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The Postoperative Course of Troponin T and NT-proBNP Levels in the Pediatric Population Implanted with the HeartMate 3 Device

ABSTRACT

Objective: Cardiac troponin T (cTnT) and N-terminal pro-B-type natriuretic peptide (NT-proBNP) are key biomarkers reflecting myocardial injury and hemodynamic load in heart failure or after cardiac surgery. However, data on their postoperative course in pediatric HeartMate 3 (HM3) recipients are limited. This retrospective case series of ten pediatric patients aimed to evaluate the clinical significance of postoperative changes in these biomarkers.

Methods: This retrospective case series included pediatric patients who underwent left ventricular assist device (LVAD) implantation between 2022 and 2024 at the center. Clinical and laboratory data were retrospectively obtained from medical records.

Results: Ten patients with dilated cardiomyopathy (PEDIMACS profiles 1-3) were included. The median preoperative cTnT level was 98.5 [IQR 42.5-236.5] ng/L. Median postoperative cTnT levels were 182.6 [IQR 88.3-342.9] ng/L at 1 month, 54.0 [IQR 32.0-92.0] ng/L at 6 months, and 43.2 [IQR 25.8-71.4] ng/L at 12 months. Median B-type natriuretic peptide (BNP) levels were 7510 [IQR 5350-10850] ng/L preoperatively, 4122 [IQR 2963-7288] ng/L at 1 month, 853 [IQR 520.3-1426] ng/L at 6 months, and 1041 [IQR 619.8-1524] ng/L at 12 months. The mean intensive care unit (ICU) stay was 24.1 ± 16.3 days. Troponin levels returned to normal by postoperative month 6 in all but 2 patients. Spearman analysis showed a significant positive correlation between preoperative cTnT and ICU stay ($\rho = 0.687$, $P = .028$).

Conclusion: In pediatric HM3 recipients, cTnT and NT-proBNP levels reflect postoperative myocardial recovery and may serve as clinically useful indicators associated with intensive care duration.

Keywords: Bridge to heart transplantation, dilated cardiomyopathy, HeartMate 3, left ventricular assist device, NT-proBNP, pediatric heart failure, troponin T

INTRODUCTION

Pediatric heart failure, although relatively uncommon during childhood, is a serious clinical condition associated with high morbidity and mortality. In patients who progress to end-stage heart failure, heart transplantation remains the most effective and definitive treatment option. However, the limited availability of suitable organ donors has led to the increasing use of ventricular assist devices (VADs) in the pediatric population as a bridge-to-transplantation therapy. In addition, in conditions such as myocarditis or systemic diseases, VADs can also be used to support myocardial recovery or serve as destination therapy.[1,2]

In recent years, advancements in VAD technology have transformed these devices from temporary bridge therapies into durable treatment options that prolong survival and enhance functional capacity.[3] These devices aim to maintain systemic circulation, preserve end-organ perfusion, and reduce the adverse multiorgan effects of heart failure until transplantation becomes feasible. Nevertheless, repeated hospitalizations, infection, bleeding, thrombosis, and right ventricular failure remain major complications that limit the widespread clinical use of VAD therapy.[4,5]

ORIGINAL INVESTIGATION

Şeyma Şebnem Ön[1]
Zülal Ülger Tutar[1]
Eser Doğan[1]
Meral Yılmaz[1]
Burcu Büşra Acar[1]
Hakan Kurt[1]
Burcugül Karasulu Beci[1]
Aslı Taşdemir[2]
Pınar Yazıcı[3]
Kübra Cebeci[3]
Hür Hassoy[4]
Ertürk Levent[1]
Osman Nuri Tuncer[5]
Çağatay Engin[5]
Tahir Yağdı[5]
Mustafa Özbaran[5]

[1]*Department of Pediatric Cardiology, Ege University Faculty of Medicine, İzmir, Türkiye*
[2]*Department of Pediatrics, Ege University Faculty of Medicine, İzmir, Türkiye*
[3]*Department of Pediatric Intensive Care, Ege University Faculty of Medicine, İzmir, Türkiye*
[4]*Department of Public Health, Ege University Faculty of Medicine, İzmir, Türkiye*
[5]*Department of Cardiovascular Surgery, Ege University Faculty of Medicine, İzmir, Türkiye*

