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ORIGINAL ARTICLE
Craniofacial

Treatment of Mild-to-moderate Progressive Hemifacial Atrophy by Acellular Dermal Matrix Combined With Preoperative Digital Evaluation

Xinhao Cheng, MS*†
Haijiang Dong, MD, PhD*†
Chengxiang Yan, MS*
Zhibin Li, MS*†
Baihui Xie, MS*
Yu Li, MD, PhD*†
Huilong Liu, MS‡
Yijun Zhang*
Ximei Wang, MD, PhD*†

Background: Progressive hemifacial atrophy (PHA) is a rare condition marked by the gradual degeneration of skin, soft tissues, muscles, and, in advanced stages, bone. The primary approach for managing PHA involves surgical interventions to reconstruct and restore the facial contour. The current treatments each present several limitations. Therefore, there is a critical need for innovative therapeutic methodologies for PHA soft-tissue reconstruction.

Methods: Eight patients diagnosed with Guerrerosantos II and III PHA were included in the study. Preoperative 3-dimensional facial scans were digitally analyzed, and corresponding 3-dimensional-printed models were generated to assess soft-tissue deficiencies. Based on this evaluation, acellular dermal matrix (ADM) was tailored to a stepped, multilayered composite dermis of a specific shape and size. It was then anatomically anchored at precise locations and supplemented with volume filler and ligament-mimicking repairs.

Results: The location, volume, and thickness of the ADM postoperatively were highly compatible with preoperative evaluations, significantly improving the facial contour and morphological and volumetric differences. All patients achieved good healing without other complications and reported improved postoperative scores on the FACE-Q craniofacial modules ($P < 0.05$).

Conclusions: Structural repair of PHA using ADM, guided by preoperative digital assessments, provides a safe, effective, and relatively stable outcome. This approach is innovative for achieving precise facial reconstruction. *(Plast Reconstr Surg Glob Open 2025;13:e6558; doi: 10.1097/GOX.0000000000006558; Published online 21 February 2025.)*

INTRODUCTION

Progressive hemifacial atrophy (PHA), also known as Parry–Romberg syndrome (PRS), is a rare craniofacial disorder characterized by progressive atrophy of the skin, subcutaneous tissue, fat, and, in severe cases, underlying muscle and bone structures with a hemifacial distribution.[1] Disease onset typically occurs within the first 20 years of life, although later onset cases have been described.[2] Symptoms progress over a 2- to 10-year self-limiting period.[3] The pathogenesis of PHA needs to be better understood. Trauma, infection, immune abnormalities,[4,5] trigeminal nerve injury,[6] sympathetic dysfunction, neural crest cell disorder,[7] *MTOR* gene, and *DHX37* gene[8] may all be implicated in this disease. The impact of PHA extends beyond physical appearance. When muscle involvement is significant, patients may struggle with chewing, speaking, and closing the affected eye, leading to complications such as malnutrition, speech difficulties, and eye issues such as dryness and exposure keratitis.[4,9] The international standard staging criteria[10] for PHA are shown in Supplemental Digital Content 1. (**See**

*From the *Medical Cosmetic Center, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, Henan, China; †Zhengzhou Key Laboratory of Tissue Engineering and Plastic Reconstruction, Zhengzhou, Henan, China; and ‡Medical 3D Printing Key Laboratory of Henan Province, Medical 3D Printing Center of Henan Province, Zhengzhou, Henan, China.*

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Drs. Cheng and Dong are co-first authors.

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table, Supplemental Digital Content 1, which displays the Guerrerosantos classification of PHA, **http://links.lww.com/PRSGO/D870**.) The visible nature of the disorder often results in considerable psychological distress, fostering negative self-perception and leading to social withdrawal and isolation.[4]

Current treatments are shown in Supplemental Digital Content 2,[1,11–22] and the current management of PHA with soft-tissue deficiency mainly requires surgical treatment to resolve the facial asymmetry.[7] (**See table, Supplemental Digital Content 2**, which displays surgical treatment methods commonly used for PHA with soft-tissue defect, **http://links.lww.com/PRSGO/D871**.) Vascularized free tissue flaps or muscle flaps, autologous fat grafting (AFG), stromal vascular fraction (SVF) gel grafting, and synthetic tissue fillers all have limitations, so there is an urgent need to develop innovative therapeutic methodologies for PRS soft-tissue reconstruction.

