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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Diaphragmatic elevations following cardiac surgery

Kardiyak cerrahi sonrasında diyafram elevasyonları

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ABSTRACT

Background: This study aims to investigate the incidence, prognosis, and etiology of diaphragmatic elevation following cardiac surgery.

Methods: Between February 2019 and December 2019, a total of 888 patients (631 males, 257 females; mean age: 58.4±12.1 years; range, 19 to 84 years) who underwent cardiac surgery were retrospectively analyzed. A series of chest X-rays taken before and after surgery were analyzed to detect diaphragmatic elevation. The patients were divided into two groups: those without diaphragmatic elevation (Group 1, n=789) and those with diaphragmatic elevation (Group 2, n=99).

Results: Diaphragmatic elevation occurred in 11.14% of patients. Of these patients, 85% recovered within a year. Patients with concomitant chronic obstructive pulmonary disease and diaphragmatic elevation exhibited prolonged mechanical ventilation compared to chronic obstructive pulmonary disease patients without elevation. The incidence of diaphragmatic elevation was higher in coronary artery bypass grafting patients compared to others (p<0.001). A secondary analysis utilizing propensity score matching revealed topical cold slush as an independent risk factor for diaphragmatic elevation. Incidence and hospitalization duration were higher among patients exposed to topical cold slush (p=0.011 and p=0.002, respectively). Left internal mammary artery harvesting and diabetes mellitus were associated with increased incidence of diaphragmatic elevation.

Conclusion: Diaphragmatic elevation is frequent following cardiac surgery, particularly in coronary artery bypass grafting patients with diabetes mellitus. Among chronic obstructive pulmonary disease patients, diaphragmatic elevation can lead to unfavorable clinical outcomes. Minimizing the use of topical cold slush and considering beating heart surgery may be prudent in high-risk groups to reduce diaphragmatic elevation incidence.

Keywords: Cardiac surgery, coronary artery bypass grafting, mammary arteries, phrenic nerve, respiratory paralysis.

ÖZ

Amaç: Bu çalışmada kardiyak cerrahi sonrası görülen diyafram elevasyonlarının sıklığı, prognozu ve bu etiyolojisi araştırıldı.

Çalışma planı: Şubat 2019-Aralık 2019 tarihleri arasında kalp cerrahisi yapılan toplam 888 hasta (631 erkek, 257 kadın; ort. yaş: 58.4±12.1 yıl; dağılım, 19-84 yıl) retrospektif olarak değerlendirildi. Cerrahi öncesi ve sonrasında çekilen bir dizi göğüs röntgeni diyafram elevasyonunu tespit etmek amacıyla incelendi. Hastalar iki gruba ayrıldı: diyafram elevasyonu olmayanlar (Grup 1, n=789) ve diyafram elevasyonu olanlar (Grup 2, n=99).

Bulgular: Hastaların %11.14'ünde diyafram elevasyonu saptandı. Bu hastaların %85'inde bir yıl içinde iyileşme izlendi. Diyafram elevasyonu olmayan kronik obstrüktif akciğer hastalığı olan hastalara kıyasla, kronik obstrüktif akciğer hastalığı ve diyafram elevasyonu birlikteliği olan hastaların mekanik ventilasyon süresi daha uzundu. Diyafram elevasyonunun insidansı, diğerlerine kıyasla, koroner arter baypas greftleme yapılan hastalarda daha yüksekti (p<0.001). Eğilim skoru eşleştirme yöntemi uygulanarak yapılan ikincil bir analizde topikal soğuk slush diyafram elevasyonu için risk faktörü olarak bulundu. İnsidans ve hastanede kalış süresi, topikal soğuk slush uygulanan hastalarda daha yüksekti (sırasıyla, p=0.011 ve p=0.002). Sol internal meme arter kullanımı ve diabetes mellitus, diyafram elevasyonu insidansında artış ile ilişkili idi.

