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Reconstruction of large meningomyelocele defects using the keystone flap: A retrospective case series

Keystone flep kullanılarak geniş meningomiyelosel defektlerinin rekonstrüksiyonu: Retrospektif bir olgu serisi

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ABSTRACT

Aim: This study aimed to evaluate the clinical outcomes and complication rates associated with the keystone design perforator flap technique for the surgical reconstruction of large meningomyelocele defects in neonates.
Materials and Methods: A retrospective analysis was conducted on 10 neonates who underwent meningomyelocele repair using the keystone flap technique between 2022 and 2023. Demographic and clinical variables, including sex, gestational age, birth weight, maternal age, presence of consanguinity, defect localization and size, day of surgery, hospital stay duration, and postoperative complications were recorded. Descriptive statistics were used, and comparisons between groups with and without complications were performed using the Mann–Whitney U test and Fisher's exact test.
Results: All patients achieved successful wound closure without major flap loss or CSF leakage. No statistically significant associations were found between postoperative complications and the evaluated clinical variables ($p > .05$). The median defect size was 228.0 cm² (IQR: 180.0–297.0 cm²), and the median hospital stay was 63.5 days (IQR: 49.25–77.25 days). Postoperative complications were observed in 4 patients (40%) and were managed conservatively without the need for flap revision.
Conclusion: The keystone flap may be a feasible option for the reconstruction of large meningomyelocele defects in neonates. Further studies with larger sample sizes are needed to confirm its effectiveness and safety.

Keywords: *Clinical outcomes, Keystone flap, Neonate, Meningomyelocele defect, Technical details*

ÖZ

Amaç: Bu çalışma, yenidoğanlarda büyük meningomiyelosel defektlerinin cerrahi rekonstrüksiyonunda keystone tasarımlı perforatör flep tekniğine bağlı klinik sonuçları ve komplikasyon oranlarını değerlendirmeyi amaçlamaktadır.
Gereçler ve Yöntemler: 2022–2023 yılları arasında keystone flep tekniği kullanılarak meningomiyelosel onarımı yapılan 10 yenidoğan retrospektif olarak incelendi. Cinsiyet, gestasyonel yaş, doğum ağırlığı, anne yaşı, akraba evliliği varlığı, defektin lokalizasyonu ve boyutu, ameliyat günü, hastanede yatış süresi ve postoperatif komplikasyonlar gibi demografik ve klinik değişkenler kaydedildi. Tanımlayıcı istatistikler kullanıldı ve komplikasyon gelişen ve gelişmeyen gruplar arasındaki karşılaştırmalar Mann–Whitney U testi ve Fisher Exact testi kullanılarak yapıldı.
Bulgular: Tüm hastalarda majör flep kaybı veya BOS kaçağı olmaksızın başarılı yara kapanması sağlandı. Komplikasyon gelişimi ile değerlendirilen klinik değişkenlerin hiçbiri (örneğin doğum ağırlığı, defekt boyutu, cerrahi zamanlama) arasında istatistiksel olarak anlamlı bir ilişki saptanmadı ($p > 0,05$). Median defekt boyutu 228,0 cm² (IQR: 180,0–297,0 cm²), median hastanede yatış süresi ise 63,5 gün (IQR: 49,25–77,25 gün) olarak belirlendi. Postoperatif komplikasyonlar 4 hastada (%40) görüldü ve flep revizyonu gerektirmeden konservatif olarak yönetildi.
Sonuç: Keystone flep, yenidoğanlarda büyük meningomiyelosel defektlerinin rekonstrüksiyonunda uygulanabilir bir seçenek olabilir. Bu tekniğin etkinliği ve güvenilirliğini doğrulamak için daha geniş örneklemli çalışmalara ihtiyaç vardır.

Anahtar Kelimeler: *Klinik sonuçlar, Keystone flep, yenidoğan, Meningomiyelosel defekt, Teknik detay*

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INTRODUCTION

Meningomyelocele (MM) is one of the most severe congenital neural tube defects of childhood and is an important cause of neonatal mortality and morbidity worldwide (1,2). This condition, in which the spinal cord and meninges protrude through the skin as a result of incomplete closure of the vertebral arches in the spine, can lead to severe neurological deficits, infections, and permanent sequelae depending on the size and location of the defect (2,3). Meningomyelocele repair, one of the most critical surgical interventions in the postnatal period, becomes technically more complex as the size of the defect increases (4). Large meningomyelocele defects, which cover more than 50% of the dorsal width, create clinical pictures that cannot be closed with simple subcutaneous dissection techniques (2,5). Therefore, the safety, efficacy, and complication rates of surgical reconstruction techniques are of vital importance for these patients (6,7).

