 2017;139(2):533e-543e.
14. Knox AD, Gilardino MS, Kasten SJ, Warren RJ, Anastakis DJ. Competency-based medical education for plastic surgery: where do we begin? *Plast Reconstr Surg.* 2014;133(5):702e-710e.
15. Waltzman JT, Tadisina KK, Zins JE. The Rise of Technology in Plastic Surgery Education: Is the Textbook Dead on Arrival (DOA)? *Aesthet Surg J.* 2016;36(2):237-243.
16. Abi-Rafeh J, Zammit D, Mojtahed Jaberi M, Al-Halabi B, Thibaudeau S. Nonbiological Microsurgery Simulators in Plastic Surgery Training: A Systematic Review. *Plast Reconstr Surg.* 2019;144(3):496e-507e.
17. Zitelli JA. Design aspect of the bilobed flap. *Arch Facial Plast Surg.* 2008;10(3):186.
18. Dvorak Z, Vavrek V, Kubek T, Streit L, Stupka I, Vesely J. Bilobed Flap in Facial Reconstruction. *Acta Chir Plast.* 2020;61(1-4):10-15.
19. Zitelli JA. The bilobed flap for nasal reconstruction. *Arch Dermatol.* 1989;125(7):957-959.

20. Knox ADC, Shih JG, Warren RJ, Gilardino MS, Anastakis DJ. Consensus of Leaders in Plastic Surgery: Identifying Procedural Competencies for Canadian Plastic Surgery Residency Training Using a Modified Delphi Technique. *Plast Reconstr Surg.* 2018;141(3):417e-429e.

21. Courteau BC, Knox AD, Vassiliou MC, Warren RJ, Gilardino MS. The Development of Assessment Tools for Plastic Surgery Competencies. *Aesthet Surg J.* 2015;35(5):611-617.

22. Stegmann M, Gomez D. A Brief Introduction to Statistical Shape Analysis. *Informatics and Mathematical Modelling, Technical University of Denmark, DTU.* 2002;15.

23. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol.* 2009;62(10):1006-1012.

24. Yeung C, McMillan C, Saun TJ, et al. Developing Cognitive Task Analysis-based Educational Videos for Basic Surgical Skills in Plastic Surgery. *Journal of surgical education.* 2017;74(5):889-897.

25. Goodall C. Procrustes Methods in the Statistical Analysis of Shape. *Journal of the Royal Statistical Society Series B (Methodological).* 1991;53:285-339.

26. Taylor HO, Morrison CS, Linden O, et al. Quantitative facial asymmetry: using three-dimensional photogrammetry to measure baseline facial surface symmetry. *J Craniofac Surg.* 2014;25(1):124-128.

27. Kelly-Sell M, Hollmig ST, Cook J. The superiorly based bilobed flap for nasal reconstruction. *J Am Acad Dermatol.* 2018;78(2):370-376.

28. Skaria AM. The medial based bi- or trilobed flap for repair of distal alar defects. *Dermatology.* 2013;227(2):165-170.

29. Jellinek NJ, Cordova KB. Bilobed flap for reconstruction of small alar rim defects. *Dermatol Surg.* 2013;39(4):649-652.

30. Monarca C, Rizzo MI, Palmieri A, Fino P, Parisi P, Scuderi N. Island pedicle and bilobed flaps in ala and back nose reconstruction: a prospective comparative analysis. *Aesthetic Plast Surg.* 2012;36(5):1168-1174.

31. Kannan R, John R. Reconstruction of Ala of Nose with Bilobed Flap: A 2 Year Follow-up. *J Maxillofac Oral Surg.* 2011;10(1):57-59.

32. Salgarelli AC, Bellini P, Multinu A, et al. Reconstruction of nasal skin cancer defects with local flaps. *J Skin Cancer.* 2011;2011:181093.

33. Steiger JD. Bilobed flaps in nasal reconstruction. *Facial Plast Surg Clin North Am.* 2011;19(1):107-111.

34. Chu EA, Byrne PJ. Local flaps I: bilobed, rhombic, and cervicofacial. *Facial Plast Surg Clin North Am.* 2009;17(3):349-360.

35. Perry JD, Taban M. Superiorly based bilobed flap for inferior medial canthal and nasojugal fold defect reconstruction. *Ophthalmic Plast Reconstr Surg.* 2009;25(4):276-279.

36. Garces JR, Guedes A, Alegre M, Alomar A. Bilobed flap for full-thickness nasal defect: a common flap for an uncommon indication. *Dermatol Surg.* 2009;35(9):1385-1388.