Corresponding author:
Eser Doğan
✉ eserdogan86@hotmail.com

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The HeartMate 3 (HM3) device (Abbott Corp., USA) is a new-generation left ventricular assist device (LVAD) that provides continuous centrifugal blood flow through complete magnetic levitation technology. With these technological features, it aims to reduce the incidence of pump thrombosis, hemolysis, and embolic complications.[6,7] However, due to its size, which poses anatomical limitations in small children, the use of HM3 in the pediatric population has so far been reported only by a limited number of centers.[8]

During the postoperative recovery period following VAD implantation, cardiac biomarkers—particularly cardiac troponin T (cTnT) and N-terminal pro-B-type natriuretic peptide (NT-proBNP) serve as important clinical indicators for monitoring myocardial stress and hemodynamic improvement. Although numerous studies have investigated these parameters in the adult population, data regarding long-term biochemical changes in pediatric patients remain limited.[9]

Myocardial injury after cardiac surgery may develop due to several factors, including prolonged cardiopulmonary bypass time, inadequate cardioprotection, systemic inflammatory response, or direct myocardial trauma. In this process, the troponin complex is considered one of the most sensitive and specific biomarkers of myocardial injury.[10-12] Troponin T levels usually begin to rise within 3-6 hours after myocardial injury, peak at 12-24 hours, and then gradually decline.[13] With these characteristics, it represents a clinically valuable parameter for assessing postoperative myocardial stress and recovery.

In adult populations, troponin levels have been reported to possess prognostic value in predicting cardiac complications, mortality, and intensive care unit stay duration.[12-14] However, in pediatric patients, the dynamics and prognostic significance of troponin T levels following LVAD implantation have not yet been well defined.

Another biomarker used in the assessment of heart failure is B-type natriuretic peptide (BNP) and its inactive fragment, NT-proBNP, which reflect ventricular wall stress and volume overload. These biomarkers are widely used in adults for the diagnosis, risk stratification, and prognostic evaluation of heart failure. However, in the pediatric population, standard reference ranges and cutoff values have not yet been clearly established due to age and body surface area–related variability. Furthermore, BNP and NT-proBNP are particularly sensitive for detecting postoperative right ventricular dysfunction, which represents one of the most important complications after left ventricular assist device implantation in children with dilated cardiomyopathy. Global cardiac hypokinesia and altered ventricular loading conditions may predispose these patients to right ventricular failure, making postoperative management challenging. Therefore, evaluation of NT-proBNP levels during the postoperative period may provide clinically relevant insight into hemodynamic changes and ventricular adaptation following mechanical circulatory support.[7,8,15-18]

In this study, the postoperative course of troponin T and NT-proBNP levels was retrospectively evaluated in pediatric patients implanted with the HM3 device. The timing of normalization of these biomarkers and their possible associations with intensive care unit stay duration were analyzed, and the findings were discussed in the context of the existing literature.

HIGHLIGHTS

- Troponin T and N-terminal pro-B-type natriuretic peptide levels reflect postoperative myocardial recovery in pediatric HeartMate 3 recipients.
- A significant correlation was found between preoperative troponin T levels and intensive care unit stay duration.
- Biomarker normalization by 6 months indicates improved ventricular unloading and recovery.
- Genetic cardiomyopathies may cause delayed biochemical recovery.
- Troponin T can serve as a potential prognostic marker in pediatric left ventricular assist device management.

METHODS

This retrospective case series included pediatric patients who were diagnosed with advanced heart failure between 2022 and 2024, listed for heart transplantation, and implanted with a LVAD as a bridge to transplantation. All patients were followed at the center. The study was approved by the Ege University Medical Research Ethics Committee (Approval No.: 25-6.1T/16; Date: 26.06.2025). Demographic data (age, sex, and body weight), primary diagnoses, PEDIMACS profiles, and pre- and post-operative clinical parameters were retrospectively reviewed from medical records. All patients were diagnosed with dilated cardiomyopathy, and the HM3 (Abbott Corp., USA) was used as the mechanical circulatory support device.