In recent years, keystone flap design has attracted attention in reconstructive surgery due to its minimal invasiveness, safe vascularisation, and aesthetic advantages (8,9). The keystone flap offers simplicity and versatility in the closure of tensioned skin defects, especially in the thoracolumbar and sacral regions (8). The use of this technique in meningomyelocele repair is supported by an increasing number of case reports and retrospective studies in recent literature (10–13). These studies show that basic surgical parameters such as flap complications, cerebrospinal fluid (CSF) leakage, and wound dehiscence have been examined with multiple analyses; additionally, they reveal unique findings on flap orientation and vascular planning in neonatal surgeries (10,12,14,15). However, there are no systematic studies with a sufficient number of cases in this field, and the existing studies are generally limited in sample size and methodological diversity (3,14,16).

In this study, prenatal and postnatal variables such as patient gender, mode of delivery, gestational age, maternal age, consanguineous marriage status, localisation, and size of the defect, and parameters related to the surgical process such as the day of surgery, length of hospitalisation, type of flap used, complications and complication management were analysed in a multifaceted manner. In addition, indicators that provide information about the clinical status of the newborn, such as weight and the presence of accompanying anomalies were also included in the evaluation.

This study aims to contribute to the existing literature on keystone flap application in large meningomyelocele defects by evaluating a consecutive patient series. It also more clearly defines the place of the keystone flap in surgical repair more clearly through technical modifications and flap selection criteria and provides explanatory findings that will contribute to the optimisation of postnatal surgical decision processes.

MATERIALS AND METHODS

Research Type and Sample

This study is a retrospective descriptive study and was conducted on the file records of patients with meningomyelocele defects operated in Şanlıurfa Metrolife Hospital between June 3, 2022, and October 17, 2023.

Inclusion Criteria

The study included infant patients between the ages of 0-1 year who were diagnosed with meningomyelocele and required surgical reconstruction. The defects of these patients were too large to be repaired with primary closure and a suitable anatomical structure for local flap closure was taken as a prerequisite. The systemic health status of these patients in whom the Keystone Flap Technique was feasible was also among the evaluation criteria. In addition, informed consent from the legal guardians was mandatory for inclusion in the study. Written informed consent was also obtained from the legal guardians for the capture and publication of the photographs included in this article. Patients who were excluded from the study included patients with small defects that could be easily repaired with primary closure, patients with previous unsuccessful reconstructive surgery, and individuals for whom family consent could not be obtained. Thus, it was aimed to ensure homogeneity of the sample group and reliability of the data.

Patient Selection and Study Population

Between June 3, 2022, and October 17, 2023, a total of 14 patients with meningomyelocele were operated on by the author. Of these, 10 patients underwent reconstruction using the keystone flap technique, while the remaining 4 patients were treated with alternative methods, including unilateral rotation flaps (n=2) and bilateral rotation flaps (n=2).

Due to the relatively high rate of consanguineous marriages in the study region, the incidence of meningomyelocele is comparatively increased. However, the presence of multiple university and tertiary referral hospitals in the region results in a substantial proportion of patients being managed at these centers. In particular, cases with small defects are typically treated in these institutions, whereas patients with large and complex defects are more frequently referred for advanced reconstructive management.

Accordingly, the study cohort represents a selected population of patients with large defects requiring advanced reconstruction. The absence of a control group should therefore be interpreted as a reflection of real-world clinical practice rather than a methodological limitation.

Only patients who underwent reconstruction using the keystone flap technique were included in this study. This selection was primarily driven by the institutional treatment algorithm, in which the surgical approach varies according to the size of the meningomyelocele defect. Small- to medium-sized defects are typically managed successfully by the neurosurgical team using primary closure or simple local flaps and therefore do not require plastic surgery consultation. In contrast, large and complex defects—where primary closure is not feasible—are referred for reconstructive management and constitute the patient population in this study. Consequently, patients treated with the keystone flap represent a selected, relatively homogeneous group requiring advanced reconstruction. This selection bias limits the generalizability of the findings and precludes the

establishment of a comparable control group for direct outcome comparison.

