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ORIGINAL RESEARCH

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A novel treatment approach for traumatic scalp defects with exposed calvaria denuded of pericranium by combined application of low-temperature plasma and negative pressure wound therapy: A case series

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Abstract

Background and Aims: Traumatic scalp defects with an exposed calvaria denuded of the pericranium are challenging to manage. In such cases, adjunctive therapies, such as milling the outer calvarial cortex and applying negative pressure wound therapy (NPWT), can promote granulation tissue. This case series describes the successful management of traumatic scalp defects after cortical craniectomy using a combination of low-temperature plasma (LTP) and NPWT.

Methods: This is a retrospective single-surgeon case series. Three patients with traumatic scalp wound defects underwent cortical calvarial bone removal after LTP combined with NPWT. LTP was applied to the diploic space of the calvaria weekly or twice weekly using BioPlasmaJet BPJ1 (BIOPlasma System: Model-BioPlasmaJet System). Subsequently, NPWT was applied with a continuous pressure of 110 mmHg until good granulation tissue formation was achieved for skin graft placement.

Results: Two males and one female were included, and the mean follow-up duration was 7 (range 3–12) months. In addition, the average time to achieve good granulation tissue formation was 4 (2–6) weeks; all patients achieved successful split-thickness skin grafting within 3 weeks after placement without signs of calvarial infection.

Conclusions: The combination of LTP and NPWT is a safe and effective treatment modality for scalp defects with exposed calvaria denuded of the pericranium resulting from trauma. Combining these two therapies may provide a synergistic effect that enhances granulation tissue formation and prevents local infections without complications.

KEYWORDS

negative-pressure wound therapy, periosteum injuries, plasma gases, scalp injuries, skull surgery

1 | INTRODUCTION

Traumatic scalp defects with exposed calvaria denuded of the pericranium can be challenging to manage and may require multiple interventions to achieve optimal healing and functional and esthetic outcomes, particularly when there is partial treatment by other surgeons. The exposed calvarial bone is prone to desiccation, sequestration, and sepsis[1]; therefore, early reconstruction or proper wound dressing in this area is of the utmost importance. Where reconstruction with a local or free flap is impossible, skin grafting is a quick, easy, and reliable method for reconstructing medium-to-large scalp defects when cosmesis is not a concern.[1] However, exposed calvaria denuded of the pericranial cover is often followed by poor skin graft adherence and survival. Adjunctive therapies that promote granulation tissue formation for skin grafting include milling or drilling of the outer cortex of the calvaria, cortical craniectomy to expose the diploic space, and negative-pressure wound therapy (NPWT).[1–4]

NPWT is a well-established treatment that uses negative pressure to promote wound healing by removing excess fluid, improving blood flow, reducing bacterial colonization, and promoting granulation tissue formation. However, most patients complain of pain during its application.[5]

Low-temperature plasma therapy (LTP) is a novel treatment modality that promotes wound healing by inducing angiogenesis and promoting cell proliferation and migration via intracellular signaling pathways. Moreover, it has been shown to reduce inflammation and exhibit antimicrobial properties via lipid peroxidation.[6–9]

In this case series, I describe my experience using a combination of NPWT and LTP after cortical craniectomies to promote granulation tissue formation, prevent local infection of traumatic scalp defects with exposed calvaria denuded of the pericranium, and potentially decrease the duration of NPWT in three patients.

2 | CASE PRESENTATION

I present a series of three patients with traumatic scalp defects and exposed calvariae denuded of the pericranium that was initially managed by other surgeons. In all cases, granulation tissue formation was poor. The patients had no significant medical history, and there was no evidence of wound infection. The patients were referred to the Tertiary Nakornping Hospital for further management between December 2021 and January 2023. Summary patient data are shown in Table 1.

2.1 | Case 1

A 37-year-old male patient was referred from a regional hospital with a scalp defect (6 cm wide × 18 cm long) from a lightning burn. The patient had undergone debridement, drilling of the outer cortex of the calvaria, and NPWT 9 months before referral. The scalp defect was in the central vertical to frontal region, with exposed calvaria

TABLE 1 Summary patient data.