Sonuç: Diyafram elevasyonu, bilhassa diabetes mellituslu koroner arter baypas greftleme yapılan hastalarda kardiyak cerrahi sonrasında sık görülür. Kronik obstrüktif akciğer hastalığı olan hastalarda diyafram elevasyonu olumsuz klinik sonuçlara yol açabilir. Yüksek riskli gruplarda diyafram elevasyon insidansını azaltmak için topikal soğuk slush kullanımını en aza indirgemek ve atan kalpte kalp cerrahisini düşünmek gerekebilir.

Anahtar sözcükler: Kalp cerrahisi, koroner arter baypas greftleme, mammaryan arterler, frenik sinir, respiratuvar paralizi.

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As the primary respiratory muscle, the diaphragm contracts during inspiration, contributing approximately 60 to 70% to tidal volume.[1] Diaphragmatic elevation (DE) is classified into congenital and acquired types.[2] Acquired DE is predominantly attributed to cardiac procedures. In addition, DE following cardiac surgeries significantly contributes to pulmonary dysfunction, resulting in increased postoperative morbidity and mortality.[3] During cardiac surgery, various factors can cause phrenic nerve damage, leading to the development of DE.[4-6]

Postoperative DE is typically identified with a chest X-ray. Clinical manifestations vary from asymptomatic findings to the necessity for prolonged mechanical ventilation and increased mortality risk. While unilateral DE often does not require intervention, patients with preexisting pulmonary conditions (e.g., chronic obstructive pulmonary disease [COPD], prior lobectomy) may exhibit symptoms necessitating rigorous pulmonary rehabilitation and, in selected cases, surgical evaluation.[7]

In the present study, we aimed to investigate the incidence of DE and its one-year prognosis in the postoperative period and to identify associated factors and vulnerable patient groups.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Ankara Bilkent City Hospital, Department of Cardiovascular Surgery between February 2019 and December 2019. A total of 915 consecutive adult patients who underwent cardiac surgery were initially screened. Of the patients, 27 were excluded from the study for not meeting the specified criteria necessary for diagnosing DE. Among these exclusions, 13 patients were excluded due to early postoperative mortality within the first three days, 11 due to preoperative DE, and three due to unobtainable imaging examinations. Finally, a total of 888 patients (631 males, 257 females; mean age: 58.4±12.1 years; range, 19 to 84 years) were recruited. Data were obtained from the hospital information system and patient records.

Routine chest X-rays and pulmonary function tests were performed for all patients. Those with COPD or abnormal results were referred to the Chest Diseases and Pulmonology Department for further evaluation. Diagnosis and management decisions, including surgery or alternative treatments, were made collaboratively for high-risk patients.

Pre- and postoperative chest X-rays taken after the removal of thoracic drains in a standing position were examined. An elevated diaphragm is diagnosed when the left diaphragmatic dome is at or above the level of the right diaphragmatic dome, or when the right diaphragmatic dome is higher than the right fifth anterior rib during deep inspiration.[6] The patients were divided into two groups: those without DE (Group 1, n=789) and those with DE (Group 2, n=99).

All patients were routinely followed at one, two, six, and 12 months. The restoration of the diaphragm level on chest X-ray was considered an improvement in DE.

The demographic, preoperative, intraoperative, and postoperative data of the groups were compared.

Surgical techniques

In our study, patients primarily underwent full sternotomy with cardiopulmonary bypass. The left internal mammary artery (LIMA) was typically used as the primary graft for coronary artery bypass grafting (CABG), supplemented by saphenous vein grafts. Procedures included routine pericardial reverse T-shaped incisions, systemic heparinization adjusted by activated clotting time (ACT) monitoring, and several cannulation methods based on valve disease or aortic cases. Topical cold slush was routinely applied during procedures utilizing a cross-clamp, with systemic hypothermia adjusted based on procedure type and duration.