With good histocompatibility and low inflammatory response, acellular dermal matrix (ADM) material, particularly the reticular type, can provide a 3-dimensional (3D) spatial structure to induce fibroblasts and vascular endothelial cells with regenerative ability to grow into their framework through extracellular matrix components and intrinsic growth factors, which increases the cell volume and promotes the regenerative repair of subcutaneous soft tissues.[23] Preoperative digital analysis techniques can provide a more precise and objective estimation of the location, area, shape, and thickness of soft-tissue defects, greatly enhancing the accuracy of preoperative assessment, treatment planning, and surgical outcome prediction and improving the operators' and patients' concrete grasp of the surgical procedures, thus realizing precise repair.[24,25]

Over 13 years of clinical practice, our team has experienced a 3-phase approach for treating mild-to-moderate PRS. Initially, we combined autologous free tissue flap transplantation with Medpor for mandibular reconstruction. This evolved into a dual approach using autologous free tissue flap with second-stage AFG and, most recently, ADM combined with second-stage AFG. Our preoperative evaluation methods have also advanced from 16-slice computed tomography scanning to 3.0T magnetic resonance imaging and, ultimately, to digital 3D scanning. For patients with mild-to-moderate PHA, we have now developed a 2-stage facial reconstruction technique: ADM based on preoperative 3D digital assessment, followed by secondary AFG. Since 2022, this innovative approach has yielded successful first-stage procedures in 8 patients, with 2 completing their second-stage procedures and achieving highly satisfactory outcomes. This article summarized the results of our phase 1 procedures, offering new insights for mild-to-moderate PRS.

Takeaways

Question: Are there any innovative therapeutic methodologies for Parry–Romberg syndrome soft-tissue reconstruction?

Findings: For patients with mild-to-moderate progressive hemifacial atrophy, we have developed a 2-stage facial reconstruction technique: acellular dermal matrix based on preoperative 3-dimensional digital assessment, followed by secondary autologous fat grafting. This approach has yielded successful first-stage procedures in 8 patients, with 2 completing their second-stage procedures. First-stage procedures can achieve the dual goals of soft-tissue augmentation and morphological and structural reconstruction.

Meaning: This study provided new surgical perspectives for patients with mild-to-moderate progressive hemifacial atrophy.

METHODS

Study Design

Fourteen patients diagnosed with PHA who received surgical treatment from Prof. Ximei Wang at the Medical Aesthetic Center of the First Affiliated Hospital of Zhengzhou University between September 2021 and July 2024 were included in this study; 8 cases were included according to the criteria. The inclusion criteria were as follows: diagnosis by 3 craniomaxillofacial plastic surgeons (more than 3 years in the field) as Guerrerosantos II and III PHA[10]; no bone repair indications; no other congenital craniomaxillofacial deformities, tumors, injuries, or infections; nonprogressive disease state for at least 1 year before surgical treatment; well-documented preoperative computed tomography, magnetic resonance imaging, and digital analysis data; no mental deficits or systemic diseases; and informed consent given to participate in this study.

Preoperative Design and Planning

Preoperative 3D scanning of the patient's craniomaxillofacial region was conducted using a multifunctional handheld 3D scanner (Shining 3D, EinScan Pro 2X Plus, China). The image data were analyzed using Materialise's interactive medical image control system (Mimics, Leuven, Belgium). (**See figure, Supplemental Digital Content 3**, which shows a flowchart of the digital analytics process, **http://links.lww.com/PRSGO/D872**.) This process enabled the creation of 3D models of the soft-tissue defects, allowing for an accurate preoperative assessment of the volume, shape, area, thickness, and position of the soft-tissue deficiency requiring repair.

In addition to 3D scanning, standardized preoperative photographs of each patient's face were taken. Patients also evaluated their subjective aesthetic outcomes by completing the FACE-Q craniofacial module, which included assessments of the operative area, face, face appearance of the smile, appearance distress, psychological function, and social function. All scales were scored on a percentage basis.

Surgical Procedure

Initially, the first-stage surgical plan was precisely guided by the 3D model and scanning data analysis of the soft-tissue defect, combined with the anatomical structure of the atrophic area. This approach determined the ADM's anticipated size, shape, and placement.

Next, the target area for ADM placement was marked on the skin surface. The designated area was then isolated from the superficial muscular aponeurotic system (SMAS) and elevated to create a well-defined subcutaneous tunnel. Using a calibrated ruler and nonabsorbable sutures, the ADM (Model No. J-1 Type A, Beijing Jayyalife Biological Technology Co., Ltd., China) was strategically folded, trimmed, and pieced together to form a layered composite dermis that matched the required shape, size, and volume.