In each patient, serum high-sensitivity cardiac troponin T (hs-cTnT) and NT-proBNP levels were assessed preoperatively and during postoperative follow-up at 1 week, and at 1, 3, 6, and 12 months.

Troponin T levels were measured using an electrochemiluminescence immunoassay (ECLIA) method on Roche Diagnostics Elecsys 2010 or Cobas e601 platforms. The measurement range was 3-10000 ng/L, with an upper reference limit of 14 ng/L.

N-terminal pro-B-type natriuretic peptide (NT-proBNP) concentrations were also determined using the ECLIA principle on the Roche Cobas e601 analyzer. The measurement range was 5-35,000 ng/L, and the upper reference limit was accepted as 125 ng/L.

Venous blood samples were collected, centrifuged, and analyzed within 24 hours while stored at 2-8°C. All measurements were performed under the same laboratory conditions without changes to the device or calibration standards.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was assessed with the Shapiro–Wilk test.

Non-normally distributed variables were summarized as median (minimum–maximum).

Correlation analysis: The relationship between serum TnT and NT-proBNP levels and the duration of intensive care unit (ICU) stay was evaluated using the Spearman correlation test.

Changes in troponin T levels measured preoperatively and at postoperative day 1, day 3, day 7, day 14, and at 1, 3, 6, and 12 months were analyzed using the Friedman non-parametric repeated-measures analysis of variance, given the small sample size and non-normal distribution of the data. When a significant overall time effect was detected, post-hoc pairwise comparisons were performed using the Wilcoxon signed-rank test with Bonferroni correction to evaluate at which postoperative time point troponin T levels converged with preoperative values. Group comparisons: Based on the mean ICU stay (24 days), patients were divided into 2 groups as "short-stay" (<24 days) and "long-stay" (≥24 days). Differences in biochemical parameters between the 2 groups were analyzed using the Mann–Whitney *U*-test. A *P*-value of $< .05$ was considered statistically significant.

RESULTS

A total of 10 patients were included in the study; 4 (40%) were male and 6 (60%) were female. The ages ranged from 8 to 17 years, with a median age of 13 years [IQR 10.5-14.75]. All patients were diagnosed with dilated cardiomyopathy, and their PEDIMACS profiles ranged from 1 to 3. Genetic testing revealed Carvajal syndrome in 1 patient and Limb-Girdle muscular dystrophy in another. All cases were supported with the HM3 device. The mean ICU stay duration was 24.1 ± 16.3 days. During follow-up, 1 patient died on postoperative day 18.

Correlation analysis demonstrated a positive but not statistically significant relationship between BNP levels and ICU stay duration ($r = 0.667$, $P = 0.071$). In contrast, a significant positive correlation was found between preoperative troponin T levels and ICU stay duration ($r = 0.687$, $P = 0.028$). Patients with ICU stay durations longer than the mean value (24 days) had significantly higher preoperative troponin T levels (Mann–Whitney *U*-test, $P = 0.016$). The demographic and clinical characteristics of the patients, as well as their ICU stay durations, are summarized in Table 1.

Table 1. Demographic Data and Pediatric ICU Stay Durations

Case	Age	Weight (kg)	Sex	ICU Stay (Days)	Diagnosis
1	15	32.0	Male	31	Limb-Girdle muscular dystrophy
2	13	28.0	Female	5	DCM
3	12	40.0	Female	11	DCM
4	10	24.0	Female	29	DCM
5	17	46.0	Male	12	DCM
6	14	42.0	Female	36	Carvajal syndrome
7	8	19.0	Male	59	DCM
8	10	26.0	Female	9	DCM
9	16	52.0	Female	23	DCM
10	13	nan	Male	20	DCM

Most patients were diagnosed with dilated cardiomyopathy (DCM). One patient had Carvajal syndrome and 1 had Limb-Girdle muscular dystrophy.
ICU, intensive care unit.

