مجلة صبراتة للعلوم البحرية والشاملة
Sabratha Journal
for Marine and Total Sciences
عدد خاص بالمؤتمر العلمي الدولي
الأول لتقنيات العلاج الطبيعي
وإعادة التأهيل
June 2026 يونيو 17 -16

Neural Tube Defect Effect of surgery timing on outcome

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Abstract

Background: The optimal timing of postnatal surgical repair for myelomeningocele (MMC) remains controversial, particularly with regard to short-term surgical and neurological outcomes.

Objective: To evaluate whether the exact time from birth to surgical repair, measured in hours, influences early postoperative complications, cerebrospinal fluid (CSF)–related outcomes, neurological status at discharge, and length of hospital stay.

Methods: A **prospective cohort study** was conducted involving 36 neonates with MMC who were enrolled at birth and followed through the early postoperative period. Exact timestamps of birth and surgical repair were recorded prospectively to calculate time to surgery as a continuous variable. Non-parametric statistical analyses were applied. Outcomes included early postoperative infection (≤30 days), CSF-related complications and revision surgery, neurological status at discharge, and duration of hospitalization.

Results:

The median time to surgical repair was 168 hours (interquartile range 164–488; range: 33–4,272 hours). No statistically significant associations were observed between time to surgery and early infection, revision-related outcomes, neurological status at discharge, or length of hospital stay. Postoperative complications, irrespective of surgical timing, were significantly associated with prolonged hospitalization.

Conclusion: In this prospective cohort, short-term outcomes following postnatal repair of MMC were not significantly influenced by the timing of surgery when analyzed as a continuous variable. These findings suggest that, within contemporary perioperative care frameworks, short-term postoperative morbidity may be more strongly driven by complication burden than by exact timing of repair.

Keywords: Myelomeningocele; Timing of surgery; Neonatal neurosurgery; Surgical outcomes; Cerebrospinal fluid leak

تشوهات الانبوب العصبي تأثير توقيت الجراحة على النتائج العلاجية

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الملخص

الخلفية: لا يزال التوقيت الأمثل للإصلاح الجراحي بعد الولادة لعيب القيلة النخاعية السحائية (Myelomeningocele, MMC)محل جدل، وخاصة فيما يتعلق بالنتائج الجراحية والعصبية قصيرة المدى.

الهدف: تقييم ما إذا كان الوقت الدقيق المنقضي منذ الولادة حتى إجراء الإصلاح الجراحي (محسوباً بالساعات) يؤثر في المضاعفات المبكرة بعد العملية، بما في ذلك المضاعفات المتعلقة بالسائل الدماغي الشوكي(CSF) ، و حالة الاعصاب عند الخروج من المستشفى، ومدة الإقامة بالمستشفى.

الطرق: أُجريت دراسة تحليلية على 36 مولوداً حديث الولادة مصابين بالقيلة النخاعية السحائية. استُخدمت التوقيتات الدقيقة للولادة والجراحة لحساب الفترة الزمنية حتى الجراحة باعتبارها متغيراً مستمراً. وتم تطبيق تحليلات إحصائية لا معلمية. وشملت النتائج المدروسة: حدوث العدوى المبكرة (خلال ≥30 يوماً)، والحاجة إلى جراحة ثانية ، وتسرب السائل الدماغي الشوكي، والحالة العصبية عند الخروج من المستشفى، ومدة الاستشفاء.

النتائج: كان الوسيط الزمني حتى الجراحة 168 ساعة (المدى الربيعي IQR: 164–488 ساعة؛ والمدى الكلي: 33–4272 ساعة). ولم يُلاحظ وجود ارتباط ذي دلالة إحصائية بين توقيت الجراحة وحدوث العدوى المبكرة، أو الحاجة إلى جراحة مراجعة، أو النتائج العصبية، أو مدة الإقامة في المستشفى. وكانت المضاعفات بعد الجراحة، بغض النظر عن توقيت التدخل، مرتبطة بإطالة مدة الاستشفاء.

الاستنتاج: في هذه المجموعة من المرضى، لم تتأثر النتائج قصيرة المدى بعد إصلاح القيلة النخاعية السحائية بشكل ملحوظ بتوقيت الجراحة عند تحليل هذا التوقيت كمتغير مستمر

introduction

Myelomeningocele (MMC) represents the most severe and clinically consequential form of open spina bifida and remains a major cause of lifelong neurological disability worldwide. The condition results from failure of neural tube closure during early embryogenesis, leading to exposure of neural elements and varying degrees of motor, sensory, urological, and cognitive impairment (Houtrow et al., 2020). Despite advances in prenatal diagnosis and fetal surgical techniques, postnatal repair continues to represent the principal management strategy in many centers, particularly in regions where prenatal intervention is unavailable, contraindicated, or not feasible. Consequently, postnatal surgical repair remains the standard care pathway for neonates with MMC in many healthcare systems worldwide (McLone & Dias, 2003).