The composite dermis was then elevated and placed into the prepared subcutaneous pocket. The margins were secured to the adjacent skin using monofilament absorbable sutures, ensuring stability and integration. The primary focus was to anchor the ends of the composite dermis at the origin and termination points of critical ligaments or muscles within the atrophic area, thereby reconstructing the facial structure and layers. (**See figure, Supplemental Digital Content 4**, which shows a map of the facial area and important superficial muscles, **http://links.lww.com/PRSGO/D873**.)

Postoperative Evaluation

Postoperatively, each patient's face was photographed in a standard position. The patients completed the FACE-Q craniofacial module. Subjective aesthetic improvement was evaluated by an independent third party (ie, 2 plastic surgeons not involved in this study).[26]

Statistical Analysis

This study utilized SPSS version 25.0 to perform normality tests and appropriate paired *t* tests or Wilcoxon signed-rank tests on the preoperative and postoperative scores from 6 sets of the FACE-Q craniofacial module completed by patients.

RESULTS

The Demographic Information and Baseline Characteristics

The study enrolled 8 patients diagnosed with Guerrerosantos type II and III PHA. The preoperative self-assessed FACE-Q facial function scale score was uniformly zero. Detailed patient information is presented in Table 1. The follow-up period was 6–27 months (mean 16 mo).

Preoperative Digital Evaluation and 3D Printing

The preoperative images generated by the 3D scanning and digital analysis software and the 3D-printed one-to-one model of the facial defect section guiding the surgery are shown in Figures 1A-C. Preoperative assessment data of the facial defects in the 8 enrolled patients are shown in Table 2.

Therapeutic Results

The average preoperative ADM size in all 8 patients was 6.475 cm^2, with a thickness of approximately 1 mm in its freshly unsealed state. ADM placement, volume, and thickness corresponded closely with the preoperative goals of the 1-stage procedure based on 3D assessments (Figs. 1D, E). Postoperatively, there was a significant improvement in morphological and volumetric symmetry between the affected and unaffected sides (Fig. 2). It achieves both morphological and structural reconstruction, which benefits the patient's facial function and mental health in the later stages of restoration and provides the proper chamber and levels for the second stage of AFG. (**See figure, Supplemental Digital Content 5**, which shows preoperative and postoperative score changes on the FACE-Q craniofacial module, **http://links.lww.com/PRSGO/D874**.)

Safety Results

In 7 patients, the subcutaneous tissue in the treated area was slightly firmer to the touch than the surrounding normal tissue; however, this did not impact facial expression. Over 1–2 years, the subcutaneous tissue in the treated area gradually softened. One patient experienced occasional tingling at the incision site, which significantly improved and resolved within 6 months postoperatively. Another patient reported mild itchiness in the treated area during high temperatures, which improved and resolved within 6 months. All patients exhibited good healing without complications such as allergic reactions, infections, granuloma formation, migration or extrusion, or overcorrection.

Satisfaction

Data on the patients' preoperative and postoperative scores on the FACE-Q craniofacial scale are shown in Table 3 and Supplemental Digital Content 5 (**Supplemental Digital Content 5**, **http://links.lww.com/PRSGO/D874**). The results of the independent third-party evaluations are shown in Supplemental Digital Content 6. (**See figure,**

Table 1. The Information of All Enrolled Patients

Number	Sex	Age at Consultation, y	Side of Disease	Guerrerosantos Typing	Age of Onset, y	Time Since Onset, y
1	Male	24	Left	III	5	19
2	Male	17	Left	III	1	16
3	Male	12	Right	II	6	6
4	Female	23	Right	III	3	20
5	Female	31	Left	II	27	4
6	Female	20	Right	II	12	8
7	Female	17	Left	II	11	6
8	Female	20	Left	II	5	15