In the preoperative period, troponin T (cTnT) levels ranged from 15 to 589 ng/L, with a median of 98.5 ng/L [IQR 42.5-236.5]. The highest preoperative troponin level was observed in the patient with Limb-Girdle muscular dystrophy carrying a homozygous mutation in the SGCA gene (Case 1). On postoperative day 1, cTnT levels ranged from 554 to 23254 ng/L, with a median of 1104.5 ng/L [IQR 818.8-2663.3]; the highest level was recorded in the patient with Carvajal syndrome (Case 6). On postoperative day 7, troponin levels ranged from 320 to 1890 ng/L, with a median of 880 ng/L [IQR 620-1320].

At 1 month postoperatively, cTnT levels ranged from 18 to 1580 ng/L, with a median of 48 [IQR 32-105]; at 3 months, values ranged from 7 to 45 ng/L, with a median of 18 ng/L [IQR 10-25]. At 6 months, cTnT levels were between 5 and 38 ng/L, with a median of 12 ng/L [IQR 7-18], and at 12 months, they ranged from 4 to 33 ng/L, with a median of 10 ng/L [IQR 6-14]. The temporal changes of postoperative troponin and NT-proBNP levels by day are presented in Table 2, and their

Table 2. Postoperative Troponin T Levels by Time Point

Case	Preop TnT	Postop Day 1 TnT	Postop Day 7 TnT	Postop 1M TnT	Postop 3M TnT	Postop 6M TnT	Postop 12M TnT
1	27	554	686	63	16.0	17.0	23.0
2	21	770	547	56	31.0	29.0	20.0
3	18	773	878	54	11.0	6.0	5.0
4	20	1008	1192	71	12.0	12.0	5.0
5	15	3344	2648	120	19.0	11.0	8.0
6	589	23254	4742	207	662.0	25.0	191.0
7	44	956	467	54	16.0	14.0	21.0
8	19	1545	1058	99	9.0	8.0	11.0
9	25	1589	476	70	15.0	11.0	10.0
10	16	3036	2123	1580	nan	nan	nan

Troponin T levels peaked immediately after surgery and decreased progressively, approaching the normal range in most patients within 6-12 months.

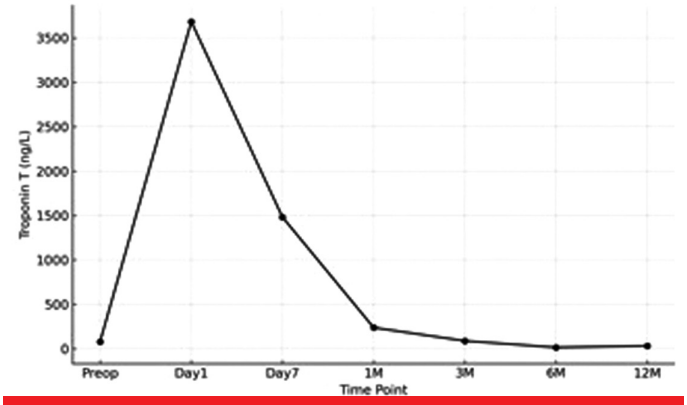

Figure 1. Postoperative 1-year trajectory of patients' cardiac troponin T (cTnT) levels. (This figure illustrates the temporal trend of serum troponin T concentrations throughout the first postoperative year.)

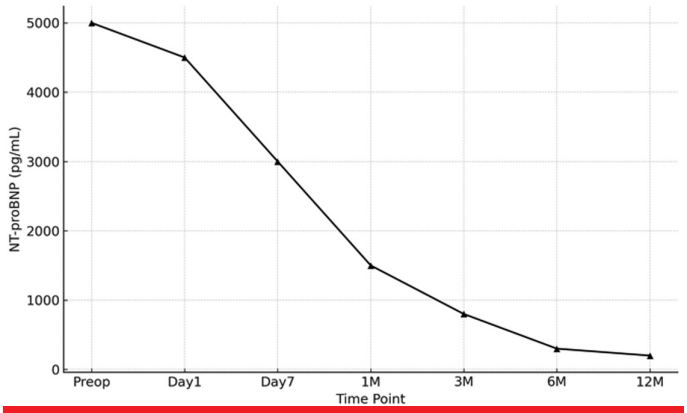

Figure 3. Postoperative 1-year trajectory of patients' N-terminal pro-B-type natriuretic peptide (NT-proBNP) levels. *(NT-proBNP declined markedly within the first 6 months and then stabilized.)*