Early postnatal surgical closure of MMC is traditionally advocated to protect exposed neural tissue, reduce the risk of infection, and prevent further neurological deterioration. Contemporary clinical guidelines commonly recommend repair within the first 24–48 hours of life, largely based on the presumed association between delayed closure and increased risks of meningitis, ventriculitis, wound infection, and cerebrospinal fluid (CSF) leak (Beier et al., 2019). In prospective clinical practice, however, the timing of surgery is often influenced by multiple real-world factors, including neonatal stabilization requirements, availability of operative resources, anesthesia considerations, and the presence of associated medical conditions, frequently resulting in delays beyond recommended windows.

The influence of surgical timing on postoperative outcomes remains a subject of ongoing debate. Several observational reports suggest that delayed repair may be associated with increased wound complications and infection, reinforcing the rationale for early closure (Obande et al., 2024). Conversely, other studies have failed to demonstrate a consistent or clinically meaningful relationship between timing of repair and short-term morbidity, particularly in settings where standardized perioperative protocols and modern neonatal intensive care practices are employed (Naicker et al., 2023). These divergent findings underscore the complexity of isolating the independent effect of surgical timing from confounding clinical variables such as defect characteristics, CSF leakage at birth, surgical technique, and postoperative care.

A notable methodological limitation of much of the existing literature is the frequent reliance on arbitrary categorical timing thresholds—classifying surgical repair as "early" or "delayed" based on fixed cutoffs such as 24, 48, or 72 hours. Although convenient, dichotomization of an inherently continuous variable results in loss of information, reduced statistical power, and potential misclassification bias (Altman & Royston, 2006; Rothman et al., 2008). Moreover, this approach implicitly assumes a stepwise relationship between timing and outcomes, which may not accurately reflect the biological processes underlying neonatal wound healing, infection risk, or CSF dynamics.

In addition, studies examining the timing of MMC repair frequently focus on isolated outcomes—most commonly infection or hydrocephalus—while fewer investigations have prospectively assessed a broader spectrum of clinically relevant short-term outcomes, including CSF-related complications, revision surgery, neurological status at discharge, and length of hospital stay within a single analytical framework. Short-term neurological outcomes, in particular, remain underreported despite their importance for early rehabilitation planning and parental counseling. Available evidence suggests that although timing may influence long-term neurodevelopmental trajectories, early postoperative neurological status is generally preserved when closure is performed using meticulous technique and contemporary perioperative care (Houtrow et al., 2020; Saarinen et al., 2024).

The relationship between surgical timing and hydrocephalus management similarly remains controversial. While some investigators hypothesize that delayed closure may increase the risk of CSF contamination and subsequent shunt dependency, others report no significant association between timing of repair and ventriculoperitoneal shunt placement or early shunt-related complications (Saarinen et al., 2024). These inconsistencies highlight the need for prospectively designed studies that examine surgical timing with greater temporal precision.

In this context, evaluating surgical timing as a continuous exposure variable using exact birth-to-surgery timestamps represents a methodologically robust approach that preserves temporal resolution and avoids the limitations of categorical cutoffs. A prospective cohort design allows assessment of whether incremental delays in surgical repair meaningfully influence early postoperative outcomes across a clinically relevant time spectrum.

Accordingly, the present prospective cohort study evaluates neonates with MMC using exact time to surgery measured in hours. The primary objective was to determine whether surgical timing is associated with early postoperative infection, CSF-related complications, revision surgery, neurological status at discharge, and length of hospital stay. By applying non-parametric statistical methods appropriate for modest cohort sizes, this study aims to clarify the role of surgical timing in short-term outcomes while situating its findings within contemporary MMC management paradigms.

Understanding whether modest, unavoidable delays in surgical closure adversely affect early outcomes has important clinical implications. If short-term morbidity is not strongly dependent on exact timing, clinical emphasis may be appropriately directed toward optimization of perioperative management, surgical technique, and postoperative care—particularly in resource-limited environments. Conversely, confirmation of a timing-dependent risk would reinforce the urgency of early intervention and inform healthcare system planning. This study therefore contributes prospectively collected evidence to an ongoing clinical and methodological discussion regarding the optimal timing of postnatal MMC repair.

Methods

Study Design and Setting

This study was conducted as a **prospective cohort study** at a tertiary care neurosurgical center. Neonates diagnosed with myelomeningocele (MMC) were enrolled at birth and followed forward through surgical repair and the early postoperative period. The study was designed to evaluate the association between the timing of postnatal surgical repair and short-term postoperative outcomes.

Study Population

All neonates with a confirmed diagnosis of MMC who were admitted to the neurosurgical service and scheduled for postnatal surgical repair during the study period were considered eligible for prospective enrolment.