Statistical analysis

Statistical analysis was conducted using the SPSS version 15.0 software (SPSS Inc., Chicago, IL, USA). The normality of the variables was examined visually (histograms and probability plots) and analytically (Kolmogorov-Smirnov/Shapiro-Wilk tests). Descriptive analyses were presented in mean±standard deviation (SD) for continuous variables and in number and frequency for categorical variables. The Mann-Whitney U test was used for comparisons between the groups with and without DE for continuous variables, while the chi-square test was used for categorical variables. To investigate the impact of slush usage, a group of 37 patients who did not use slush was matched 1:1 with a group of 37 patients who used slush, based on trend scores for LIMA usage, age, sex, and DM (R30 statistical software, version 4.0.2). Multivariate logistic regression analysis was conducted to identify the factors affecting DE. Odds ratio (OR) and 95% confidence interval (CI) values were calculated for the parameters found to be statistically significant in the logistic regression models. A *p* value of 0.05 was considered statistically significant.

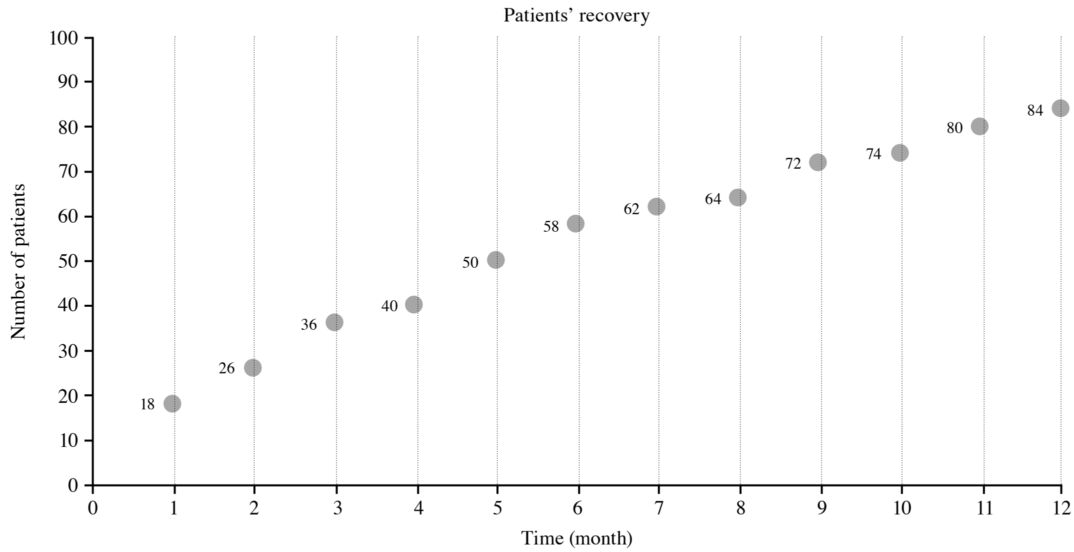

Figure 1. Recovery time of diaphragmatic elevation.

Table 1. Baseline characteristics of patients

	Group 1 (n=789)				Group 2 (n=99)				
	n	%	Mean±SD	Range	n	%	Mean±SD	Range	*p*
Age (year)			58.3±12.4	19-83			59.4±9.6	36-84	0.389
Sex									0.078
Female	236	29.9			21	21.2			
Male	553	70.1			78	78.8			
ASA									0.741
1	3	0.3			0	0.0			
2	253	32.0			34	34.3			
3	492	62.3			58	58.5			
4	37	4.6			7	7.7			
5	2	0.2			0	0.0			
Diabetes mellitus	253	32.0			41	41.4			0.062
Hypertension	318	40.3			47	47.4			0.067
COPD	83	10.5			9	9.9			0.848
Cerebrovascular accident	34	4.3			3	3.0			0.788
Chronic kidney disease	41	5.1			4	4.4			1.000
End-stage renal disease	5	0.6			0	0.0			1.000
Previous cardiac surgery	31	3.9			3	3.0			0.567
Mean ejection fraction			53.7±8.2	20-77			52.6±8.7	25-65	0.209
Emergency									
Surgery	34	4.3			5	5.0			0.796

SD: Standard deviation; ASA: American Society of Anesthesiologists; COPD: Chronic obstructive pulmonary disease.