monthly trends are illustrated in Figure 1. Consistent with these descriptive findings, Friedman analysis demonstrated a statistically significant change in troponin T levels over time across the preoperative and postoperative measurements (overall time effect). In post hoc pairwise comparisons (Wilcoxon signed-rank tests with Bonferroni correction), troponin T showed an early postoperative increase followed by a gradual decline, approaching preoperative values during mid- to long-term follow-up.

On postoperative day 1, NT-proBNP levels ranged from 3130 to 23693 ng/L, with a median of 11138 ng/L [IQR 5889-15724]. On postoperative day 7, NT-proBNP levels ranged from 2800 to 20400 ng/L, with a median of 9020 ng/L [IQR 6400-13250]. At 1 month, levels ranged from 1650 to 8900 ng/L, with a median of 4600 ng/L [IQR 3250-5800]. At 3 months, NT-proBNP levels were between 665 and 1887 ng/L, with a median of 1071 ng/L [IQR 725-1550]. At 6 months, levels ranged from 180 to 1887 ng/L, with a median of 853 ng/L [IQR 450-1268], and at 12 months, from 222 to 2105 ng/L, with a median of 980 ng/L [IQR 445-1480]. The temporal changes in NT-proBNP levels are shown in Figures 2 and 3.

The duration of ICU stay ranged from 5 to 59 days, with a mean of 24.1 ± 16.3 days. According to Spearman correlation analysis, postoperative day 1 NT-proBNP levels showed a positive but statistically non-significant correlation with ICU stay duration ($\rho = -0.395$, $P = .258$) (Figure 4).

When patients were grouped according to ICU stay duration, those in the long-stay group (≥24 days, n = 5) had preoperative troponin T levels ranging from 45 to 589 ng/L, with a median of 275 (IQR 125-512). In this group, a positive correlation was observed between troponin T levels and ICU stay duration (Spearman $\rho = 0.872$, $P = .054$).

In the short-stay group (<24 days, n = 5), preoperative troponin T levels ranged from 15 to 128 ng/L, with a median of 54 [IQR 32-92]. In this group, a negative correlation was found between troponin T levels and ICU stay duration (Spearman $\rho = -0.900$, $P = .037$) (Table 3).

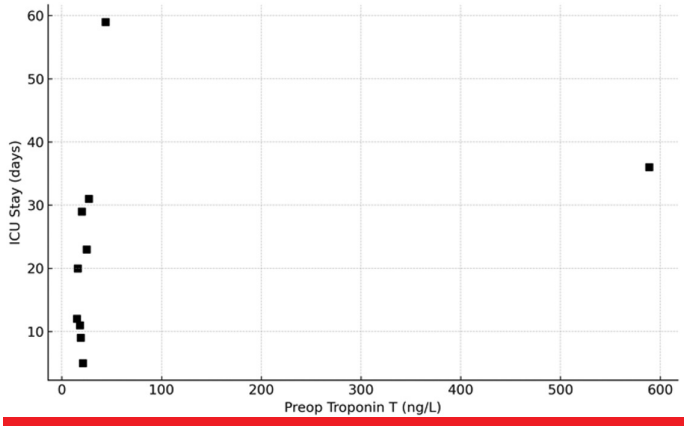

Figure 2. Correlation between preoperative troponin T levels and intensive care unit (ICU) stay duration. (The scatter plot demonstrates the relationship between preoperative cTnT values and postoperative ICU length of stay, with the regression/LOWESS line indicating the overall trend.)