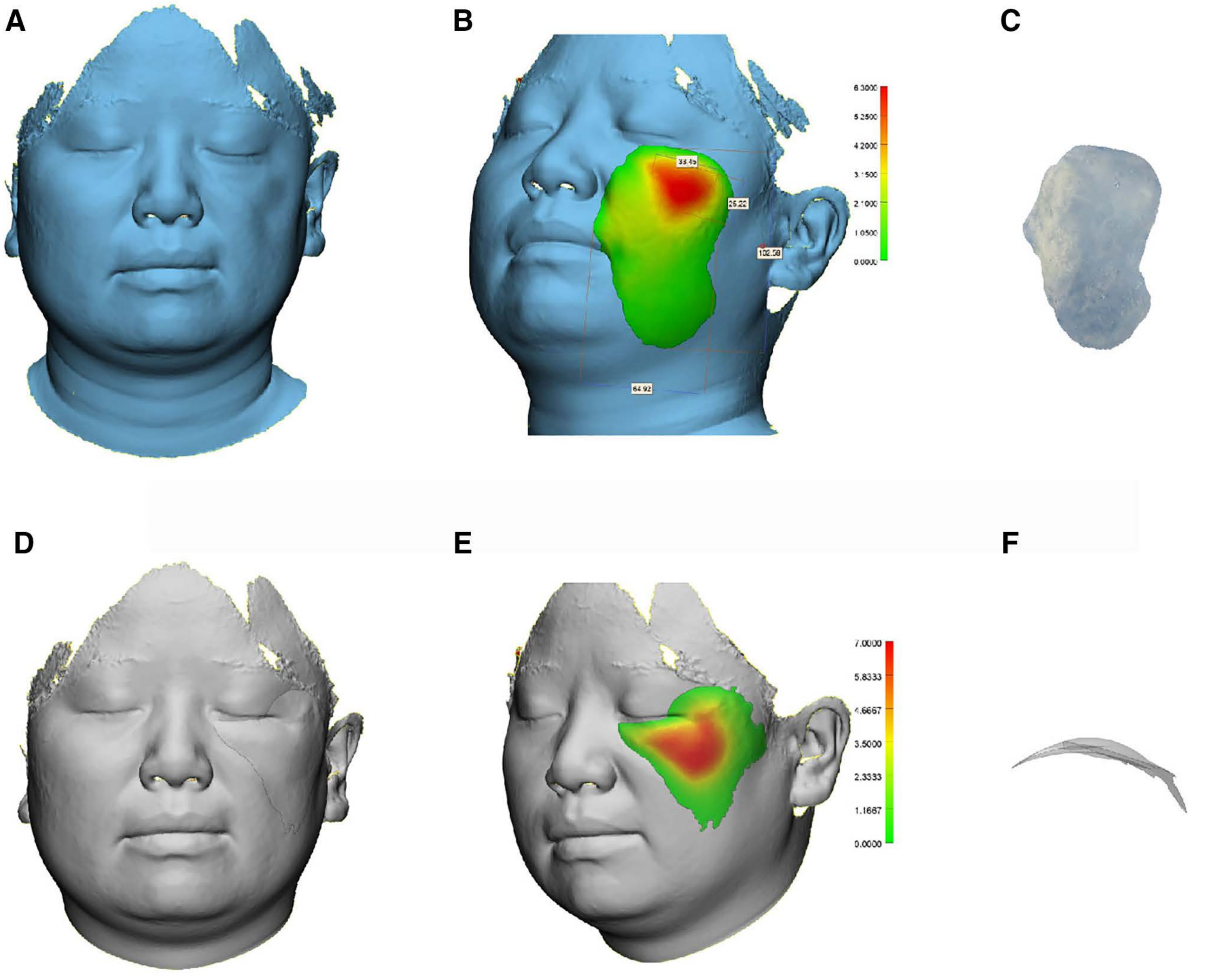

Fig. 1. A graph that shows digital analysis and 3D printing of preoperative soft-tissue deficits in case 1, along with postoperative digital analysis of the soft-tissue augmentation: Preoperative assessment revealed a maximum soft-tissue depression of approximately 6.9 mm, with a surface area of about 1085 mm^2 where the depth exceeded 4 mm. Postoperative analysis showed a maximum soft-tissue gain of approximately 7 mm. A, Orthostatic view of preoperative patient scan data. B, Size measurement and depth distribution of facial defects. C, One-to-one 3D modeling of defects. D, Frontal view of postoperative changes relative to preoperative changes. E, Thickness analysis of the increased portion of the postoperative relative to the preoperative period. F, Partial fluoroscopic view of postoperative changes relative to preoperative changes.