Patient	Sex	Aged (year)	Caused	Duration of before referral (day)	Scalp defect (width, cm)	Scalp defect (length, cm)	Old granulation tissue coverage area (%)	Complete granulation tissue coverage (week)	Frequency of LTP therapy (week)	Complications	Pain on applied NPWT	Pain on applied LTP therapy
Case 1	Male	37	Lightening	270	6	18	15	4	1	None	Moderate	No
Case 2	Female	17	Motor cycle accident	12	8	10	2	6	2	None	Severe	No
Case 3	Male	35	Motor cycle accident	17	4	12	70	2	2	None	Mild	No

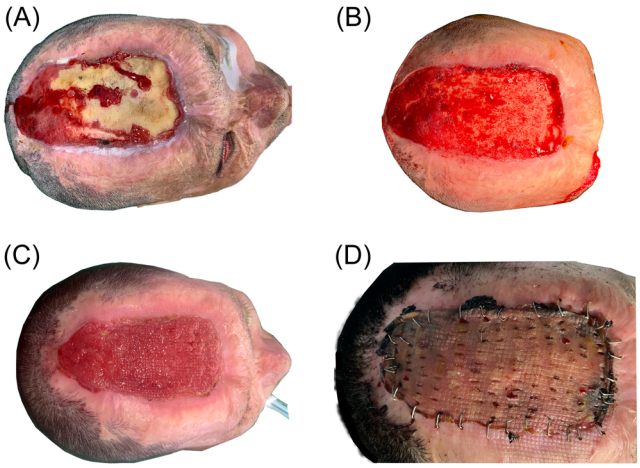

FIGURE 1 A 37-year-old male patient was referred from the regional hospital with a 6 × 18 cm scalp defect. The scalp defect was in the central vertical to frontal region, with the exposed calvaria denuded of pericranium and some granulation tissue estimated to cover approximately 15% of the scalp defect (A), followed by an initial complete cortical craniectomy and removal of old granulation tissue (B). After 4 weeks of treatment, the wound showed significant granulation tissue formation (C), and a split-thickness skin graft was placed (D).

denuded of the pericranium and some granulation tissue covering approximately 15% of the scalp defect (Figure 1A). After the initial complete cortical craniectomy and removal of the old granulation tissue, as shown in Figure 1B, the patient was treated with LTP therapy for 30 min followed by NPWT with continuous−110 mmHg pressure; the procedure was repeated a week later. After 4 weeks of treatment, the wound showed significant granulation tissue formation, suitable for reconstruction with a split-thickness skin graft (Figure 1C,D). There was no evidence of local infection or adverse treatment effects; however, the patient reported moderate pain and discomfort throughout the NPWT treatment period, which was controlled with opioid medication.

2.2 | Case 2

A 17-year-old female patient with an 8 × 10 cm scalp defect from a motorcycle accident had undergone debridement and suturing of the wound 12 days before the referral from the regional hospital. The scalp defect was in the right frontal region, with the exposed frontal bone denuded of the pericranium and some granulation tissue formation covering approximately 2% of the area at the border of the scalp defect (Figure 2A–C). After the initial cortical craniectomy and wound debridement (Figure 2D,E), the patient was treated with LTP therapy for 30 min followed by NPWT with continuous−110 mmHg pressure, and the LTP procedure and NPWT were repeated after a week. Photographs taken on postoperative Days 7, 14, and 28 are shown in Figure 2F–H. A second cortical craniectomy was performed after 4 weeks of treatment because some areas did not show granulation tissue formation. Intraoperatively, the residue of the outer cortex of the calvaria was easily removed through milling. After 6 weeks of treatment, the wound showed significant granulation tissue formation, suitable for reconstruction with a split-thickness skin graft (Figure 2H,I). Photographs from postoperative Days 7, 14, and 28 after wound coverage with a split-thickness skin graft are shown in Figure 2J–N. There was no evidence of infection or adverse treatment effects. The patient reported severe pain and discomfort throughout the treatment period with NPWT, which was controlled with opioid medication.

2.3 | Case 3

A 35-year-old male patient with a 4 × 12 cm scalp defect from a motorcycle accident had undergone debridement and suturing of the wound 17 days previously and was referred from the regional hospital. The scalp defect was in the right parietal region, with exposed parietal bone denuded of the pericranium and granulation tissue covering approximately 70% of the scalp defect (Figure 3A). After the initial cortical craniectomy and wound debridement (Figure 3B), the patient received LTP therapy for 15 min in the diploic space. Old granulation tissue following NPWT was subjected to continuous negative pressure of−110 mmHg; this was repeated over the next 4 days. After 2 weeks of treatment, the wound showed significant granulation tissue formation, suitable for reconstruction with a split-thickness skin graft (Figure 3C). The wound showed good granulation tissue formation after debridement (Figure 3D). Photographs from postoperative Days 7, 14, 21, and 28 after wound coverage with the split-thickness skin graft are shown in Figure 3E–H. The patient reported mild pain and discomfort throughout the treatment period with NPWT, which was controlled with nonopioid medication.