The absence of a comparative control group is acknowledged as a limitation that restricts the strength of statistical inferences. However, the primary aim of this study was not to compare different surgical techniques, but rather to evaluate the reliability and feasibility of the keystone flap technique in large meningomyelocele defects.

In our clinical practice, small- to medium-sized defects are typically managed with primary closure or simple local flaps, whereas large defects requiring advanced reconstruction are referred to our unit. This referral pattern has limited the ability to establish a homogeneous comparison group.

Furthermore, the existing literature similarly consists predominantly of small case series with limited comparative analyses. In this context, our study is consistent with current evidence and aims to demonstrate the effectiveness and reliability of the technique within a selected patient population.

Data Collection Method

Data were collected retrospectively through patient files and surgical records. The variables used in the study were selected to evaluate the effect of the keystone flap technique on clinical success in a multidimensional way. Neonatal parameters such as age, weight, gestational age, mode of delivery are potential factors that may affect wound healing, complication development, and overall postoperative status. Prenatal characteristics such as maternal age and consanguineous marriage enable the investigation of genetic and environmental factors in the development of meningomyelocele. Localisation and size of the defect have been noted as anatomical variables that directly affect the choice of surgical technique and the applicability of the flap. Timing parameters such as the postnatal day of surgery and the duration of hospitalisation were evaluated in terms of operational efficiency and hospital resource utilisation. Flap type, presence of complications and their management are key clinical indicators to determine the safety and sustainability of the technique. All these variables were included in the analysis to evaluate the extent to which the keystone flap technique is an effective and safe surgical method for large meningomyelocele defects.

Keystone Flap Technique

The keystone design perforator island flap (KDPIF), first described by Felix Behan, is defined as a local fasciocutaneous flap based on multiple random perforators without the need for specific perforator dissection. The flap is designed as a curvilinear trapezoid adjacent to the defect and incorporates both advancement and V–Y closure principles. This technique provides reliable tissue coverage by distributing tension over a wide surface area while preserving vascular integrity. According to the classification proposed by Felix Behan, the keystone flap is divided into four main types. In Type I, the flap is elevated with minimal dissection without incising the deep fascia and is typically used for small defects with low tension. In Type II, the deep fascia is incised to enhance flap mobility; this is further subdivided into Type IIa, involving partial fascial division, and Type IIb, involving complete fascial division. Type III consists of double opposing (bilateral) keystone flaps used for larger defects, allowing balanced tension distribution. Type IV is a modified technique applied in more complex or asymmetric defects and includes partial flap undermining and a rotational component. The surgical success of the keystone flap relies on fundamental reconstructive principles emphasized by Felix Behan. Preservation of perforator circulation is paramount; therefore, aggressive dissection should be avoided, and a minimal dissection approach should be adopted. The flap width is generally planned to match the defect width to achieve tension-free closure. The V–Y advancement mechanism applied at the flap margins enables homogeneous distribution of tension across the flap, thereby reducing the risk of distal ischemia and wound dehiscence. Unlike conventional perforator flaps, the keystone flap does not require individual perforator dissection; instead, it is nourished by the intrinsic vascular network within the flap. This feature shortens operative time and enhances the technical feasibility of the procedure. In larger defects, bilateral flap application or limited fascial release may be necessary to achieve adequate mobility. Due to its reliability, technical simplicity, and reproducibility, the keystone flap has gained increasing popularity in reconstructive surgery. Particularly in large meningomyelocele defects, it offers an effective reconstruction option owing to its muscle-sparing nature and ability to provide well-vascularized tissue coverage (Figure 1) (17).

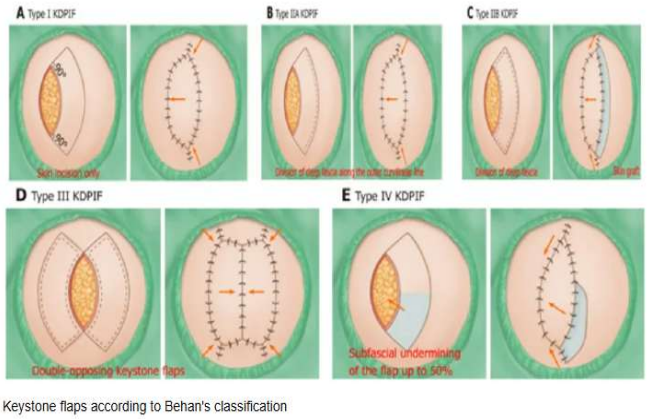

Figure 1. Keystone flap technique (18)

Surgical Procedure and Follow-up

All surgical procedures were performed under general anaesthesia. Initially, the neurosurgery team performed excision of the meningomyelocele sac, followed by meticulous dural reconstruction to achieve a watertight closure while preserving neural structures (Figure 2 and Figure 3).