RESULTS

Of the patients, DE was identified in 99 (Group 2), with an incidence rate of 11.14%. This included three cases of bilateral DE, eight cases of right DE, and 88 cases of left DE. During the 12-month follow-up, 84 (85%) patients exhibited improvement in DE (Figure 1). Demographic data of the patients are summarized in Table 1. There were no statistically significant differences in demographic characteristics, except for diabetes mellitus (DM) between the groups.

Intraoperative data

The incidence of DE was higher among patients who underwent CABG compared to other surgical procedures (p<0.001) (Table 2). Upon reviewing the operative data of the patients, no significant differences were observed between the two groups except in case of LIMA harvesting, which was significantly higher in Group 2 (Table 3).

Furthermore, while comparing surgeries conducted on the beating heart without topical cold slush to those using topical cold slush, DE was statistically significantly more common in patients subjected to topical cold slush (p=0.026).

To facilitate a more precise comparison, we analyzed patients who underwent both LIMA harvesting and topical cold slush application versus those who received topical cold slush without LIMA harvesting. Among patients who underwent both procedures, 80 out of 533 (15.0%) developed DE. On the other hand, only 19 out of 318 patients (5.97%) who received topical cold slush without LIMA harvesting experienced DE (p=0.0003).

Postoperative data

No significant differences in postoperative parameters were found between the groups (Table 4). The subgroup analysis of these data revealed that patients with COPD and DE had a longer mean duration of mechanical ventilation time compared to patients with COPD who did not develop DE (24.22±11.63 and 11.14±19.10 h, respectively; p=0.01).

Table 2. Summary of surgical procedures

	Group 1 (n=789)		Group 2 (n=99)		
	n	%	n	%	*p*
Aortic surgery	36	100.0	0	0.0	
Isolated CABG surgery	467	86.2	75	13.8	
CABG + aortic surgery	13	92.9	1	7.1	
CABG + valvular surgery	29	82.9	6	17.1	0.003
CABG + valvular + aortic surgery	3	75.0	1	25.0	
Isolated valvular surgery	176	94.2	11	5.8	
Valvular + aortic surgery	43	89.6	5	10.4	
Other cardiac surgeries	22	100.0	0	0.0	
Patients who had CABG	512	86.7	83	13.9	<0.001
Patients who did not have CABG	277	94.6	16	5.4	

CABG: Coroner artery bypass grafting; All procedures were initially compared followed by an analysis of patients grouped by CABG status.

Table 3. Intraoperative data of patients

	Group 1 (n=789)				Group 2 (n=99)				
	n	%	Mean±SD	Min-Max	n	%	Mean±SD	Min-Max	*p*
Cross-clamp time (min)*			78.15±37.60	17-258			74.85±30.64	16-194	0.402
CPB time (min)*			116.88±50.73	26-360			113.43±40.39	44-281	0.515
Operative time (min)			289.63±71.37	100-660			296.03±64.35	180-540	0.352
Beating heart surgeries	37	100.0			0	0.0			0.027
Non-beating heart surgeries	752	88.4			99	11.6			
With LIMA harvesting	483	85.7			80	14.3			<0.001
Without LIMA harvesting	306	94.1			19	5.9			

SD: Standard deviation; CPB: Cardiopulmonary bypass; LIMA: Left internal mammary artery. * The parameters for cross-clamp time and CPB time were calculated without including the patients operated on using the beating heart technique (n=37). Data were subsequently grouped and analyzed based on the use of the beating heart technique and, then, separately based on LIMA harvesting.

Table 4. Postoperative data of patients

	Group 1 (n=789)			Group 2 (n=99)			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Mechanical ventilation time (h)			30.16±158.68			12.71±19.66	0.808
ICU stay (day)			2.51±6.03			1.86±2.23	0.774
Hospital stay (day)			8.03±6.17			7.34±3.80	0.200
Hospital mortality	31	3.9		2	2.2		0.567

SD: Standard deviation; ICU: Intensive care unit.