3 | DISCUSSION

Traumatic scalp defects with exposed calvariae denuded of the pericranium can be challenging to manage; the decision to follow the reconstructive ladder is not straightforward, owing to partial treatment. Scalp reconstruction should be based on the defect's location, size, etiology, tissue quality, wound environment, exposed structures, and hairline distortion.[1] The simplest reconstruction should be used to provide the most functional and esthetic scalp reconstruction with the least complexity.[1] The unique characteristic of the scalp that should be considered before reconstruction to provide an esthetic outcome is whether it is a hair-bearing or non-hair-bearing area.[1]

Skin grafting is unlikely to take on the denuded bone owing to a lack of a suitable vascular bed to close the wound; thus, granulation of the exposed bone needs to occur.[2,10] The estimated time of granulation tissue formation in weeks equals three times its diameter in centimeters.[2] Spilt-thickness skin grafting is a quick, easy, and

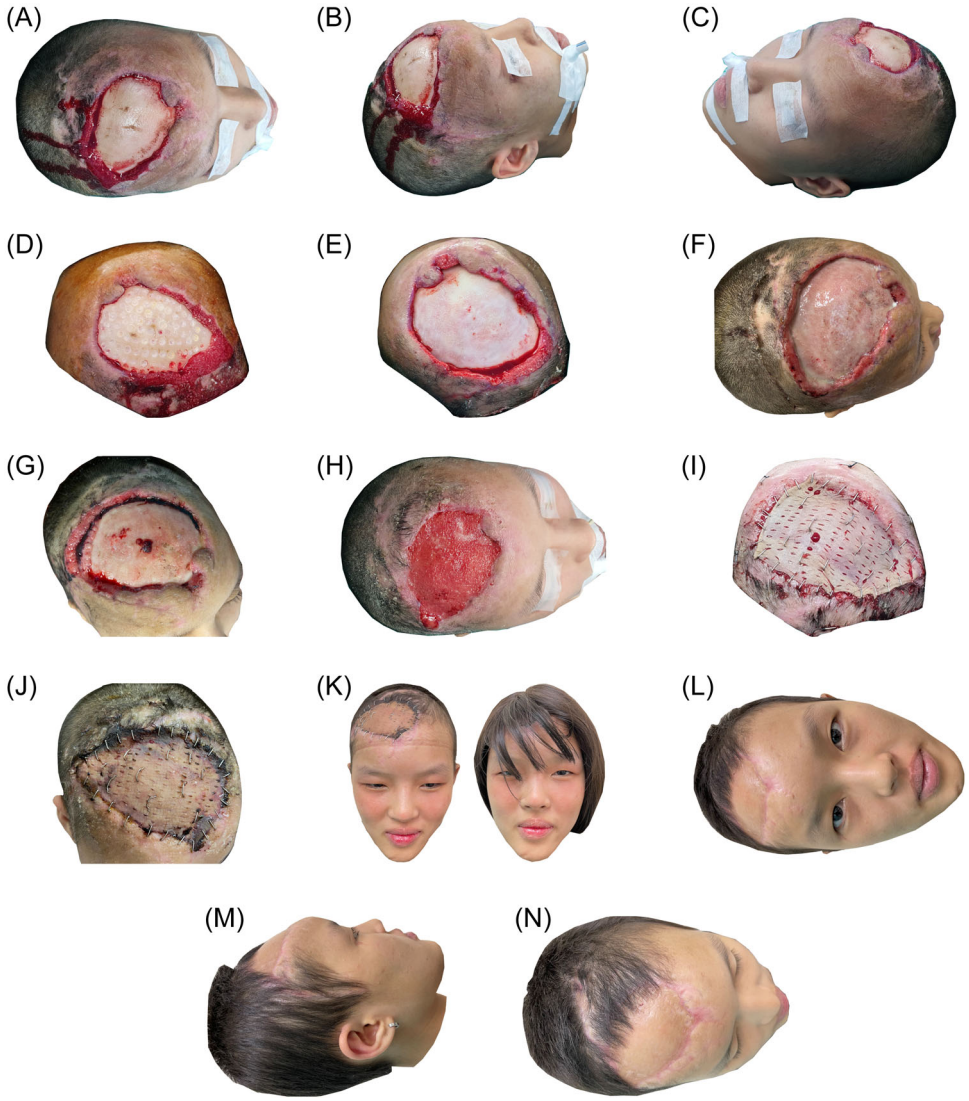

FIGURE 2 A 17-year-old female patient was referred from the regional hospital with an 8 × 10 cm scalp defect. The scalp defect was in the right frontal region, with the exposed frontal bone denuded of pericranium and some granulation tissue formation covering 2% at the border of the scalp defect on the anterior (A), right lateral (B), and left lateral (C) views. We performed initial milling of the outer cortex of the calvaria (D), drilling of the outer cortex of the calvaria, and wound debridement (E). Photographs were taken on postoperative Days 7 (F), 14 (G), and 28 (H). After 6 weeks of treatment, a split-thickness skin graft was placed (I). Photographs were taken on postoperative Days 7 (J), 14 (K), and 28 postoperatively (L–N).