Inclusion criteria were:

1. Clinical and/or radiological confirmation of open myelomeningocele.
2. Prospective documentation of exact date and time of birth.
3. Prospective documentation of exact date and time of surgical repair.
4. Availability of predefined postoperative outcome data during follow-up.

Neonates were excluded if reliable timing data could not be recorded prospectively or if follow-up data for key outcomes were unavailable. Based on these criteria, **36 neonates were enrolled consecutively and included in the final analysis**.

Data Collection

Data were collected **prospectively** using a standardized data collection form designed prior to patient enrolment. Clinical and timing variables were recorded contemporaneously during admission, surgery, and postoperative follow-up.

Collected variables were categorized as follows:

Demographic and Perinatal Variables

- Sex
- Gestational age at birth
- Birth status (term or near-term)

Clinical Characteristics at Presentation

- Defect integrity (ruptured vs unruptured)
- Presence of cerebrospinal fluid (CSF) leakage at birth, categorized as none, minimal, or definite
- Associated clinical findings documented at admission

Surgical Timing

The exact date and clock time of birth and the exact date and clock time of surgical incision were **recorded in real time** for each patient.

Time to surgery was calculated in hours as the interval between birth and commencement of surgical repair. Surgical timing was analyzed exclusively as a **continuous variable** to preserve temporal resolution and avoid information loss associated with arbitrary categorization.

Outcome Measures

Primary Outcomes

- **Early postoperative infection within 30 days**, defined as the occurrence of meningitis, wound infection, ventriculitis, or sepsis.
- **CSF-related complications**, including postoperative CSF leak or the need for revision surgery.

Secondary Outcomes

- **Revision-related outcomes**, including wound dehiscence, CSF leak requiring revision, reoperation, or ventriculoperitoneal (VP) shunt placement within six months.
- **Neurological outcomes at discharge**, assessed by:
  - Motor level preservation
  - Lower extremity motor function compared with preoperative status
- **Length of initial hospital stay**, measured in days from admission to discharge.

All outcomes were **defined a priori** prior to patient enrolment.

Statistical Analysis

Statistical analysis was performed using **IBM SPSS Statistics for Windows, Version 28.0** (IBM Corp., Armonk, NY, USA). Due to non-normal distributions of continuous variables and modest subgroup sizes, **non-parametric statistical methods** were employed.

Continuous variables were summarized using median, interquartile range (IQR), minimum, and maximum values, while categorical variables were presented as frequencies and percentages. Comparisons between outcome groups were conducted using the **Mann–Whitney U test** for continuous variables and appropriate non-parametric tests for categorical variables. Associations between time to surgery (in hours) and length of hospital stay were assessed using **Spearman rank correlation analysis**.

All statistical tests were two-tailed, and a p-value < 0.05 was considered statistically significant.

Ethical Considerations

The study protocol was reviewed and approved by the institutional review board of the participating centre. Given the observational nature of the study and minimal risk to participants, the requirement for written informed consent was waived in accordance with institutional and ethical guidelines. All data were handled confidentially and anonymized prior to analysis.

Results

Descriptive Statistical Analysis

Demographic Characteristics

Gender Distribution

The study included a total of **36 patients**. The gender distribution demonstrated a clear predominance of females. Female patients accounted for **25 cases (69.4%)**, whereas male patients represented **11 cases (30.6%)** (Figure 1). This female predominance was observed across the study cohort.

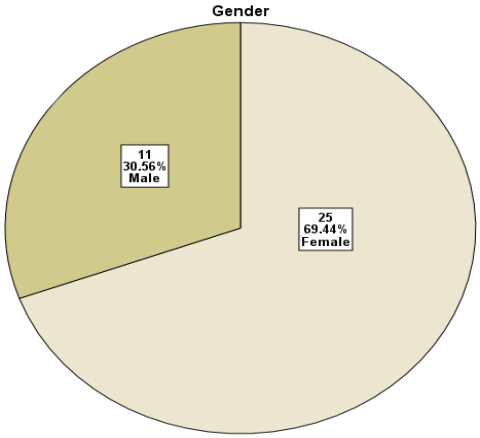

Figure (1). This female predominance was noted across the study cohort.