Table 5. Propensity score matching analysis

	Slush group			Non-slush group			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (year)			62.0±12.6			61.7±12.3	0.691
Sex							1.000
Female	9	24.3		9	24.3		
Males	28	75.7		28	75.7		
Diabetes mellitus	13	35.1		15	40.5		0.632
Hypertension	18	48.6		20	54.1		0.642
COPD	5	13.5		1	2.7		0.199
Mean ejection fraction			55.24±7.14			50.51±11.49	0.138
Surgical procedures							0.691
CABG ± other	31	83.8		30	81.1		
Aortic	0	0.0		1	2.7		
Valvular ± aortic	5	13.5		4	10.8		
Other	1	2.7		2	5.4		
LIMA	30	81.1		30	81.1		1.000
CPB time (min)			108.30±39.61			86.57±37.13	0.143
MV time (h)			13.78±19.77			9.95±7.09	0.614
ICU stay (days)			2.57±4.05			1.41±1.12	0.128
Hospital stay (day)			9.25±5.17			6.08±2.28	0.002
Hospital mortality	1	2.7		0	0.0		1.000
Diaphragmatic elevation	7	18.9		0	0.0		0.011

SD: Standard deviation; COPD: Chronic obstructive pulmonary disease; CABG: Coroner artery bypass grafting; LIMA: Left internal mammary artery; CPB: Cardiopulmonary bypass, MV: Mechanical ventilation; ICU: Intensive care unit. The patients were compared in two groups, with and without the use of topical cold slush, using age, sex, diabetes mellitus, and LIMA harvesting parameters as matching criteria.

Propensity score matching

Propensity score matching was employed to assess the impact of topical cold slush (Table 5). Matching criteria included age, sex, DM, and LIMA harvesting, resulting in 37 patients matched without topical cold slush against 37 who received it (Figure 2). Among those who received topical cold slush, 18.9% developed DE compared to none in the non-slush group (p=0.011). Hospital stays were significantly longer in the slush group (9.25±5.17 days) compared to the non-slush group (6.08±2.28 days) (p=0.002), highlighting the higher incidence of DE and extended hospitalization among slush-treated patients.

Multivariate logistic regression

Multivariate logistic regression analysis revealed that LIMA harvesting and DM constituted a

Table 6. Multivariate logistic regression analysis

	Multivariate logistic		
	Odds Ratio	95% CI	*p*
Age	1.008	0.990-1.026	0.389
Sex	0.631	0.381-1.046	0.074
Diabetes mellitus	0.668	0.436-1.023	0.05
Chronic obstructive pulmonary disease	0.851	0.431-1.751	0.660
Hypertension	1.339	0.880-2.036	0.173
Ejection fraction	0.985	0.961-1.009	0.210
Cross-clamp time	0.998	0.992-1.003	0.402
Cardiopulmonary bypass time	0.999	0.994-1.003	0.515
Operative time	1.002	0.999-1.005	0.111
Body temperature	1.046	0.937-1.169	0.423
Left internal mammary artery harvesting	2.668	1.585- 4.448	**0.001**
Mechanical ventilation time	0.996	0.989-1.004	0.372

CI: Confidence interval.

significant risk factor concerning DE (p=0.001 and p=0.05, respectively). Furthermore, the likelihood of DE development increased by 2.6-fold with LIMA harvesting (Table 6).

DISCUSSION

Before the era of cardiac surgery, DE was considered a rare condition, primarily congenital in nature. Currently, cardiac surgeries are the leading cause of acquired DE.[8] The reported incidence of DE following cardiac surgery varies widely due to diverse surgical techniques and diagnostic methods, ranging from 2.5 to 38%.[9,10] In our cohort of 888 patients, DE was observed as 11.14%. Contrary to some previous studies,[7,10] our initial findings showed no significant differences in postoperative outcomes between the patients with and without DE.

Diaphragmatic elevation following cardiac surgery tends to have a better clinical course than those due to neuromuscular diseases.[11] Recovery rates range from 70 to 98% within the first year.[8,11] In our study, 85% of patients with DE showed recovery at one-year follow-up, consistent with literature findings.