reliable method for reconstructing medium-to-large scalp defects when esthetics is not a concern.[1]

Full-thickness scalp defects with a denuded pericranium are preferably treated with local flaps because they may permit granulation tissue growth at a slow rate.[1,3] An additional cortical craniectomy, milling, or drilling of the outer cortical calvaria can be performed to expose the diploic space, which has good vascularity and allows fibroblasts to migrate, promoting granulation tissue formation and a healing bed for secondary skin grafting.[1–4,10,11] The thickness of the calvaria is significantly dependent on the skull region (frontal, temporal, parietal, etc.), race, age, weight, and sex of the patient; these should be considered when performing the procedure.[3] However, the preferable time window remains within 6–8 weeks.[2] Some authors have placed skin grafts in the same sessions as these procedures to reduce healing time; however, the patients showed a visible depression at the site of the surgery as the outer surface of the bone of the skull was missing.[2]

NPWT has been shown to promote tissue granulation and decrease wound volume by debriding devitalized tissue, promoting blood flow and tissue perfusion, decreasing bacterial colonization, and removing excess serous fluid.[1,5,12,13] However, in my experience of this and previous cases, patients report pain and discomfort throughout the NPWT treatment period; two required opioid medications for pain control. Therefore, additional NPWT should be administered during the treatment period.

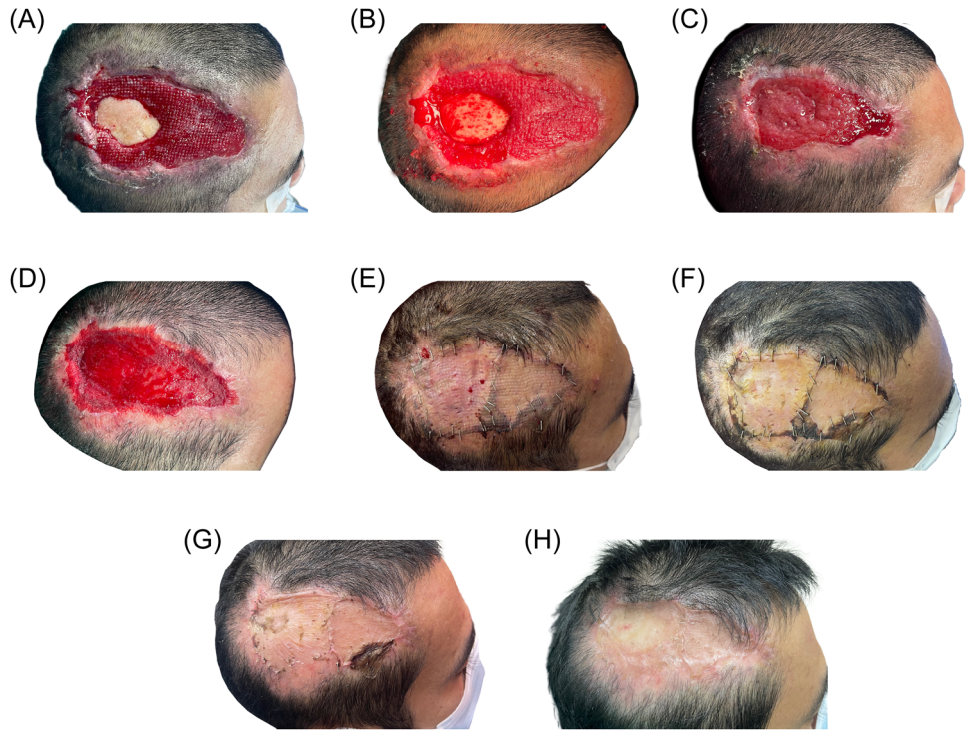

FIGURE 3 A 35-year-old male patient was referred from the regional hospital with a 4 × 12 cm scalp defect. The scalp defect was in the right parietal region, with the exposed parietal bone denuded of the pericranium and granulation tissue covering approximately 70% of the defect (A). Photographs were taken after the initial cortical craniectomy and wound debridement (B), and after 2 weeks of treatment, the wound showed significant granulation tissue formation (C). The wound showed good granulation tissue formation after debridement (D). Photographs were taken on postoperative Days 7 (E), 14 (F), 21(G), and 28 (H).