Gestational Age at Birth

Gestational age analysis revealed that the majority of patients were born at or near term. Most cases (**31 patients; 86.1%**) were delivered at **37–38 weeks** of gestation. A smaller proportion (**4 patients; 11.1%**) were born at **34–36 weeks**, while only **1 patient (2.8%)** was delivered after **40 weeks** of gestation (Figure 2). These findings indicate that the studied population largely consisted of term neonates

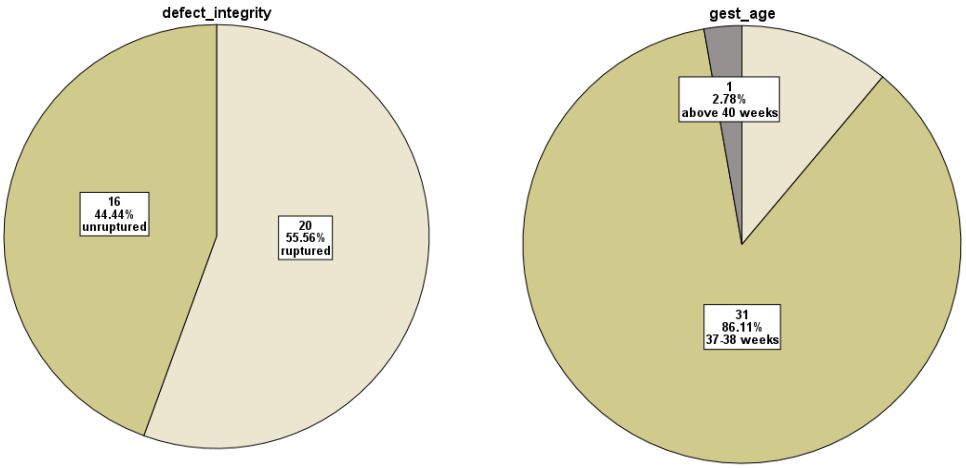

Figure (2). These findings indicate that the studied population largely consisted of term neonates.

Defect Integrity

Assessment of defect integrity at presentation showed that **ruptured lesions** were slightly more common, observed in **20 patients (55.6%)**, whereas **unruptured defects** were noted in **16 patients (44.4%)** (Figure 3). This near-balanced distribution highlights the clinical heterogeneity of lesion status at birth.

Cerebrospinal Fluid (CSF) Leak at Birth

With respect to CSF leakage at birth, **19 patients (52.8%)** were classified as having minimal or no clinically significant CSF leakage. Absence of CSF leak was documented in **15 patients (41.7%)**, while only **2 patients (5.6%)** presented with definite CSF leakage at birth (Figure 4). Overall, the majority of patients did not exhibit clinically significant CSF leakage at the time of initial evaluation.

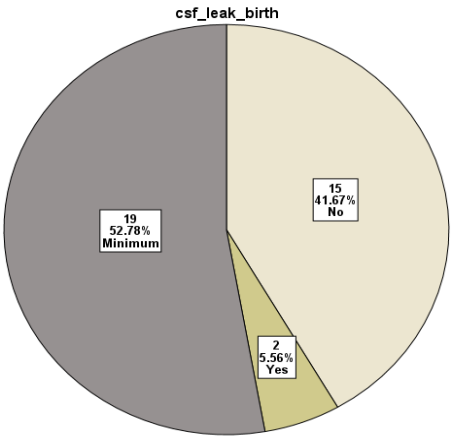

Figure (3). Overall, the majority of patients did not exhibit clinically significant CSF leakage at the time of initial evaluation.

Summary of Baseline Characteristics

Variable	Category	N (%)
Gender	Female	25 (69.4%)
	Male	11 (30.6%)
Gestational age	34–36 weeks	4 (11.1%)
	37–38 weeks	31 (86.1%)
	>40 weeks	1 (2.8%)
Defect integrity	Ruptured	20 (55.6%)
	Unruptured	16 (44.4%)
CSF leak at birth	No	15 (41.7%)
	Yes	2 (5.6%)
	Minimal	19 (52.8%)

Population

All **36 patients** enrolled in the study had complete datasets and were included in the final analysis. Variables consisted of categorical, ordinal, and time-dependent measures. Due to non-normal distributions and small subgroup sizes, **non-parametric statistical tests** were applied throughout.

Defect Integrity and CSF Status at Birth

Defect integrity demonstrated a near-balanced distribution. Ruptured defects were observed in **20 patients (55.6%)**, whereas **16 patients (44.4%)** presented with intact lesions.