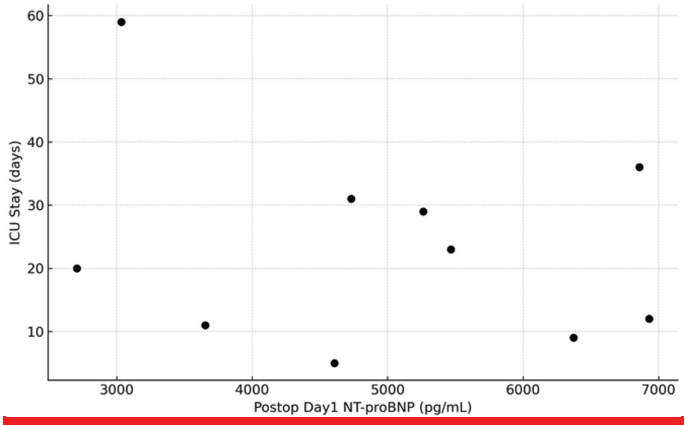

Figure 4. Correlation of postoperative day 1 N-terminal pro-B-type natriuretic peptide (NT-proBNP) levels and intensive care unit (ICU) stay duration. (A positive trend was observed, though statistical significance was not reached.)

Table 3. Spearman Correlation Analysis Between Preoperative Troponin T Levels and ICU Stay Duration in Patient Subgroups With Short and Long ICU Stay

Group	Spearman's rho (ρ)	*P*	Interpretation
All patients (n = 10)	0.687	.028	Significant positive correlation
Long ICU stay (≥ 24 days, n = 5)	0.872	.054	Strong positive correlation, borderline significance
Short ICU stay (< 24 days, n = 5)	−0.900	.037	Strong negative correlation, statistically significant

ICU, intensive care unit.

DISCUSSION

This study is one of the few to investigate the relationship between postoperative changes in troponin T (cTnT) and NT-proBNP levels and the duration of ICU stay in pediatric patients implanted with a HM3 LVAD. The findings provide a comprehensive evaluation not only of the temporal changes in these biomarkers during the postoperative period but also of their associations with demographic and clinical parameters.

The study included 10 patients aged between 10 and 16 years, with a median age of 13 years [IQR 10.5-14.75]. Body weights ranged from 23 to 52 kg, with a median of 31 kg [IQR 27-36]. Sixty percent of the patients were female and 40% were male. All patients were diagnosed with dilated cardiomyopathy, and their PEDIMACS profiles ranged between 1 and 3.

This demographic distribution is consistent with previous pediatric mechanical circulatory support series reported in the literature. Bhatia et al[1] reported a similar age range in their series of 11 patients, most of whom were diagnosed with dilated cardiomyopathy, demonstrating that both HeartMate 2 and HM3 devices could be safely used in this population. Similarly, data from the PEDIMACS registry presented by Rossano et al[19] indicated an increasing use of device support among patients aged 6-17 years, with lower mortality rates compared with younger pediatric groups.[18]

In the center, pediatric patients with advanced heart failure, particularly those who are inotropic-dependent with low PEDIMACS profiles, undergo routine daily laboratory monitoring in both the preoperative and postoperative intensive care setting. As part of this standard clinical follow-up, daily cTnT and NT-proBNP measurements are available for all patients. For the purposes of this study, we selected biomarker values obtained on postoperative days 1, 3, 7, and 14, and subsequently at 1, 3, 6, and 12 months. These specific time points correspond to the institution's structured postoperative monitoring schedule, which is designed to evaluate early myocardial injury, stabilization, and longer-term myocardial recovery after LVAD implantation. Therefore, the chosen sampling intervals reflect routine clinical practice and provide representative markers of both acute and chronic postoperative trajectories.

In the preoperative period, troponin T levels in all patients were above the upper reference limit, ranging from 15 to 589 ng/L, with a median value of 98.5 ng/L [IQR 42.5-236.5]. This finding indicates that myocardial cell injury was already present before device implantation. Lipshultz et al[12] reported that troponin T levels reflect the severity of myocardial damage in pediatric heart failure patients. Similarly, Licka et al[13] and Collinson et al[14] demonstrated a strong correlation between troponin elevation and myocyte necrosis.