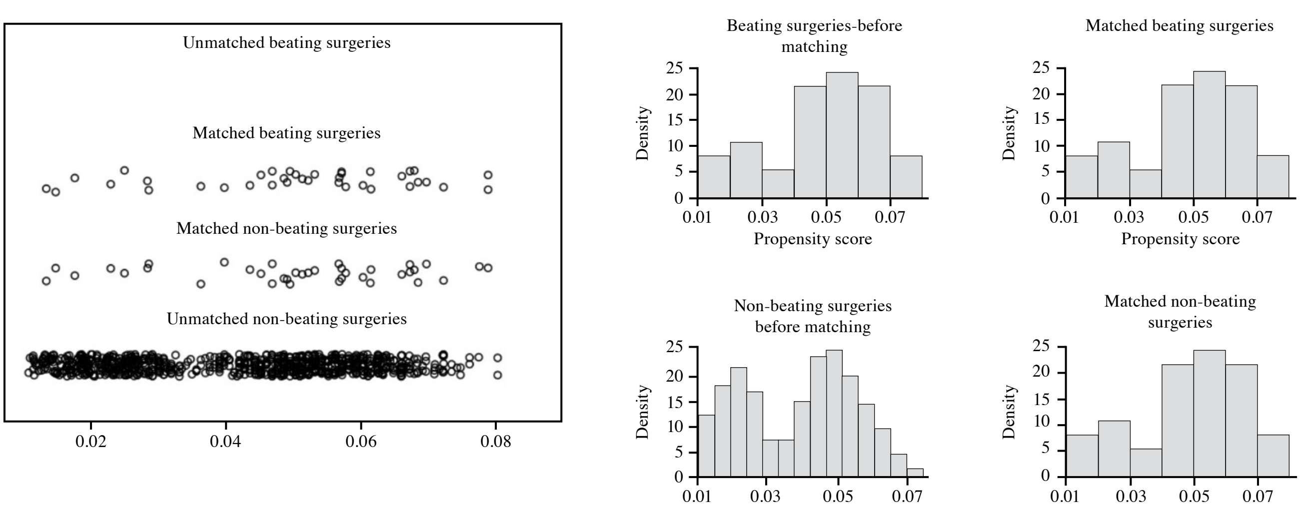

Figure 2. Distribution of propensity scores.

The literature identifies topical cold slush and LIMA harvesting as primary culprits for DE following cardiac surgery.[12,13] Isolated valvular surgeries, using only topical cold slush, have lower DE incidence than CABG procedures, suggesting that topical cold slush alone does not fully explain higher DE incidence in CABG patients. This finding is consistent with findings reported in existing literature.[10]

Further investigation compared patients who received topical cold slush, stratified by whether LIMA harvesting was performed. Those with both risk factors showed a significantly higher incidence of DE. The study reported by Bruni et al.[10] supports this additive effect, indicating that LIMA harvesting may exacerbate the occurrence of DE when combined with topical cold slush. Therefore, the highest DE risk group appears to be CABG cases involving both LIMA harvesting and topical cold slush, consistent with previous studies.[14,15]

The utilization of topical cold slush remains a subject of debate. While previous studies have shown its protective effects on myocardial tissue,[4] some studies have demonstrated that it can lead to phrenic nerve damage.[16] With modern cardioplegia solutions, the necessity of this protective effect remains to be elucidated. Some studies, such as the one by Maccherini et al.,[17] found shorter hospital stays and reduced DE risk without topical cold slush. Additionally, a study by Braathen et al.[18] showed no additional myocardial benefits from topical cold slush. Substituting cold slush with cold saline may mitigate adverse effects while still offering myocardial protection.[19]

Considering postoperative data, we observed unexpected results in our study. Patients without DE experienced longer durations of mechanical ventilation, intensive care unit (ICU) stay, and hospitalization. Specifically, two patients with DE who experienced hospital mortality had ventilation times of 28 and 78 h, contrasting with a mean of 231.8±221.9 (range, 12 to 720) h for 31 patients without DE. These findings highlight the impact of multiple confounding factors on ventilation and hospital outcomes, indicating a need for more focused research to gain accurate insights.