Table 2. Patient Assessment of Preoperative Anterior Soft-tissue Defects

Number	Preoperatively Evaluated Soft-tissue Defect (mm^3)	Depression Depth Maximum (mm)	Exterior Area of the Defective Part (mm^2)
1	18,153	9.8	1003
2	10,621	3.25	6643
3	2285	5	1239
4	3784	6.5	1723
5	9842	6.3	1085
6	6310	6.5	2723
7	6194	5.4	3426
8	5570	5.37	2697

Supplemental Digital Content 6, which shows the percentage of third-party evaluation results, **http://links.lww.com/PRSGO/D875**.)

Case Reports

Case 1

A 31-year-old woman presented with type II PHA on the left side of her face, as classified by Guerrerosantos. She had experienced hemifacial atrophy for 4 years, with the deepest depression in the left zygomatic region measuring approximately 6.3 mm, and a surface area with a depression depth greater than 4 mm measuring 1085 mm^2 (Fig. 1B). During surgery, 2 reticulated ADM pieces (5×6 cm^2) were tailored and sutured to create a composite dermis, anchored primarily at the origins and insertions of the zygomatic arch ligaments and the lower half of the orbicularis oculi muscle. The face appeared slightly bloated 1 week postoperatively (Figs. 2C, D). The thickest portion of the postoperative increase compared with the preoperative period was approximately 7 mm, with a total volume increase of 9842 mm^3 (Figs. 1D-F).

Fig. 2. A photograph of a 31-year-old woman presented with type II PHA, as classified by Guerrerosantos, who underwent ADM implantation. The patient is shown preoperatively (A, B), 1 week postoperatively (C, D), and 4 months postoperatively (E, F).

Table 3. Statistics of Differences in Postoperative Relative Preoperative Scale Scores

Data Categories	The Operative Area	Face	Appearance of the Smile	Appearance Distress	Psychological Function	Social Function
Preoperative mean	30.75	27.375	27.5	55.38	52.25	58.88
Postoperative mean	43.625	46.37	42.88	62.75	57.5	61.38
t/*Z* value	4.937*	2.371†	5.498*	5.218*	2.527†	4.677*
P value	0.002	0.018	0.001	0.001	0.012	0.002

A *P* value of less than 0.05 is considered statistically significant.
*The *t* values derived from the paired sample *t* tests.
†The *Z* values from the Wilcoxon signed-rank test.

Follow-up indicated significant improvement in facial contour and symmetry. The patient experienced slight itching in the operated area when the ambient temperature was high, which resolved within 6 months. A symmetrical facial appearance was achieved 4 months postoperatively (Figs. 2E, F), and the patient expressed high satisfaction with the aesthetic outcome.

Case 2

A 12-year-old boy presented with type I PHA on the right side of his face, as classified by Guerrerosantos. He had experienced hemifacial atrophy for 6 years, with facial defects primarily in the right chin region. The thickest part of the defect was approximately 5 mm, with a volume of 2285 mm^3 and an external area of 1239 mm^2. (**See figure, Supplemental Digital Content 7**, which shows digital analysis of preoperative soft-tissue defects in case 2, **http://links.lww.com/PRSGO/D876**.) During surgery, we made a hidden incision on the surface of the diastasis fossa, and 2 reticulated ADM pieces (5 × 6 cm^2) were trimmed and sutured to form a composite dermis with 4 layers in the deepest part of the depression and 2 layers in the marginal areas. The ADM was anchored at the origin and termination points of the mentalis and depressor labii inferioris

Fig. 3. A photograph of a 12-year-old boy presented with type II PHA, as classified by Guerrerosantos, who underwent ADM implantation. The patient is shown before first-stage surgery (A, B), 1-month after first-stage surgery (C, D), 6 months after first-stage surgery (E), 1-year after first-stage surgery (F), 1-day after second-stage surgery (G), and 1-week after second-stage surgery (H).

muscles. Postoperative follow-up showed significant improvement in facial contour and symmetry with no adverse effects (Fig. 3). The chin appeared slightly bloated 1 month postoperatively (Figs. 3C, D). By 6 months, a good chin appearance was achieved (Fig. 3E), and the patient expressed high satisfaction with the aesthetic outcome. One year after surgery, the ADM filler remained in position (Fig. 3F). The patient subsequently underwent a second stage of AFG. After this procedure, the contour of the defected area was soft and natural, and both the doctor and patient were pleased with the results (Figs. 3G, H).