LTP is a nonthermal, noninvasive treatment that uses positive and negative ion gases to promote tissue healing via ion-catalyzed peroxidation. The BioPlasmaJet BPJ1 system (BIOPlasma System: Model-BioPlasmaJet System, BioPhotoCare Co., Ltd.) is a novel LTP device that uses cold plasma jets to treat wounds. The device generates an LTP field with an intermediate effective dose (2–6 J/cm^2) and has been shown to induce angiogenesis, promote cell proliferation, reduce inflammation, and exert an antimicrobial effect.[7–9] This is a potential wound care option for patients with non-healing wounds, such as pressure ulcers, diabetic ulcers, and chronic wounds. Furthermore, this approach is easy to use and causes less pain.[7]

Case 1 had a large vertical scalp defect from a lightning burn, with exposed calvaria denuded of the pericranium that measured 91.8 cm^2. However, there were no signs of local infection, sequestration, or osteomyelitis. A large local or rotational flap was impossible, and there was a high risk of flap necrosis. Therefore, skin grafting was the first choice of treatment. Cortical craniectomy should be performed considering trauma to the inner cortex of the calvarial bone due to previous partial milling of the outer cortical calvaria, close to the sagittal and coronal suture lines.

Case 2 had a large frontal scalp defect with exposed calvaria denuded of the pericranium that measured 78.4 cm^2 and had minimal granulation tissue. The scalp defect regions comprised hair-bearing and non-hair-bearing areas of approximately 30% and 70%, respectively. A local scalp flap may have resulted in poor esthetic outcomes due to a mislocated hair-bearing area on the non-hair-bearing area of the forehead. Another choice for reconstruction was free tissue transfer; however, the donor site scar and scalp esthetics remained problematic owing to color and contour mismatch. The patient was preoperatively advised of the risks and benefits. The patient chose skin grafting because of an unacceptable donor wound and scarring of the free flap. However, full-thickness skin grafts for large defects were unavailable owing to the patient's young and slim physique. Split-thickness skin grafting was performed to hide the donor wound on the medial aspect of the upper thigh. Young female patients tend to have lower frontal bone thicknesses than older female and male patients; therefore, milling of the outer cortex of the calvaria should be performed with caution as it may involve the inner cortex, reducing the thickness of the frontal bone in young female patients.[3] Skin grafting was delayed until granulation tissue formation was achieved, which appeared as an imperceptible depression and discoloration of the forehead scalp; the mislocated hairline was obscured by a periwig.

Case 3 had a parietal scalp defect with exposed calvaria, denuded of the pericranium, of 14.4 cm^2, suitable for skin grafting. In addition, my experience of applying LTP therapy for chronic wounds, such as diabetic and pressure ulcers, revealed faster granulation tissue formation when done twice a week than once a week. Therefore, applying LTP therapy twice a week may have facilitated faster

granulation tissue formation than in the previous two cases. However, of note, this patient had a relatively smaller defect than the previous patients.

None of the patients treated with LTP experienced pain or had signs of calvarial infection, sequestration, or necrosis.

This limited case series suffers from the known limitations of this type of report, namely, no epidemiological quantities, no causal inferences possible, no generalization possible, and potential publication bias. However, given the positive and clinically important findings in the management of these patients, the dissemination of this information is relevant and necessary. Further studies with larger sample sizes in a more heterogenous population are warranted in the future.

4 | CONCLUSIONS

The combination of NPWT and LTP is a safe and effective treatment modality for scalp defects with exposed calvaria denuded of pericranium resulting from trauma and burns. This combination helps to enhance the formation of the granulation tissue by providing synergistic effects and decreasing the duration of applied negative pressure therapy without complications. LTP can be safely applied to scalp defects with exposed calvaria denuded of the pericranium. This is a novel treatment approach for scalp reconstruction with long-term durability, contour preservation, acceptable cosmesis, and minimal donor-site morbidity. However, further studies are required to validate the effectiveness of this approach in larger patient populations.

AUTHOR CONTRIBUTIONS

Pattana Ongkasuwan: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; writing—original draft; writing—review & editing.

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CONFLICT OF INTEREST STATEMENT

The author declares that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

Data is openly available in a public repository that issues datasets with DOIs. The author has completed the ICMJE uniform disclosure form. The author has completed the AME Case Series reporting checklist.

ETHICS STATEMENT

The authors are accountable for all aspects of the work and ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The Ethics Committee of Nakornping Hospital approved the publication of the present manuscript (No. 042/66). The patients signed an informed consent form to publish their pictures in this case series.

TRANSPARENCY STATEMENT

The lead author Pattana Ongkasuwan affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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