In the current study, we used propensity score matching as a secondary analysis. The findings revealed that topical cold slush utilization resulted in a significantly higher incidence of DE. Additionally, average hospital stay was three days longer among these patients. Consequently, this analysis identified topical cold slush as an independent risk factor for DE following cardiac surgery.

While unilateral DE typically does not lead to severe issues by itself, it can cause problems such as dyspnea and hypoxia when COPD is present.[20] Of note, COPD has been associated with phrenic neuropathy in a study by Cohen et al.[7] Although our study did not identify an additional risk specifically linked to COPD, patients with both COPD and DE experienced longer mechanical ventilation (p=0.01). Although the beating heart surgery technique theoretically appears to be beneficial to reduce postoperative pulmonary complications in CABG patients with COPD, our study had limited cases. Among 93 COPD patients, only one underwent beating heart surgery and did not develop DE. Therefore, larger patient cohorts are necessary to establish definitive recommendations.

Diabetes mellitus is also known to contribute to phrenic neuropathy.[21,22] The multivariate logistic regression analysis in our study revealed that DM was a significant risk factor for developing DE. Although the relative risk observed was not as high as in previous studies,[21,23] a diagnosis of diabetes still remained a significant risk factor for postoperative DE.

Multivariate logistic regression analysis showed a clear association between LIMA harvesting and increased incidence of DE, suggesting LIMA harvesting as a significant cause of phrenic neuropathy. This finding underscores potential nerve damage due to traction, thermal effects, or direct injury during the procedure. These findings do not invalidate the established benefits of using LIMA as a graft, but highlight the importance of careful anatomical consideration and precise surgical technique to minimize this complication.

In previous studies, DE is reported more frequently in redo cardiac surgery patients.[6] In our study, among 34 patients with prior cardiac surgery, DE occurred in three patients (8.82%). Follow-up revealed improvement in one patient and persistence in two others at 12 months, suggesting iatrogenic injury from anatomical changes. However, no cases of direct phrenic nerve injury during surgery were observed in our study.

Patients with bilateral DE had a longer mean hospital stay of 11.33±2.84 (range, 9 to 14) days. Despite this, none of these cases required reintubation or tracheostomy. Diaphragm plication post-cardiac surgery was not performed in any patient, suggesting a declining trend possibly due to modern cold slush methods replacing older cold applications. However, we refrain from drawing definitive conclusions due to the absence of data on this issue in our study. Based on existing literature, early and intensive pulmonary rehabilitation may reduce the risk of reintubation in vulnerable patients.[24,25]

The main limitations of this study include its retrospective design, relatively short follow-up period, and small sample size of patients undergoing beating heart surgery. Variability in the quality and temperature of topical cold slush solutions among patients may have affected results. Detecting bilateral DE solely through chest X-rays, particularly early postoperatively, can be challenging and may lead to missed cases. Another limitation is the study's reliance on chest X-rays without ultrasound or fluoroscopy confirmation. Additionally, they may have been undetected cases of DE among patients excluded due to early mortality or lack of available chest X-ray images.

In conclusion, our study highlights a potential correlation between the combined utilization of left internal mammary artery harvesting and cold slush with an increased risk of diaphragmatic elevation. Through distinct analyses, both the application of topical cold slush and left internal mammary artery harvesting were independently validated as contributing risk factors for diaphragmatic elevation. Based on these findings, in planning coronary artery bypass grafting for patients with both diabetes mellitus and chronic obstructive pulmonary disease, it may be advisable to avoid the use of topical cold slush and consider off-pump surgery, if technically feasible, to mitigate the risk of diaphragmatic elevation.

Ethics Committee Approval: The study protocol was approved by the Ankara City Hospital Ethics Committee (date: 09.12.2020, no: E1-20-1366). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: Written informed consent was not required due to the study's retrospective nature.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Concept, design, data collection, data analysis, literature review, drafting the article: İ.C.; Data collection, data analysis, literature review A.E.Ç.; Design, data analysis, drafting the article: H.M.Ö.; Concept, design, data collection, data analysis: B.B.A.; Design, critical review: A.Ö.;Data analysis and interpretation, critical review: E.U.Ü.; Concept, design, critical review: C.L.B.

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