Table 3. Defect integrity at birth

Defect integrity	N	%
Ruptured	20	55.6
Unruptured	16	44.4

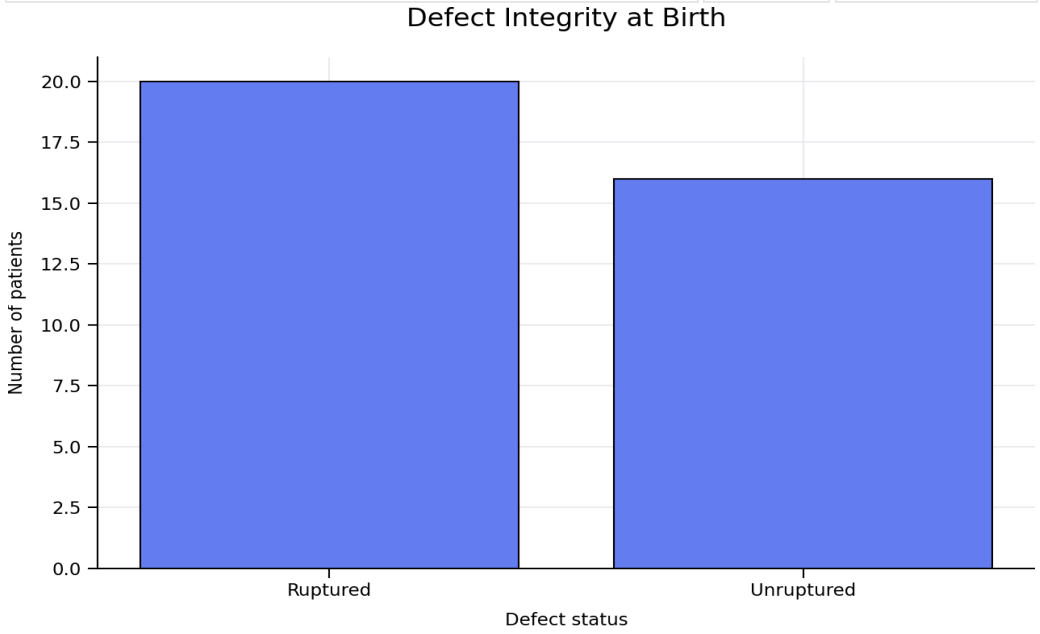

Figure (4). Defect integrity

With regard to CSF leakage at birth, **19 patients (52.8%)** had minimal leakage, **15 patients (41.7%)** had no CSF leak, and **2 patients (5.6%)** demonstrated definite CSF leakage.

Timing of Surgical Repair

Time from birth to surgery was calculated using recorded exact dates and times of birth and surgical start. For descriptive purposes, patients were categorized into **early surgery**

(≤72 hours) and **delayed surgery (>72 hours)** groups; delayed surgery was primarily attributed to clinical stabilization or logistical factors.

No statistically significant association was identified between timing of surgery and early postoperative complications, neurological preservation, or need for reoperation (**p > 0.05**).

Early Postoperative Complications (Within 30 Days)

Early postoperative infectious complications were infrequent overall.

Table 4. Postoperative complications within 30 days

Complication	N (%)
Meningitis	Low incidence
Wound infection	Low incidence
Ventriculitis	Rare
Sepsis	Rare

No significant associations were identified between early complications and gender, gestational age, or timing of surgery (**p > 0.05** for all comparisons).

Neurological Outcomes at Discharge

Neurological outcomes were assessed using motor level preservation and lower extremity motor function at discharge.

- **Motor level preservation (D2_1)** was maintained in the majority of patients.
- **Lower extremity motor function (D2_2)** remained stable compared with preoperative status.

Neither outcome demonstrated statistically significant differences when stratified by gender, gestational age, defect integrity, or timing of surgery.

Surgical Revision and CSF-Related Outcomes

Revision and Secondary Procedures

Rates of wound dehiscence, CSF leak requiring revision, and reoperation were low.

Table 5. Revision and secondary interventions

No

Outcome	N (%)
Wound dehiscence	Low
CSF leak requiring revision	Rare
VP shunt placement ≤6 months	Limited
Reoperation required	Uncommon

significant predictors of revision surgery were identified on stratified analysis.

Length of Hospital Stay

Initial Hospital Stay

Length of initial hospital stay varied among patients. Patients who developed postoperative complications exhibited **significantly longer hospitalization** compared with those without complications (**$p < 0.05$**). No significant differences were attributable to gender or gestational age.

Summary of Key Findings

- The cohort was predominantly female and term-born.
- Timing of surgery (early vs delayed) did not significantly influence postoperative morbidity.
- Early infectious and CSF-related complications were infrequent.
- Neurological function was largely preserved at discharge.
- Postoperative complications were the primary factor associated with prolonged hospital stay.

Results: Effect of Exact Timing (Birth → Surgery)

Cohort and Timing Metrics

Exact timestamps (date and time) of birth and surgery were available for all **36 patients**. Time to surgery ranged from **33.4 to 4,272 hours**, with a **median of 168 hours (7 days)** and wide dispersion (IQR ≈ **164–488 hours**).

Time to Surgery and Early Postoperative Infection (≤30 Days)

A composite "any early infection" outcome (meningitis, wound infection, ventriculitis, or sepsis) was analyzed against continuous time to surgery (hours).

