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The role of thromboelastometry in the prevention of complications in DIEP flap breast reconstruction

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Abstract

Introduction and Objective. The deep inferior epigastric perforator (DIEP) flap is widely used in breast reconstruction and offers advantages such as muscle preservation and a sufficient tissue volume for coverage. However, complications such as thrombosis and flap failure remain a concern in postoperative care. Thromboelastography (TEG)/Thromboelastometry (ROTEM) is a valuable tool for monitoring coagulation in the perioperative period, providing real-time data on clot formation, stability, and fibrinolysis.

Materials and Method. The study included 26 patients undergoing DIEP flap reconstruction, with ROTEM performed preoperatively, intraoperatively, and postoperatively. Clinical data and laboratory results were analyzed, with a particular focus on thromboelastometric parameters. Anticoagulation strategies were individually adjusted based on ROTEM findings.

Results. ROTEM detected abnormal clotting profiles in a substantial proportion of patients. The use of ROTEM facilitated targeted intra-operative management, resulting in reduced thrombotic events and improved blood product utilization compared to conventional coagulation tests (CCTs). Flap-related complications were limited to one total flap loss (4%) and three instances of marginal necrosis (11%). These findings align with current evidence supporting the increasing role of visco-elastic testing in optimizing outcomes in microsurgical procedures.

Conclusions. TEG/ROTEM provided more accurate and timely coagulation information than routine laboratory tests, leading to improved management of anticoagulation and reduced thrombotic complications in DIEP flap breast reconstruction. Proper perioperative management guided by ROTEM can minimize complications, such as thrombosis, while optimizing blood transfusion requirements and flap survival.

Key words

DIEP, thromboelastometry, thromboelastography, breast reconstruction, microsurgical free flaps, blood coagulation tests

INTRODUCTION

The deep inferior epigastric perforator (DIEP) flap is a widely accepted and routinely used technique in microsurgical breast reconstruction (Fig. 1). It represents a significant refinement of the transverse rectus abdominis musculocutaneous (TRAM) flap, offering comparable reconstructive volume while avoiding the need to sacrifice the rectus abdominis muscle. The DIEP flap is composed of skin and subcutaneous fat harvested from the lower abdomen, based on one or more perforating branches—typically paraumbilical—of the deep inferior epigastric artery [1]. By preserving the muscular integrity of the abdominal wall, the DIEP flap reduces donor site morbidity and enhances both functional and aesthetic outcomes [1–4].

Beyond breast reconstruction, the DIEP flap has demonstrated utility in the repair of extensive soft tissue defects involving the anterior trunk and proximal extremities, offering versatility in complex reconstructive scenarios [2, 3]. Key advantages of the DIEP flap include the availability of a

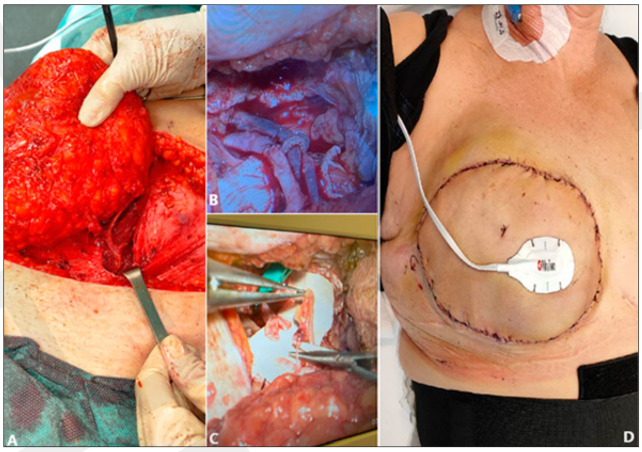

Figure 1. DIEP flap breast reconstruction. Dissected vascular pedicle of the DIEP flap (Photo A). Performing surgical microanastomoses (Photo B and C). Reconstruction result on the fourth postoperative day (Photo D).