37. Collins SC, Dufresne RG, Jr., Jellinek NJ. The bilobed transposition flap for single-staged repair of large surgical defects involving the nasal ala. *Dermatol Surg.* 2008;34(10):1379-1385; discussion 1385-1376.

38. Yoon T, Benito-Ruiz J, Garcia-Diez E, Serra-Renom JM. Our algorithm for nasal reconstruction. *Journal of plastic, reconstructive & aesthetic surgery : JPRAS.* 2006;59(3):239-247.
39. Aasi SZ, Leffell DJ. Bilobed transposition flap. *Dermatol Clin.* 2005;23(1):55-64, vi.
40. Cook JL. A review of the bilobed flap's design with particular emphasis on the minimization of alar displacement. *Dermatol Surg.* 2000;26(4):354-362.
41. Golcman R, Speranzini MB, Golcman B. The bilobed island flap in nasal ala reconstruction. *British journal of plastic surgery.* 1998;51(7):493-498.
42. Moy RL, Grossfeld JS, Baum M, Rivlin D, Eremia S. Reconstruction of the nose utilizing a bilobed flap. *Int J Dermatol.* 1994;33(9):657-660.
43. Tardy ME, Jr., Tenta LT, Azem K. The bilobed flap in nasal repair. *Arch Otolaryngol.* 1972;95(1):1-5.
44. Janis JE. *Essentials of plastic surgery.* CRC Press; 2014.
45. Neligan P, Warren RJ, Van Beek A. *Plastic Surgery: Craniofacial, head and neck surgery and pediatric plastic surgery.* Elsevier; 2018.
46. Baker S, Neil A. Local Flaps in Facial Reconstruction, St. Louis. *MO: Mosby.* 2007;340.
47. Chung K. *Grabb and Smith's plastic surgery.* Lippincott Williams & Wilkins; 2019.
48. Zenn M, Jones G. *Reconstructive Surgery: Anatomy, Technique, and Clinical Application.* CRC Press; 2012.
49. Maull DJ, Grayson BH, Cutting CB, et al. Long-term effects of nasoalveolar molding on three-dimensional nasal shape in unilateral clefts. *Cleft Palate Craniofac J.* 1999;36(5):391-397.

50. Kania RE, Verillaud B, Tran H, et al. Online Script Concordance Test for Clinical Reasoning Assessment in Otorhinolaryngology: The Association Between Performance and Clinical Experience. *Archives of Otolaryngology–Head & Neck Surgery.* 2011;137(8):751-755.

51. Fournier JP, Demeester A, Charlin B. Script concordance tests: guidelines for construction. *BMC Med Inform Decis Mak.* 2008;8:18.

52. Madani A, Watanabe Y, Bilgic E, et al. Measuring intra-operative decision-making during laparoscopic cholecystectomy: validity evidence for a novel interactive Web-based assessment tool. *Surg Endosc.* 2017;31(3):1203-1212.

53. Riggle JD, Wadman MC, McCrory B, et al. Task analysis method for procedural training curriculum development. *Perspect Med Educ.* 2014;3(3):204-218.

54. Sullivan ME, Brown CV, Peyre SE, et al. The use of cognitive task analysis to improve the learning of percutaneous tracheostomy placement. *Am J Surg.* 2007;193(1):96-99.

55. Yates K, Sullivan M, Clark R. Integrated studies on the use of cognitive task analysis to capture surgical expertise for central venous catheter placement and open cricothyrotomy. *Am J Surg.* 2012;203(1):76-80.

56. Yule S, Flin R, Paterson-Brown S, Maran N, Rowley D. Development of a rating system for surgeons' non-technical skills. *Med Educ.* 2006;40(11):1098-1104.

57. Ghanem AM, Hachach-Haram N, Leung CC, Myers SR. A systematic review of evidence for education and training interventions in microsurgery. *Arch Plast Surg.* 2013;40(4):312-319.

58. McKinnon VE, Kalun P, McRae MH, Sonnadara RR, Fahim C. A Shift on the Horizon: A Systematic Review of Assessment Tools for Plastic Surgery Trainees. *Plast Reconstr Surg.* 2018;142(2):217e-231e.

59. Zevin B, Levy JS, Satava RM, Grantcharov TP. A consensus-based framework for design, validation, and implementation of simulation-based training curricula in surgery. *J Am Coll Surg.* 2012;215(4):580-586 e583.