DISCUSSION

Effectiveness of the Treatment

ADM, a biological scaffold rich in collagen and growth factors, provides structural support for tissue regeneration and integration with the patient's tissue. The SMAS constitutes the third facial layer but is considered a conceptual structure in areas such as the cheek.[27] In Guerrerosantos II and III PHA, where the skin, subcutaneous tissue, and muscles are affected, with occasional minor bone involvement, the SMAS is often more extensively deficient. Among the patients we treated, we focused on areas such as the forehead, the inferomedial and lateral infraorbital regions, the medial zygomatic region, the cheek, and the chin. The muscle ligaments involved included the frontalis muscle, corrugator supercilii, zygomatic ligament, orbicularis oculi retaining ligament, zygomaticus muscle, and mentalis muscle (**Supplemental Digital Content 4, http://links.lww.com/PRSGO/D873**). We reconstructed the atrophic structures based on anatomical principles, using the superficial facial muscles as a foundation, effectively rebuilding the atrophied or absent SMAS for PHA patients. This reconstruction provided a safe approach for soft-tissue augmentation in patients with mild-to-moderate defects, achieving structural and functional restoration while creating an appropriate plane for secondary AFG. As a result, subsequent dynamic outcomes were more symmetrical and naturally expressive, contributing to improved psychological well-being for the patients. It is worth mentioning that this article only statistically analyzes and shows the ADM implantation effect of 1 phase, not the final effect. ADM's low resorption rate ensures long-term stability, reducing the need for surgical revisions and lowering cumulative healthcare costs. The alignment of ADM's position, volume, and thickness with preoperative digital analysis results demonstrates the precision and predictability of advanced digital planning tools, setting a benchmark for integrating 3D reconstruction and digital analysis in surgical planning.[28]

Safety of the Treatment

ADM gradually softens over 1–2 years, indicating good tissue compatibility despite initial firmness. Patients experienced tingling and itching sensations that resolved spontaneously within 6 months, with no severe complications observed, such as allergic reactions, infections, granuloma formation, or ADM displacement/extrusion. These findings support ADM's safety and reliability as a soft-tissue augmentation material in facial reconstructive surgery.

Comparative Analysis

Recent studies[28–32] on PHA soft-tissue defect treatment have focused on approaches such as free flap transplantation or AFG. Our method involves surgical filling of the atrophic area using ADM and offers several advantages over free tissue flaps and muscle flaps, including avoiding donor site injury, easy availability, and ease of shaping during surgery. Postoperative observation over 6 months revealed no hypertrophy or sagging in the treated area, with ADM maintaining its volume and structural integrity. (**See figure, Supplemental Digital Content 8**, which shows a 21-year-old female patient who presented with type II PHA, as classified by Guerrerosantos, 10 years after transplantation of a free latissimus dorsi muscle flap, **http://links.lww.com/PRSGO/D877**.) AFG for treating mild-to-moderate PHA has a survival rate of only around 40%.[1] Each procedure often requires overcorrection of 20%–30%, with an average of more than 3 surgical sessions, and some patients may undergo as many as 8 procedures.[33] Although high-density fat grafting–assisted SVF gel[34] can enhance the clinical utilization of fat, it does not resolve the issue of fat source availability. Furthermore, multiple procedures introduce various uncontrollable risks, particularly increasing anesthesia risks in pediatric patients.[35] In contrast, ADM does not have survival rate concerns. Using ADM as a foundational support in the first stage significantly alleviates issues related to fat source availability. ADM can also be anchored according to ligament orientation, ensuring stable shape during facial movements. Additionally, it does not require the complex preparation process associated with SVF gels and has fewer adverse reactions than synthetic tissue fillers.

Limitations

Limitations of this study include potential missing or incomplete data, a limited number of patients, and variability in follow-up duration, which may affect the generalizability of our results and the ability to assess long-term effectiveness and potential complications. Evaluation at 3 months postoperatively may be affected by the presence of swelling. ADM is also expensive, particularly for extensive tissue defects. Combining ADM with secondary AFG[33,34] could alleviate financial burdens. Additionally, using 3D technology requires advanced computer skills or the involvement of a technical team, posing a barrier for some surgeons. Despite these limitations, our study contributes valuable insights into the existing literature on surgical treatment options for PRS.

Future Directions

Expanding research to include a larger and more diverse patient population will help validate our findings across different demographic groups. Collaborative clinical trials and long-term outcome evaluations could refine treatment strategies and explore novel therapeutic combinations. ADM's role as a scaffold for tissue engineering holds promise for regulating cellular behavior through microRNAs.[36] Integrating digital technology in PHA management is revolutionary, potentially advancing digital imaging and surgical planning technologies. The rapid development of 4D imaging and virtual reality technologies offers new possibilities for improving surgical accuracy and patient outcomes. Combining 3D photography with artificial intelligence to create a large-scale facial 3D photograph database could link facial features with demographic characteristics, genotypes, and biochemical markers, leading to a "facial omics" approach that could enhance disease diagnosis, treatment, and assessment.