On postoperative day 1, troponin T levels ranged from 554 to 23.254 ng/L, with a median of 1.104 ng/L [IQR 818.8-2.663]. A marked early postoperative rise was observed in all patients, followed by a decline at 1 month and a gradual return toward normal reference levels between 6 and 12 months. Ragusa et al[9] similarly reported that troponin T levels increase in the early period following VAD implantation and subsequently show a progressive decline. Immer et al[10] noted that postoperative troponin elevation correlates with cardiopulmonary bypass duration and surgical complexity. Lasocki et al[11] and Babuin and Jaffe[20] also emphasized that elevated troponin levels represent the biochemical manifestation of early myocardial injury. The trend observed in the series is consistent with the literature and suggests that myocardial stress gradually decreases following device implantation, likely due to the reduction in ventricular wall tension provided by mechanical unloading. These findings should be interpreted as reflecting general temporal trends rather than definitive time-specific conclusions, particularly in light of the limited sample size. Nevertheless, the observed postoperative decline in troponin T levels is consistent with the expected pattern of myocardial recovery following mechanical ventricular unloading. Preoperative BNP levels ranged from 3201 to 16322 ng/L, with a median of 7510 ng/L [IQR 5350-10850] ng/L. Elevated BNP levels are associated with left ventricular volume overload and increased intracardiac pressures. Braunwald[21] and Sarhene et al[15] reported that BNP possesses both diagnostic and prognostic value in heart failure, while York et al[16] emphasized its significant association with mortality. In this context, the high BNP values observed in this study can be interpreted as a biochemical indicator of ventricular dysfunction in the pre-implantation period.

N-terminal pro-B-type natriuretic peptide (NT-proBNP) levels on postoperative day 1 ranged from 3130 to 23693 ng/L, with a median of 11138 ng/L [IQR 5889-15724] ng/L, demonstrating a marked decline by the first postoperative month. The median NT-proBNP level was 853 ng/L [IQR 450-1268] ng/L at 6 months and 980 ng/L [IQR 445-1480] ng/L at 12 months. The early postoperative elevation in BNP is primarily attributed to surgical stress and hemodynamic loading.[15,20,21] In adult LVAD series, BNP levels have been reported to reflect improvements in ventricular function following device implantation.[15,16] The 2022 AHA/ACC/HFSA heart failure guideline published by Heidenreich et al[18] recommends the use of BNP for risk stratification and monitoring in heart failure management. However, in pediatric populations,

standardization remains challenging due to age and body surface area–related variability in reference values.

The duration of ICU stay ranged from 5 to 59 days, with a mean of 24.1 ± 16.3 days. Correlation analysis revealed a statistically significant positive relationship between preoperative troponin T levels and ICU stay duration ($\rho = 0.687$, $P = .028$). In contrast, postoperative day 1 NT-proBNP levels showed a positive but statistically non-significant correlation with ICU stay duration ($\rho = -0.395$, $P = 0.258$). These findings suggest that patients with a greater degree of preoperative myocardial injury experience a longer postoperative recovery period. Similarly, Immer et al,[10] Boroński et al,[22] and Mildh et al[23] reported correlations between troponin levels, postoperative morbidity, and ICU length of stay. The Mann–Whitney U-test also demonstrated significantly higher preoperative troponin T levels in the long-stay group ($P = .016$), supporting this association.

Delayed normalization of troponin T levels was observed in patients with genetic cardiomyopathies. In two cases diagnosed with Carvajal syndrome and Limb-Girdle muscular dystrophy, troponin T levels remained above the reference range even at the sixth postoperative month. This finding suggests that genetic etiology may contribute to delayed myocardial recovery. Boroński et al[22] also reported that postoperative troponin elevation may be associated with the inflammatory response. Therefore, the interpretation of troponin levels should consider not only myocardial necrosis but also potential contributions from inflammatory processes and genetic background.