Figure 2. Preoperative view of a patient with a large meningomyelocele sac.

Figure 3. Intraoperative view of the defect following excision of the meningomyelocele sac by the neurosurgical team.

After completion of the neurosurgical stage, soft tissue reconstruction was undertaken. In cases where primary closure was not feasible and the defect could not be closed using local or small regional flaps, a keystone design perforator island flap was selected for reconstruction (Figure 4).

The flap was designed according to the size, shape, and location of the defect. The flap width was generally planned to be equal to the defect width to ensure tension-free closure. In larger defects, bilateral opposing keystone flaps were utilized to achieve balanced tension distribution (Figure 5).

Skin incisions were made along the marked design down to the deep fascia. During flap elevation, a minimal dissection technique was employed to preserve perforator vessels. The flap was mobilized using blunt dissection, and aggressive undermining that could compromise vascularity was avoided. No specific perforator dissection was performed; instead, the flap relied on multiple perforators within its vascular territory.

Figure 4. Schematic illustration of the keystone design perforator island flap (KDPIF) planning and markings.

Figure 5. Intraoperative view demonstrating elevation of the keystone flap from all margins.

The advancement of the flap was achieved using the characteristic V-Y advancement component of the keystone design. The lateral ends of the flap were advanced toward the defect, allowing redistribution of tension along the flap borders. This approach minimized the risk of distal flap ischemia and wound dehiscence.

In selected cases, limited deep fascial release was performed to enhance flap mobility. However, flap thickness was preserved to maintain vascular integrity.

The flap was inset over the defect without tension and closed in layers. Careful hemostasis was maintained throughout the procedure. Postoperatively, patients were positioned to avoid pressure on the reconstructed area (Figure 6).

Figure 6. Intraoperative view of meningomyelocele defect closure using a keystone design perforator island flap.

Defect size was calculated intraoperatively using maximal width and length measurements. All patients received early postoperative care and were followed for at least 30 days. During hospitalization, patients were evaluated daily until discharge. Postoperative complications were assessed according to a standardized clinical protocol: seroma and hematoma were evaluated on postoperative day 3, surgical site infection on postoperative day 7, wound dehiscence and delayed wound healing on postoperative day 12, and major complications, including partial or total flap loss, on postoperative day 13. During follow-up, flap viability, wound healing, complication development, and any required interventions were systematically evaluated. Preservation of perforator circulation, minimal dissection, and optimal tension redistribution were considered the key technical principles contributing to successful flap outcomes.

Ethics Committee Approval

Ethics committee approval was obtained from the Eskişehir City Hospital Scientific Research Ethics Committee (Decision No: ESH/BAEK 2025/256, 06/11/2025). The study was planned in accordance with the principles of the Declaration of Helsinki, the relevant legislation of the Ministry of Health and the ethical rules of scientific research. All patient data used in the study were analysed retrospectively and the confidentiality of personal data was protected. Informed consent forms were signed by the legal guardians of all patients.

Data Analysis

All statistical analyses were performed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize patient demographics and clinical variables. Categorical variables were presented as frequencies and percentages. The normality of continuous variables was evaluated using analytical and visual methods. As the continuous variables did not follow a normal distribution and the sample size was small, non-parametric tests were used for inferential analyses. Continuous variables were summarized using the mean, standard deviation (SD), median, interquartile range (IQR; 25th–75th percentiles), and minimum–maximum values. Comparisons between groups with and without postoperative complications were performed using the Mann–Whitney U test. Categorical variables were compared using Fisher's exact test. For variables with contingency tables larger than 2 × 2, the Freeman–Halton extension of Fisher's exact test was applied. A p-value of <0.05 was considered statistically significant.

RESULTS

Postoperative complications were observed in 4 out of 10 patients (40%). Minor complications were defined as wound-related events including wound dehiscence, delayed wound healing, seroma, hematoma, and surgical site infection. Major complications were defined as partial or total flap loss. Seroma developed in one patient and was successfully managed with aspiration. One patient developed a wound infection, which was treated with local wound care and dressings. Wound dehiscence occurred in two patients, both of whom were managed conservatively with secondary healing. No major complications such as flap loss or CSF leakage were observed.