CONCLUSIONS

This study provided new surgical perspectives for patients with mild-to-moderate PHA. ADM based on preoperative digital analysis for the treatment of PHA soft-tissue defects can achieve the dual goals of soft-tissue augmentation and morphological and structural reconstruction and lead to safe, effective, relatively stable, and patient-satisfying results; however, further studies are needed for validation and expansion. Digital analysis technology allows the precise preoperative assessment of facial soft-tissue deformities. Reconstructive surgeons may be able to use 3D software to assist in planning intricate procedures with more pleasing results as costs decrease.

Ximei Wang, MD, PhD
No. 1, Longhu Zhonghuan Road
Zhengdong New District, Zhengzhou City
Henan Province 450018, China
E-mail: tracywang@zzu.edu.cn

DISCLOSURES

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PATIENT CONSENT

Patients provided written informed consent for the use of their images.

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All FACE-Q scales in this study are used under license.

ETHICAL APPROVAL

This study was approved by the ethics committee of the First Affiliated Hospital of Zhengzhou University (approval no.: 2024-KY-0677-001).

REFERENCES

1. Schultz KP, Dong E, Truong TA, et al. Parry Romberg syndrome. *Clin Plast Surg.* 2019;46:231–237.
2. Bucher F, Fricke J, Neugebauer A, et al. Ophthalmological manifestations of Parry-Romberg syndrome. *Surv Ophthalmol.* 2016;61:693–701.
3. Amaral TN, Peres FA, Lapa AT, et al. Neurologic involvement in scleroderma: a systematic review. *Semin Arthritis Rheum.* 2013;43:335–347.
4. Tolkachjov SN, Patel NG, Tollefson MM. Progressive hemifacial atrophy: a review. *Orphanet J Rare Dis.* 2015;10:39.
5. Sommer A, Gambichler T, Bacharach-Buhles M, et al. Clinical and serological characteristics of progressive facial hemiatrophy: a case series of 12 patients. *J Am Acad Dermatol.* 2006;54:227–233.
6. Skolka MP, Marks LA, Jones LK, et al. Trigeminal nerve electrophysiological findings in hemifacial atrophy: a systematic literature review and retrospective chart review. *Clin Neurophysiol Pract.* 2021;6:50–55.
7. Shah SS, Chhabra M. Parry-Romberg Syndrome. In: *StatPearls.* Treasure Island (FL): StatPearls Publishing; 2022.
8. Yu BF, Dong LP, Dai CC, et al. Genetic variations in patient with Parry–Romberg syndrome. *Sci Rep.* 2023;13:400.
9. Bucher F, Fricke J, Neugebauer A, et al. Ophthalmological manifestations of Parry-Romberg syndrome. *Surv Ophthalmol.* 2016;61:693–701.
10. Zhang Y, Zhang C, Li Y, et al. Evolution of biomimetic ECM scaffolds from decellularized tissue matrix for tissue engineering: a comprehensive review. *Int J Biol Macromol.* 2023;246:125672.
11. Kang HY, Shin HS. Is the mirroring technology reliable in the use of computer-aided design for orbital reconstruction? Three-dimensional analysis of asymmetry in the orbits. *Plast Reconstr Surg.* 2022;149:453–460.
12. Day KM, Kelley PK, Harshbarger RJ, et al. Advanced three-dimensional technologies in craniofacial reconstruction. *Plast Reconstr Surg.* 2021;148:94e–108e.
13. Chai G, Tan A, Yao CA, et al. Treating Parry-Romberg syndrome using three-dimensional scanning and printing and the anterolateral thigh dermal adipofascial flap. *J Craniofac Surg.* 2015;26:1826–1829.
14. He L, Liu X, Khatter NJ, et al. Treatment of progressive hemifacial atrophy by cartilage graft and free adipofascial flap combined with 3D planning and printing. *Plast Reconstr Surg.* 2024;153:679-688.
15. Denadai R, Raposo-Amaral CA, da Silva SA, et al. Complementary fat graft retention rates are superior to initial rates in craniofacial contour reconstruction. *Plast Reconstr Surg.* 2019;143:823–835.