60. Kanevsky J, Safran T, Zammit D, Lin SJ, Gilardino M. Making Augmented and Virtual Reality Work for the Plastic Surgeon. *Ann Plast Surg.* 2018.

Chapter 5 – Discussion

Future Directions to Validate and Implement SMaRT Assessment Tool

By critically reviewing the literature available on local flaps design simulation endeavours, we confirmed that lack of high-level education is due to lack of an objective assessment tool. Accordingly, we proposed an innovative assessment tool (SMaRT) which uses statistical shape analysis and has the capacity to proportionally score a spectrum of designs ranging from subtle to significant variations off optimal. During facial reconstruction, where precise planning and execution is paramount for excellent aesthetic and functional outcomes, we hope our novel assessment tool can be incorporated in future simulator development efforts and therefore allow trainees to gain the confidence and safely practice the design skills required to be competent. In order to justify implementation, the SMaRT assessment tool needs to be further validated in terms of construct validity, content validity, reliability, economic utility, and transferability of skills to a clinical scenario.[10]

In order to establish construct validity, the required steps would include providing further data that the assessment tool has the capacity to score proportionally novice and expert designs by collecting design samples from variety of plastic surgery residents at different level of training for a specific design task. Construct validity can be demonstrated if higher level residents outperform novice learners.[11] To achieve this objective in future studies, we aim to recruit a cohort of 5 senior medical students, 5 junior plastic surgery residents, 5 senior plastic surgery residents, and 5 attending plastic surgeons. Participants will first be introduced to the SMaRT assessment tool and the study rationale; subsequently, they will be asked to design a bilobed flap for a sample defect presented on a sketched lateral view of a nose on a smart tablet. Participation in a structured, interactive training module will ensue in order to teach subjects the basic principles of bilobed flap design. The training module will be designed as a series of slides based on the findings of the systematic review discussed in chapter 4. Trainees will be able to practice performing the essential steps presented in a sequential fashion. There will be opportunities for deliberate practice until subject is satisfied with design efforts. Following completion of training, participants will be asked to design a bilobed flap for two sample defects in order to assess for objective improvements in performance as measured by SMaRT assessment tool after undergoing the structured training curriculum. A post-participation survey will be administered to participating staff plastic surgeons in order to establish the model's content validity addressing the value of the feedback provided by SMaRT assessment tool with regards to the flap design tasks and the capacity to show improvements towards competency.

Once construct and content validity of the SMaRT assessment tool is established, another fundamental aspect to be studied would be the reliability of this novel tool. Practically, reliability of the scores can be demonstrated if senior residents, who have developed a rational thought process, score more accurately during multiple repeat design tasks. Accordingly, more junior residents will likely show significant variability in their SMaRT scores due to lack of an established geometric design thought process. Future research should be directed at collecting the SMaRT scores of residents participating in an educational module for a specific flap and defect focusing on repeated designs before and after training using the educational module. Demonstrating that by deliberate practice, the scores improve accordingly will provide evidence that the simulation platform accompanying the educational module has an impact on residents understanding of complex design processes.

Establishing economic utility remains a critical barrier to implementation for any simulation-based assessment tool. With prevalence of smart phones, the subsequent efforts should focus to incorporate the SMaRT assessment tool into a user-friendly mobile application which is compatible to be utilized by personal smart phones, without the need for purchase of further equipment. The potential for real-time feedback, without the need for in-person supervision, provides another educational tool that decreases the burden on educators and the resource intensive need for human supervision. SMaRT assessment tool has immense potential to be cost-effective by allowing independent deliberate practice.

Finally, transferability of the skills attained using a bench-top or digital simulator in conjuction with an educational module should be validated in a clinical scenario. Future studies should focus on recruiting resident learners who perform a design exercise on a simulated patient with a drawn-on lesions of various sizes and locations in clinical scenarios. Expert supervisors would assess the learner's performance based on traditional examiner checklists. Subsequently, the subjects undergo training using an educational module providing real-time feedback using SMaRT assessment tool. The learner's progress would be serially tracked until competency is achieved as per pre-determined thresholds. Transferability of skills would be demonstrated by the improvement in evaluations of residents pre-training compared to post-training performance in clinical scenarios with simulated patients. The above-mentioned concepts to establish validity and justify implementation are of interest to our group and are subject of future studies.