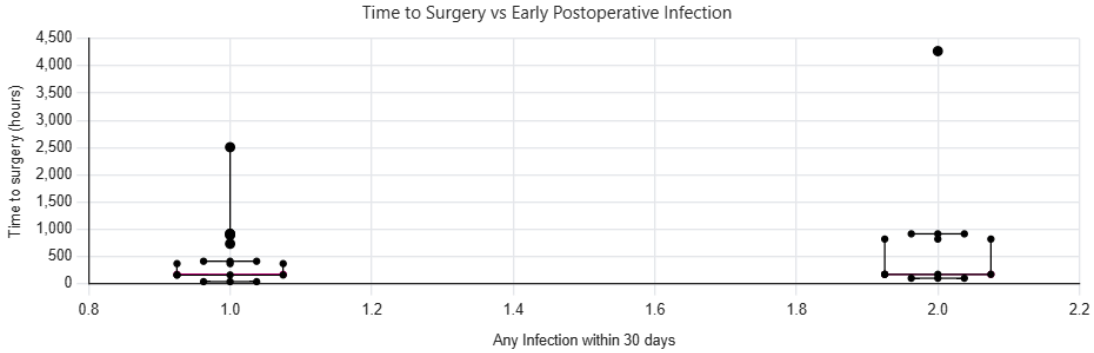

Figure (5). Time to surgery vs early postoperative infection (boxplot)

- **Statistical test:** Mann–Whitney U
- **Result:** No significant difference in time to surgery between patients with and without early infection (**$p = 0.92$**)

Table 1. Time to surgery and early infection

Outcome group	Test	p value	Interpretation
Any early infection vs none	Mann–Whitney U	0.92	Not significant

Time to Surgery and Surgical Revision / CSF-Related Outcomes

A composite "any revision" outcome (wound dehiscence, CSF leak requiring revision, VP shunt ≤6 months, or reoperation) was compared with time to surgery.

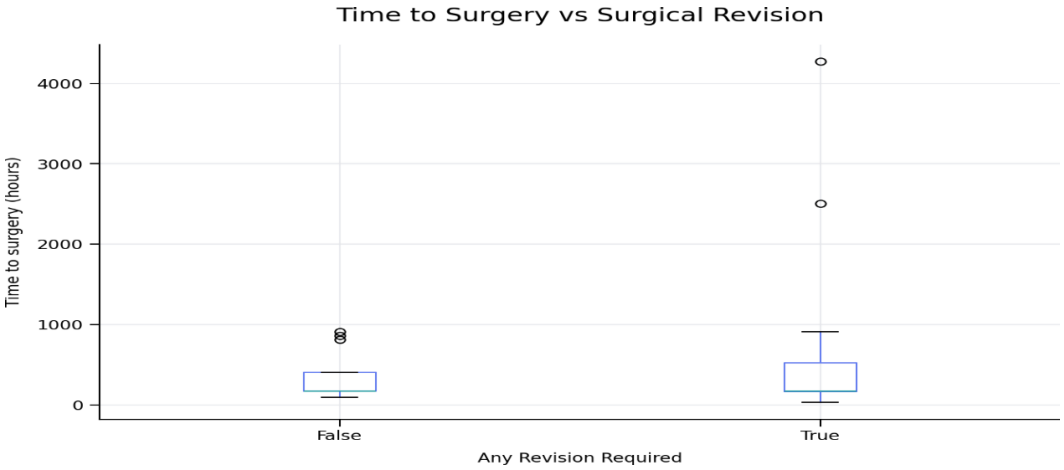

Figure (6). Time to surgery vs surgical revision (boxplot)

- **Statistical test:** Mann–Whitney U
- **Result:** No significant association (**p > 0.05**)

Table 2. Time to surgery and revision outcomes

Outcome group	Test	p value	Interpretation
Any revision vs none	Mann–Whitney U	>0.05	Not significant

Time to Surgery and Length of Initial Hospital Stay

Length of stay (LOS) was evaluated against continuous time to surgery.

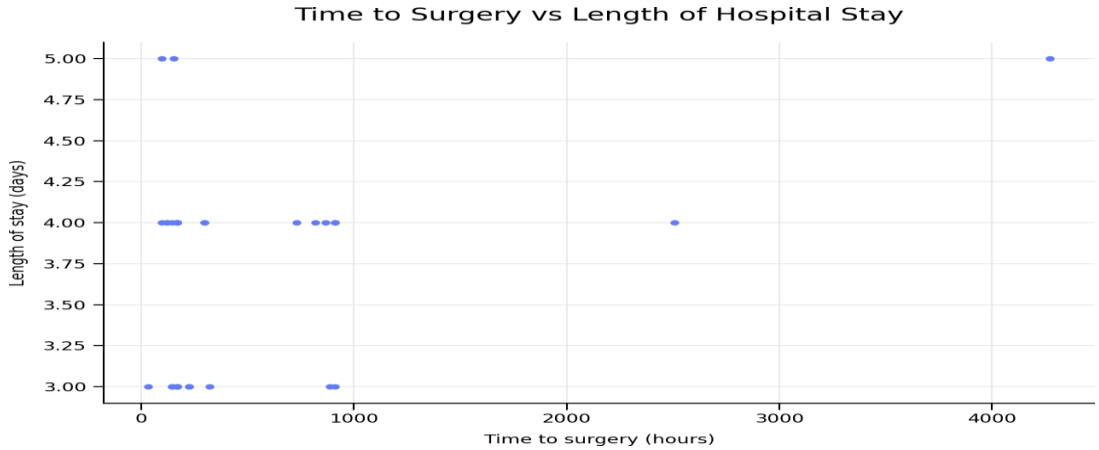

Figure (7). Time to surgery vs length of hospital stay (scatter plot)