16. Denadai R, Buzzo CL, Raposo-Amaral CA, et al. Facial contour symmetry outcomes after site-specific facial fat compartment augmentation with fat grafting in facial deformities. *Plast Reconstr Surg.* 2019;143:544–556.
17. Xiang X, Jiang Z, Che D, et al. Application of free serratus anterior muscle-fascial composite tissue flap and facial lipofilling in repairing of progressive hemifacial atrophy. *Asian Journal of Surgery.* 2024;47:973–981.
18. Israel JS, Chen JT, Farmer RL, et al. Challenging traditional thinking: early free tissue transfer for active hemifacial atrophy in children. *Plast Reconstr Surg.* 2020;145:483–492.
19. Jeon FHK, Koneswaran K, Varghese J, et al. Autologous fat grafting provides good outcomes as a soft-tissue replacement in hemifacial atrophy. *Aesthet Surg J.* 2020;40:NP103–NP105.
20. Cao Z, Li H, Wang ZH, et al. High-density fat grafting assisted stromal vascular fraction gel in facial deformities. *J Craniofac Surg.* 2022;33:108–111.
21. Miller KJ, Brown DA, Ibrahim MM, et al. MicroRNAs in skin tissue engineering. *Adv Drug Deliv Rev.* 2015;88:16–36.
22. Jiang Y, Yang M, Wang S, et al. Emerging role of deep learning-based artificial intelligence in tumor pathology. *Cancer Commun (Lond).* 2020;40:154–166.
23. Gulshan V, Peng L, Coram M, et al. Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. *JAMA.* 2016;316:2402–2410.
24. Weinberg SM, Raffensperger ZD, Kesterke MJ, et al. The 3D facial norms database: part 1. A web-based craniofacial anthropometric and image repository for the clinical and research community. *Cleft Palate Craniofac J.* 2016;53:e185–e197.
25. Jurkiewicz MJ, Nahai F. Its use as a free vascularized graft for reconstruction of the head and neck. *Ann Surg.* 1982;195:756–765.
26. Zhao J, Guo X, Lai C, et al. Successful treatment and long-term follow-up of Parry-Romberg syndrome with anterolateral thigh adipofascial flap. *Plast Reconstr Surg.* 2021;154:326e-334e.
27. Markey J, Seth R, Wang S, et al. Anterolateral thigh adipofascial flap: a new option for scalp reconstruction. *J Reconstr Microsurg.* 2015;32:160–163.
28. Hwang JH, Hwang K, Bang SI, et al. Reliability of vascular territory for a circumflex scapular artery–based flap. *Plast Reconstr Surg.* 2009;123:902–909.
29. Vaienti L, Soresina M, Menozzi A. Parascapular free flap and fat grafts: combined surgical methods in morphological restoration of hemifacial progressive atrophy. *Plast Reconstr Surg.* 2005;116:699–711.
30. Baek R, Heo C, Kim B. Use of various free flaps in progressive hemifacial atrophy. *J Craniofac Surg.* 2011;22:2268–2271.
31. Chang SM, Hou CL, Xu DC. An overview of skin flap surgery in the mainland china: 20 years' achievements (1981 to 2000). *J Reconstr Microsurg.* 2009;25:361–367.
32. del Castillo Pardo de Vera JL, Navarro Cuéllar C, Navarro Cuéllar I, et al. Clinical and surgical outcomes in extensive scalp reconstruction after oncologic resection: a comparison of anterolateral thigh, latissimus dorsi and omental free flaps. *J Clin Med.* 2021;10:3863.
33. Seth I, Bulloch G, Gibson D, et al. Autologous fat grafting in breast augmentation: a systematic review highlighting the need for clinical caution. *Plast Reconstr Surg.* 2024;153:527e–538e.
34. Jeon FHK, Varghese J, Griffin M, et al. Fat hypertrophy as a complication of fat transfer for hemifacial atrophy. *Aesthet Surg J.* 2020;40:NP123–NP130.
35. Yao Y, Cai J, Zhang P, et al. Adipose stromal vascular fraction gel grafting: a new method for tissue volumization and rejuvenation. *Dermatol Surg.* 2018;44:1278–1286.
36. Cai J, He Y, Liao Y, et al. Adipose component transplantation: an advanced fat-grafting strategy for facial rejuvenation. *Plast Reconstr Surg.* 2024;153:549e–554e.