Current benchtop and digital models for local flaps simulation-based education, as discussed in chapter 2, have not been utilized as design assessment tools. The SMaRT assessment tool could potentially be paired with these models. Digital models need software modifications to allow data extraction, which is in the realm of current technologies available. The main challenge remains capturing data points for analysis of benchtop models that have 3D appearance. Simple solution would be to utilize standardized photographs of local flap design markings on benchtop models and to convert these 3D surgical markings into 2D designs. Although possible, efforts to capture 3D data from benchtop models may be cumbersome without significant value added. The advantages of 3D vs. 2D datasets for education of surgical designs remain to be established.

Although current studies presented here focus on bilobed flap as a proof of concept, the SMaRT assessment tool has the potential to be applied to other local flaps. Given its four-component score feedback, the SMaRT tool is effective at, not only discerning mismatch, but also geometric deviations. For example, a rhomboid flap design needs to be properly aligned with relaxed skin tension lines of the face. Determination of orientation remains one of the common challenges when designing the rhomboid flap, which will be reflected in the rotation component of the score. We believe that SMaRT assessment tool or modified versions based on statistical shape analysis have the potential to be applied to other fields of plastic surgery, such as cleft lip or breast reduction surgery, where surgical planning and design dictates the functional and aesthetic outcomes.[12,13] In order to establish the optimal design assessment tool, each design task should be first studied thoroughly utilizing similar methods presented here for the bilobed flap, in order to elucidate the clinically relevant design aspects. Subsequently, similar validation efforts should be done with such complex surgical design tasks with the goal of eventually establishing a surgical design training curriculum for plastic surgery procedures.

In conclusion, the research presented in this thesis provide the foundational steps to move away from subjective assessment of surgical designs to objective, specific, practical feedback while allowing deliberate practice. Finally, with an objective assessment tool available, researchers have the necessary metrics to justify the cost-effectiveness of simulation models developed.

References (Chapters 1,3,5)

1. Kazan R, Cyr S, Hemmerling TM, Lin SJ, Gilardino MS. The Evolution of Surgical Simulation: The Current State and Future Avenues for Plastic Surgery Education. Plast Reconstr Surg 2017;139:533e-43e.
2. Bradley P. The history of simulation in medical education and possible future directions. Medical education 2006;40:254-62.
3. Waltzman JT, Tadisina KK, Zins JE. The Rise of Technology in Plastic Surgery Education: Is the Textbook Dead on Arrival (DOA)? Aesthetic surgery journal 2016;36:237-43.
4. Cosman PH, Hugh TJ, Shearer CJ, Merrett ND, Biankin AV, Cartmill JA. Skills acquired on virtual reality laparoscopic simulators transfer into the operating room in a blinded, randomised, controlled trial. Studies in health technology and informatics 2007;125:76-81.
5. Anastakis DJ, Regehr G, Reznick RK, et al. Assessment of technical skills transfer from the bench training model to the human model. American journal of surgery 1999;177:167-70.
6. Rao JK, Shende KS. Overview of Local Flaps of the Face for Reconstruction of Cutaneous Malignancies: Single Institutional Experience of Seventy Cases. Journal of Cutaneous and Aesthetic Surgery 2016;9:220-5.
7. Bauer F, Koerdt S, Rommel N, Wolff K-D, Kesting MR, Weitz J. Reconstruction of facial defects with local flaps – a training model for medical students? Head & Face Medicine 2015;11:30.
8. Okamoto T, Hirota Y, Kimura Y, Senda E, Ueda K. 3D Separable 2-layered Elastic Models of the Face for Surgical Planning of Local Flaps. Plastic and reconstructive surgery Global open 2018;6:e1857.

9. Stegmann M, Gomez D. A Brief Introduction to Statistical Shape Analysis. Informatics and Mathematical Modelling, Technical University of Denmark, DTU 2002;15.

10. Janis JE, Vedder NB, Reid CM, Gosman A, Mann K. Validated Assessment Tools and Maintenance of Certification in Plastic Surgery: Current Status, Challenges, and Future Possibilities. Plast Reconstr Surg 2016;137:1327-33.

11. Alshuaibi M, Perrenot C, Hubert J, Perez M. Concurrent, face, content, and construct validity of the RobotiX Mentor simulator for robotic basic skills. Int J Med Robot 2020;16:e2100.

12. Deshpande G, Schonmeyr B. Using electronic tablet as a teaching tool for marking cleft lip repairs. Journal of plastic, reconstructive & aesthetic surgery : JPRAS 2015;68:122-3.

13. Gulyas G. Marking the position of the nipple-areola complex for mastopexy and breast reduction surgery. Plast Reconstr Surg 2004;113:2085-90.