As demonstrated in Figure 7, reconstruction with a keystone design perforator island flap resulted in successful defect closure with satisfactory contour and viable flap coverage (Figure 7).

Figure 7. Preoperative and postoperative views of a patient with a large meningomyelocele defect following reconstruction with a keystone design perforator island flap.

The median gestational age was 37.0 weeks (IQR: 36.0–37.0 weeks), indicating that most infants were born during the late preterm to early-term period.

Table 1. Descriptive statistics for continuous variables

Variable	n= 10						
	Mean	**SD**	**Min**	**25th %**	**Median**	**75th %**	**Max**
Day of Surgery	3.20	1.48	1	2.00	3.00	4.75	5
Length of Stay (days)	61.30	25.43	16	49.25	63.50	77.25	104
Gestational Age (weeks)	36.80	0.92	36	36.00	37.00	37.00	39
Maternal Age (years)	26.90	3.90	21	24.50	27.50	29.75	32
Birth Weight (g)	2561.50	390.50	2000	2200.00	2650.00	2893.75	3000
Defect Size (cm²)	240.40	88.12	120	180.00	228.00	297.00	400

The median birth weight was 2650 g (IQR: 2200–2893.75 g), with several infants having birth weights close to the low birth weight threshold. Surgical intervention was performed early after birth, with a median time to surgery of 3.0 days (IQR: 2.0–4.75 days). The median maternal age was 27.5 years (IQR: 24.5–29.75 years). The median length of hospital stay was 63.5 days (IQR: 49.25–77.25 days), reflecting a prolonged postoperative course. The median defect size was 228.0 cm² (IQR: 180.0–297.0 cm²), indicating that the study included patients with relatively large meningomyelocele defects requiring keystone flap reconstruction (Table 1).

No statistically significant differences were observed between patients with and without postoperative complications in the comparative analysis. The median time to surgery was similar between the two groups (U = 15.5, p = 0.511). Although the median length of hospital stay was longer in patients who developed complications, the difference was not statistically significant (U = 6.0, p = 0.257). Likewise, no statistically significant differences were found in birth weight, gestational age, or maternal age between the groups (all p > 0.05). These findings suggest that postoperative complications were not significantly associated with the evaluated demographic and perinatal characteristics in this cohort (Table 2).

Table 2. Comparison of Continuous Variables by Complication Status (Mann–Whitney U Test)

Variable	Median (IQR) (No Complication)	Median (IQR) Complication)	U Statistic	*p*-value
Day of Surgery	3.00 (2.00–4.75)	2.5 (1.75-4.50)	15.5	0.5107
Length of Stay (days)	63.50 (49.25–77.25)	72.5 (62.25-86.00)	6.0	0.2571
Birth Weight (g)	2650.00 (2200.00–2893.75)	2400 (2185-2925)	8.0	0.4528
Gestational Age (weeks)	37.00 (36.00–37.00)	36.5 (36.0-37.5)	12.0	1.0000
Maternal Age (years)	27.50 (24.50–29.75)	28.5 (26.0-30.5)	9.5	0.6689

Values are presented as median (IQR: 25th–75th percentiles). P-values were calculated using the Mann–Whitney U test.

According to Fisher's exact test, sex (p = 0.571), delivery type (p = 0.076), and consanguineous marriage (p = 0.524) were not significantly associated with the development of postoperative complications. Similarly, the Freeman–Halton extension of Fisher's exact test showed no significant association between defect localization and postoperative complications (Table 3).

Table 3. Association Between Categorical Variables and Postoperative Complications

Variable	No Complications n (%)	Complications n (%)	*p*-value
Sex			
Female	3 (50.0)	3 (50.0)	
Male	3 (75.0)	1 (25.0)	0.571
Delivery Type			
Vaginal	4 (66.7)	0 (0.0)	
Caesarean	2 (33.3)	4 (100.0)	0.076
Consanguineous Marriage	2 (33.3)		
Yes	4 (66.7)	3 (75.0)	
No		1 (25.0)	0.524
Defect Localization			
Thoracolumbar	3 (50.00)	1 (25.0)	
Lumbar	2 (33.3)	1 (25.0)	
Lumbosacral	0 (0.0)	2 (50.0)	0.743

P-values were calculated using Fisher's exact test. For defect localization (3×2 contingency table), the Freeman–Halton extension of Fisher's exact test was used.