Despite these valuable observations, certain limitations should be acknowledged. First, the small sample size inherently restricts the statistical power of the analyses and limits the generalizability of the findings. In addition, although the use of the mean ICU stay of 24 days as a cutoff was clinically reasonable, the small number of patients may have influenced the robustness of this stratification. Therefore, interpretations regarding ICU stay–biomarker associations should be approached with caution.

Beyond ICU stay, additional patient outcomes were also evaluated. One patient died due to progressive multiple organ dysfunction that had already developed by the time of presentation. This patient presented to the emergency department at an end-stage, with markedly elevated renal and hepatic function tests secondary to severe heart failure, and was already progressing toward multiple organ dysfunction; under these circumstances, despite LVAD implantation, the patient could not be stabilized and died on postoperative day 18. Another patient, who was later found to have Carvajal syndrome based on a genetic result consistent with arrhythmogenic right ventricular dysplasia, experienced gradually worsening right ventricular failure despite LVAD support and died from severe right ventricular dysfunction in the twentieth postoperative month while awaiting heart transplantation. No significant postoperative complications were observed in the remaining patients during their intensive care or early postoperative course.

This study represents one of the few datasets demonstrating the temporal changes of troponin T and NT-proBNP levels and their clinical correlations in the pediatric HM3 population. The findings indicate that troponin T may serve as a biochemical marker of postoperative recovery, whereas NT-proBNP primarily reflects early hemodynamic loading. Larger, multicenter, and prospective studies are warranted to better define the prognostic value and clinical utility of these biomarkers in pediatric LVAD patients.

CONCLUSION

In pediatric patients implanted with the HM3 left ventricular assist device, troponin T (TnT) and NT-proBNP levels reflect postoperative myocardial recovery and may serve as clinically useful indicators associated with intensive care unit stay duration. The early postoperative rise in TnT levels, followed by gradual normalization within 6-12 months, can be interpreted as evidence of ventricular decompression and hemodynamic improvement achieved through mechanical support.

However, in cases where TnT levels normalize more slowly, underlying genetic cardiomyopathies and persistent inflammatory processes should be carefully investigated.

This study is original in demonstrating a significant correlation between preoperative TnT levels and postoperative intensive care unit stay duration, suggesting that this biomarker may serve as a potential prognostic indicator in pediatric LVAD patients.

Future studies with larger sample sizes, prospective designs, and multicenter participation are warranted to more clearly define the clinical utility and prognostic value of TnT and NT-proBNP levels in the management of this patient population.

Study Limitations

Despite these valuable observations, certain limitations should be acknowledged. First, the small sample size (n = 10) inherently limits the statistical power of the analyses and restricts the generalizability of the findings. Therefore, the results should be interpreted as exploratory observations rather than definitive conclusions. In addition, although serial troponin T and NT-proBNP measurements were available up to 12 months postoperatively, the limited number of patients may have reduced the ability to detect subtle differences between individual postoperative time points.

Artificial Intelligence (AI) Statement: Artificial Intelligence–assisted technologies (such as ChatGPT, OpenAI) were used solely for language editing and formatting assistance. The authors are fully responsible for the scientific content of the manuscript.

Ethics Committee Approval: This study was approved by the Ege University Medical Research Ethics Committee (Approval No.: 25-6.1T/16; Date: 26.06.2025).

Informed Consent: Written informed consent was obtained from the patients who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept & Design – Ş.Ş.Ö., Z.Ü.T., E.D., M.Ö.; Supervision – M.Ö., T.Y., Ç.E., O.N.T.; Resources & Materials – M.Y., B.B.A., H.K., B.K.B., A.T., P.Y., K.C.; Data Collection/Processing – Ş.Ş.Ö., Z.Ü.T., E.D., M.Y., B.B.A., H.K.; Analysis/Interpretation – Ş.Ş.Ö., E.D., Z.Ü.T., H.H., E.L.; Literature Search & Writing – Ş.Ş.Ö., E.D., Z.Ü.T.; Critical Review – M.Ö., T.Y., Ç.E., O.N.T., H.H., E.L., B.K.B.

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