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long and reliable vascular pedicle essential for microsurgical anastomosis, sufficient soft tissue volume for defect coverage, and preservation of the abdominal musculature, which contributes to reduced functional impairment and improved abdominal wall contour [1, 4]. However, limitations remain. In patients with low body mass index, inadequate donor site volume may preclude use, and motor nerve injury during flap harvest may result in abdominal bulging or weakness [5].

Accurate and timely assessment of coagulation status is critical in microsurgery due to the high risk of thrombotic complications that can compromise flap viability. Rotational thromboelastometry (ROTEM) is a viscoelastic method that allows real-time evaluation of the entire haemostatic process—including clot formation, strength, and fibrinolysis—using whole blood [6]. Compared to conventional coagulation assays, ROTEM provides a dynamic and integrative profile of haemostasis, facilitating individualized decision-making in perioperative settings [6, 7]. The ROTEM system operates by detecting changes in the mechanical resistance to the rotation of a pin immersed in a cup containing whole blood. As coagulation progresses, fibrin formation and platelet interaction increase resistance, and these changes are graphically recorded as a 'temogram' representing various stages of clot kinetics. Deviations in the curve and corresponding numerical values reflect disturbances in coagulation or fibrinolysis [6, 8, 9].

In the ROTEM system, the diagnostic management should begin with the EXTEM pathways (activation of the extrinsic coagulation pathway) and INTEM pathways (stimulation of the intrinsic clotting pathway). Each uses appropriate reagents to initiate the process. Three additional tests are available: FIBTEM, where cytochalasin D is added, which blocks platelet function, allowing for selective assessment of the effectiveness of polymerization of fibrin produced from fibrinogen, APTEM, where aprotinin (a fibrynolysis inhibitor) is used and allows for confirmation or exclusion of hyperfibrinolysis and HEPTEM, where the addition of heparinase allows to eliminate the influence of heparin on the time of blood clot formation, leading to the confirmation or exclusion of heparin presence in the tested sample (Fig. 2) [8, 10, 11].

The aim of the study is to evaluate the utility of perioperative ROTEM monitoring in patients undergoing DIEP flap breast reconstruction. The primary goal is to assess whether dynamic visco-elastic testing can improve individualized anticoagulation management.

MATERIALS AND METHOD

Patients and study design. The study enrolled 26 patients who met the inclusion criteria: age ≥18 years, qualification for deep inferior epigastric perforator (DIEP) flap breast reconstruction, and availability of thromboelastometric measurements during hospitalization. Comprehensive clinical data were collected at admission and discharge, including patient age, body weight, comorbidities, history of oncologic treatment, and specifics of the reconstructive procedure. Thromboelastometric analyses and standard laboratory tests were performed on the day of surgery and/or on the first postoperative day, depending on the clinical course. The study period spanned from 17 June 2020, when the first eligible patient underwent surgery, to 5 October 2022, marking the final inclusion.