DISCUSSION

Our retrospective analysis confirms that the keystone design perforator flap is a feasible and clinically safe option for neonates with large meningomyelocele defects. All ten infants in our series achieved successful, tension-free defect closure with minimal morbidity. Notably, we found no statistically significant association between the development of postoperative complications and any of the examined variables, including birth weight, timing of surgery, defect size, gestational age, maternal age, consanguinity, or defect location. This absence of correlating risk factors suggests that within our cohort the keystone flap provided consistently reliable outcomes across a range of clinical scenarios. In other words, even neonates with potential risk characteristics – such as low birth weight or relatively larger defects – did not experience higher complication rates. While the limited sample size urges caution in over-interpreting this finding, it tentatively highlights the robustness of the keystone flap technique. The success of the flap appears not to be restricted

to ideal conditions only, which is encouraging for broader applicability.

Our findings are in line with the growing body of literature demonstrating excellent results with keystone flaps in myelomeningocele reconstruction. Park et al. (2016) were among the first to apply the keystone perforator island flap for lumbosacral myelomeningocele closure in neonates, reporting no postoperative wound complications in their series of five newborns (19). They concluded that the keystone flap is an effective, reliable, and durable option for these defects (20), which our experience strongly corroborates. Similarly, Hifny and Hamdan (2020) described successful closure of large myelomeningocele defects in seven infants using a keystone flap, with only one case of superficial infection and no flap loss, dehiscence, or CSF leak reported (12). These low complication rates mirror our own results and underscore the safety of the technique. In fact, across multiple case series in the literature, keystone flaps have shown uniformly high success rates with at most minor wound-healing issues. Formentin et al. (2019), for example, reported zero instances of skin flap necrosis, dehiscence, infection, or CSF leakage in a series of neonates with large myelomeningocele closures using bilateral keystone flaps (21). In the largest published series to date (14 cases), only minor complications (small dehiscences or distal flap tip necrosis) were observed in under half of patients, all of which healed secondarily without need for reoperation (22). This consistency in outcomes across different centers and surgeons indicates that the keystone design flap is a robust reconstructive solution for even extensive myelomeningocele defects. Our study adds to these data, further generalizing the applicability of the technique to diverse patient populations and clinical settings. We also extend the literature by formally analyzing potential predictors of complications – an aspect not explicitly addressed in prior reports – and finding no strong predictors, which reinforces the notion that the technique's success is broadly reproducible.

The clinical significance of these findings is considerable. Achieving early, secure coverage of the spinal defect in neonates with myelomeningocele is critical to prevent infection and protect neural structures (19). Traditionally, large lumbosacral defects that cannot be closed primarily have required complex solutions such as regional musculocutaneous flaps (e.g. using latissimus dorsi or gluteal muscle), multiple local skin flaps, or skin grafts overlying dura (19). Many of these methods carry drawbacks: muscle flaps sacrifice functional tissue and can create additional donor site morbidity, while skin grafts provide less durable coverage and may heal with fragile scars. In contrast, the keystone perforator flap offers a one-stage, like-for-like tissue reconstruction using the immediately adjacent skin and subcutaneous tissue. This flap design recruits well-vascularized tissue from around the defect and distributes closure tension broadly, which helps avoid the focal stress that can lead to wound breakdown (21). Our experience confirms these advantages: all wounds in our series were closed with the patient's own nearby skin, achieving stable coverage without the need for distant donor sites or prosthetic materials. The aesthetic outcomes have also been satisfactory, as the reconstructed area uses similar skin, and scar lines are placed at the flap margins in a way that often lies in natural skin folds. This observation echoes the report by Almadani et al. (2016) who used a modified bilateral keystone flap for a large thoracolumbar myelomeningocele and noted durable soft-tissue coverage with prompt healing and a good cosmetic result, without any postoperative complications (23). The ability to achieve a robust closure that is both functional and cosmetically acceptable is a valuable benefit in the neonatal period, potentially reducing the need for revisional surgeries or prolonged wound care. Thus, the keystone flap technique not only addresses the immediate surgical challenge of closure but also contributes to the overall quality of life for these infants by providing a resilient reconstruction.