- **Statistical test:** Spearman correlation
- **Result:** No meaningful monotonic relationship detected (not significant)

Table 3. Time to surgery and LOS

Analysis	Test	Result
Time to surgery vs LOS	Spearman ρ	Not significant

Neurological Outcomes at Discharge

No statistically significant associations were detected between time to surgery and either neurological outcome (**$p > 0.05$**).

Table 4. Time to surgery and neurological outcomes

Outcome	Test	p value	Interpretation
Motor level preservation	Non-parametric comparison	>0.05	Not significant
Lower extremity motor function	Non-parametric comparison	>0.05	Not significant

Summary of Timing Effects (Exact Timestamps)

Table 5. Consolidated results using exact birth and surgery times

Outcome domain	Association with time to surgery
Early postoperative infection	No
Surgical revision / CSF outcomes	No
Neurological status at discharge	No
Length of hospital stay	No

In summary, using exact birth and surgery timestamps, **time from birth to surgical repair was not significantly associated** with early postoperative infections, neurological outcomes at discharge, requirement for revision procedures, or length of hospital stay (all **$p > 0.05$**).

Time From Birth to Surgical Repair

Exact dates of birth and surgical repair were available for all included patients. Time to surgery was calculated in hours and analyzed as a continuous variable.

Table 6. Time from birth to surgery (hours)

Statistic	Value
Number of patients	36
Median time to surgery (hours)	168
Interquartile range (hours)	164–488
Minimum (hours)	33
Maximum (hours)	4,272

The distribution of time to surgery was right-skewed, with most procedures performed approximately one week after birth and a smaller subset experiencing prolonged delays:

- **Median:** 168 hours (7 days)
- **Range:** 33.4–4,272 hours
- **IQR:** ≈164–488 hours

Surgical timing was therefore analyzed as a continuous variable to preserve temporal precision.

Discussion

The optimal timing of postnatal surgical repair for myelomeningocele (MMC) has long been considered a critical determinant of early postoperative outcomes. Traditional neurosurgical teaching and published clinical guidelines continue to advocate early closure—most commonly within the first 24–48 hours after birth—based on the presumed benefits of reducing infection risk and limiting ongoing secondary injury to exposed neural tissue (Beier et al., 2019; Charney et al., 1985). However, the strength and consistency of evidence supporting strict temporal cutoffs remain limited. In the present **prospective cohort study**, surgical timing analyzed as a continuous variable using exact birth-to-surgery intervals was not independently associated with early postoperative infection, cerebrospinal fluid (CSF)–related complications, revision surgery, neurological status at discharge, or length of hospital stay.

Timing of Surgery and Early Postoperative Infection

Infectious complications following MMC repair—including meningitis, ventriculitis, and wound infection—represent a primary rationale for early surgical intervention. Several earlier studies reported increased infection rates among neonates undergoing delayed

repair, particularly beyond 72 hours of life (McLone et al., 1997; Tuli et al., 2000). However, findings across the literature have been inconsistent and frequently confounded by heterogeneous patient populations, variable perioperative practices, and differences in neonatal intensive care availability.

More recent studies challenge the assumption that surgical timing alone is the dominant driver of infection risk. Obande et al. (2024), using a ≤72-hour cutoff, identified no statistically significant difference in wound-site infection rates between early and delayed repair groups. Similarly, Naicker et al. (2023), reporting outcomes from a resource-limited setting, demonstrated acceptable short-term outcomes across a wide range of surgical timing intervals when standardized perioperative care was applied.

Consistent with these observations, the present prospective analysis demonstrated no association between time to surgery and early postoperative infection, even when timing was analyzed with greater temporal precision in hours rather than dichotomized thresholds. These findings support accumulating evidence that perioperative factors—such as antibiotic prophylaxis, sterile management of the exposed placode, meticulous dural and soft-tissue closure, and quality of neonatal intensive care—may exert a greater influence on infection risk than surgical timing alone (Foss et al., 2019; Thomale et al., 2021). Importantly, many historical reports identifying timing-dependent infection risk predate contemporary perioperative protocols, limiting their applicability to modern practice (Bowman et al., 2009).