Our study's results also underscore the versatility of the keystone design in this clinical context. In our series, successful wound closure was achieved across different defect sizes and anatomical locations, including lumbosacral and thoracolumbar lesions. These findings are consistent with the adaptability of keystone flaps, which can be tailored in size and configuration to accommodate complex defects (21). In fact, creative modifications of the basic keystone design have been described to handle especially challenging defect geometries. Hifny et al. recently introduced a "rotation advancement" variant of the keystone flap to tackle transversely oriented lumbosacral defects that have limited lateral skin laxity (12). Such innovations expand the applicability of the technique to scenarios where a standard unilateral or bilateral keystone might be geometrically constrained. The successful use of a keystone flap in all ten of our patients, without need for conversion to alternative methods, attests to its adaptability. From a clinical standpoint, this means that reconstructive and neurosurgeons can confidently plan for keystone flap repair in most large open spina bifida cases, knowing that adjustments can be made intraoperatively (such as extending the flap or raising bilateral flaps) if needed to achieve a tension-free closure. The consistency of our outcomes – uniform healing regardless of patient differences – is particularly reassuring for centers with varied case mixes. It suggests that the keystone flap can provide a dependable option even in resource-limited settings or in patients who present late, where other advanced reconstructive resources might not be available.

Unlike previous reports, this study provides a multidimensional evaluation of keystone flap reconstruction in large meningomyelocele defects by integrating prenatal, perinatal, and surgical variables. In addition, complications were systematically classified and analyzed, and detailed technical considerations were presented to improve clinical reproducibility. These aspects represent the main contributions of the present study.

CONCLUSION

The findings of this study support the keystone design perforator flap as a safe, effective, and versatile technique for the reconstruction of large meningomyelocele defects in neonates. Its consistent success across varied clinical presentations, combined with low complication rates and muscle-sparing advantages, make it a valuable surgical option in pediatric neurosurgical practice. Broader use of this

method may enhance outcomes in centers managing complex spinal dysraphism. Future prospective studies with larger cohorts are warranted to confirm these findings and further refine technique selection.

Limitations

This study has several limitations that should be acknowledged. First, the small sample size limits the statistical power to detect subtle associations between patient-related factors and postoperative outcomes. This limitation is largely attributable to the relative rarity of meningomyelocele cases requiring flap reconstruction, as most defects can be managed with primary closure, and only a selected group of patients present with large defects necessitating advanced reconstructive techniques. Therefore, the study population represents a highly selected cohort, which is also consistent with the existing literature, where most reports consist of small case series.

Second, the retrospective design of the study introduces the potential for selection and documentation bias. To minimize this, strict inclusion criteria were applied, and only patients who underwent reconstruction with the keystone design perforator flap were included to ensure methodological homogeneity. However, the lack of a control group limits direct comparison with alternative reconstructive methods, such as musculocutaneous or other local flap techniques.

Third, the follow-up period was limited to the early postoperative phase, focusing primarily on wound healing and complication development. Long-term functional and aesthetic outcomes could not be assessed due to the neonatal patient population and referral-based follow-up. In addition, there is currently no validated scoring system specifically designed to evaluate long-term outcomes in neonatal meningomyelocele reconstruction.

Finally, due to the limited sample size, the study was not powered to detect small effect sizes. Despite these limitations, the homogeneity of the surgical technique and the consistency of the outcomes strengthen the internal validity of the study. Future prospective, multicenter studies with larger cohorts, comparative designs, and extended follow-up are needed to further validate these findings.

Ethical Approval

Ethics committee approval was obtained from the Eskişehir City Hospital Ethics Committee (Decision No: ESH/BAEK 2025/256, 06/11/2025). The study was planned in accordance with the principles of the Declaration of Helsinki, the relevant legislation of the Ministry of Health and the ethical rules of scientific research. All patient data used in the study were analysed retrospectively and the confidentiality of personal data was protected. Informed consent forms were signed by the legal guardians of all patients.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Authors' Contributions

AC: Methodology, Conceptualization, Investigation, Data Curation, Formal Analysis, Supervision, Writing – review &editing, Writing – original draft

Data Sharing Statement

The data supporting this research are available from the author(s) on reasonable request

Declaration of generative AI and AI-assisted technologies in the writing process

The authors used generative AI tools solely for proofreading and language editing. No AI-assisted tools were used for generating, analyzing, or interpreting the scientific content of the manuscript. The authors take full responsibility for the final version of the manuscript.

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