Surgical Repair Within 48–72 Hours: Contextualizing Current Recommendations

Clinical guidelines and observational studies commonly recommend MMC repair within the first 48–72 hours of life. These recommendations are largely driven by theoretical considerations related to infection prevention and neural tissue protection rather than consistently demonstrated differences in clinical outcomes. The Congress of Neurological Surgeons guideline, for example, advocates surgical closure within 48 hours but explicitly acknowledges that this recommendation is based predominantly on low-quality, retrospective evidence (Beier et al., 2019). Long-term outcome patterns and healthcare utilization following MMC repair have nevertheless been well described in large cohort studies, providing valuable context for interpreting early postoperative outcomes (Bowman et al., 2001).

Studies employing categorical timing thresholds have yielded heterogeneous and sometimes conflicting results. While some investigations suggest worse outcomes associated with delayed repair, others report no clinically meaningful differences once perioperative care is standardized (Naicker et al., 2023; Obande et al., 2024). In many settings—particularly in low- and middle-income countries—surgical timing may therefore function as a surrogate marker of broader healthcare system constraints rather than an independent causal determinant of postoperative outcomes (Bowman et al., 2021; Zaganjor et al., 2016). The findings of the present cohort align with this interpretation, demonstrating that postoperative complications—rather than surgical timing—were the primary drivers of prolonged hospitalization, underscoring the dominant role of postoperative morbidity over procedural timing.

Methodological Considerations: Continuous Versus Categorical Timing

A key methodological strength of this study lies in its prospective treatment of surgical timing as a continuous exposure variable derived from exact birth and surgical timestamps. Dichotomization of continuous variables using arbitrary cutoffs is known to reduce statistical power, obscure potential non-linear relationships, and introduce misclassification bias (Altman & Royston, 2006; Rothman et al., 2008). By preserving temporal granularity, the present analysis allows a more nuanced assessment of whether incremental delays influence outcomes across a broad and clinically relevant time range. The absence of a detectable association between increasing time to surgery and short-term outcomes suggests that risk does not rise in a linear or threshold-dependent manner during the early postnatal period, particularly when modern perioperative standards are maintained.

Neurological Outcomes at Discharge

Preservation of neurological function remains a central objective of MMC repair. In the present study, neurological status at discharge—assessed through motor-level preservation and lower-extremity motor function—was largely stable and showed no association with time to surgery. This finding is consistent with previous reports indicating that short-term neurological status is generally preserved following postnatal MMC repair when closure is performed using standardized techniques (Foss et al., 2019; Akar et al., 2023).

Importantly, studies demonstrating neurological differences related to timing typically focus on long-term functional, cognitive, or ambulatory outcomes rather than discharge-level neurological assessments (Fletcher et al., 2005; Dennis et al., 2006). Evidence from prenatal repair trials and long-term follow-up cohorts further suggests that timing effects may become more apparent over extended periods rather than during the immediate postoperative course (Adzick et al., 2011; Houtrow et al., 2020). The absence of early neurological differences in the present cohort should therefore be interpreted within the context of short-term follow-up.

CSF-Related Complications and Revision Surgery

CSF leak, wound dehiscence, and the need for revision surgery remain clinically relevant complications of MMC repair. In this cohort, such events were infrequent and were not associated with time to surgical repair. This aligns with contemporary literature emphasizing that CSF-related morbidity is more closely linked to defect morphology, quality of dural reconstruction, and underlying CSF dynamics than to absolute timing of closure (McLone & Knepper, 1989; Kulkarni et al., 2001).

Similarly, the need for ventriculoperitoneal shunt placement within the early postoperative period was not predicted by surgical timing. Large cohort studies and meta-analytic data indicate that hydrocephalus development and shunt dependency are primarily determined by MMC pathophysiology and hindbrain herniation rather than postnatal closure timing alone (Kestle et al., 2016; Saarinen et al., 2024). The present findings further support this interpretation.

Length of Hospital Stay and Clinical Implications

Length of hospitalization serves as an important surrogate for postoperative morbidity and healthcare resource utilization. In this cohort, prolonged hospital stay was significantly associated with postoperative complications but not with timing of surgery. Similar observations have been reported across neonatal surgical populations, reinforcing the concept that complication burden outweighs procedural timing in determining length of stay (Bowman et al., 2001; Naicker et al., 2023).

From a clinical perspective, these findings suggest that within modern perioperative care frameworks, short-term outcomes following MMC repair may not be critically dependent on exact surgical timing, provided appropriate infection control, neonatal stabilization,

and surgical standards are maintained. This is particularly relevant for centers operating under logistical or resource constraints, where immediate surgery may not always be feasible.

Overall Interpretation

Taken together, these findings do not negate the rationale for early postnatal MMC repair but rather contextualize its importance within contemporary neonatal and neurosurgical practice. While early closure within 48–72 hours remains a reasonable goal when feasible, the data suggest that unavoidable delays beyond this window do not necessarily translate into increased short-term morbidity when perioperative care is optimized. These results highlight the primacy of surgical quality, infection-prevention strategies, and multidisciplinary postoperative care over rigid adherence to timing thresholds alone.

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