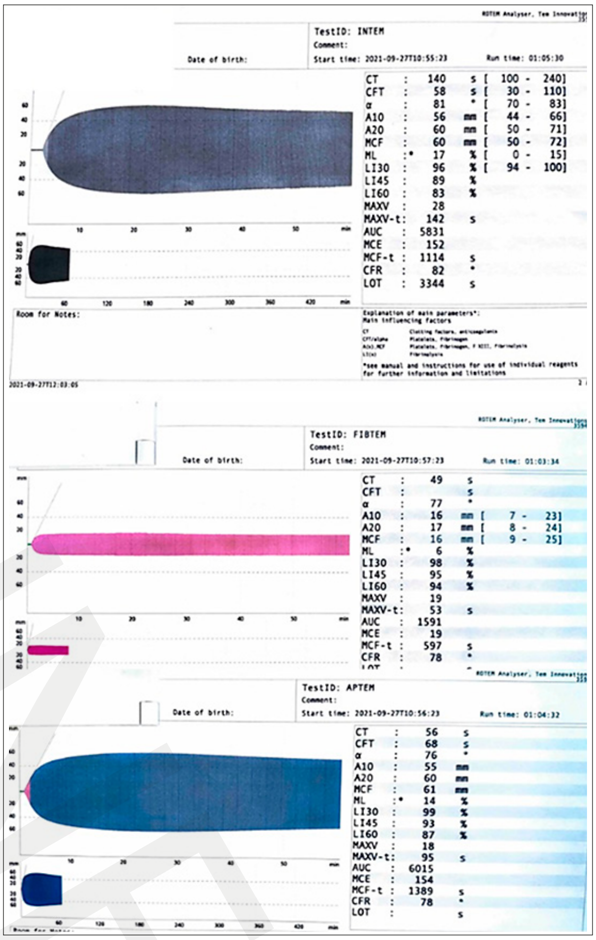

Figure 2. An example of INTEM, FIBTEM, and APTEM test results using the ROTEM instrument

Clinical parameters of thromboelastometry. Thromboelastometry enables dynamic, real-time assessment of the coagulation process in whole blood, capturing the kinetics of clot initiation, propagation, stabilization, and lysis. Among the key parameters, the clotting time (CT) is defined as the interval from test initiation to when the curve amplitude reaches 2 mm. It reflects the onset of coagulation and corresponds to conventional tests such as prothrombin time (PT) or activated partial thromboplastin time (aPTT), depending on the specific activator used [12, 13]. The clot formation time (CFT) quantifies the time required for the amplitude to increase from 2 mm to 20 mm, providing insight into the speed of clot development. The α-angle, defined as the tangent to the curve at the 2 mm point, reflects the acceleration of fibrin build-up and cross-linking. Intermediate parameters such as A10 and A20, representing clot amplitude at 10 and 20 minutes after CT, respectively, serve as early indicators of clot firmness and stability. The maximum clot firmness (MCF) corresponds to the peak amplitude of the curve and represents the mechanical strength of the clot. The MCF time (MCF-t) denotes the time at which MCF is achieved, marking the completion of clot consolidation. Clot degradation is assessed through maximum lysis (ML), which represents the reduction in amplitude following MCF. ML values below 15% within one hour are consistent with clot stability, whereas values exceeding this threshold suggest enhanced fibrinolysis. Additional parameters—LI30, LI45, and LI60—quantify the degree of lysis at defined time points post-CT, expressed as a percentage of MCF. Dynamic aspects of clot formation are captured by the maximum clot velocity (MAXV), reflecting the fastest rate of clot growth (first derivative of the curve), and by the time to maximum velocity (MAXV-t), which measures the interval from test initiation to the point of MAXV. The area under the curve (AUC), calculated over the first 6 minutes of the recording, estimates the overall extent of clot development and platelet aggregation. The maximum clot elasticity (MAE), derived from MCF, offers an additional perspective on the physical properties of the clot. The clot formation rate (CFR), expressed as the slope during fibrin polymerization, provides a measure of polymerization dynamics. Finally, the lysis onset time (LOT) is defined as the interval from CT to a 15% reduction in MCF amplitude, marking the beginning of clot breakdown. These parameters are illustrated schematically in Figure 3, which visualizes a typical ROTEM tracing and its corresponding measurements [12, 13].

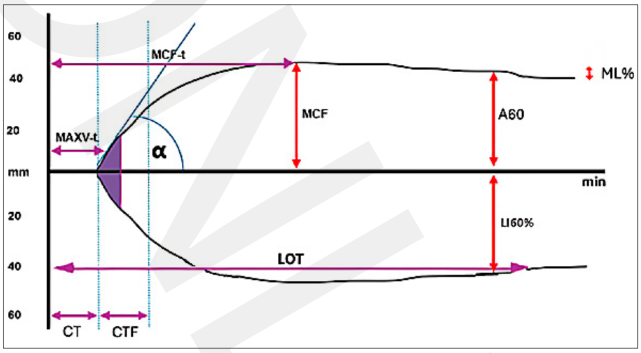

Figure 3. Schematic diagram of thromboelastography performed with the ROTEM device, with thromboelastometric parameters marked

Ethical statement. The data used in the study were obtained from a single-centre, retrospective clinical analysis. The study protocol was approved by the Ethics Committee at the Medical University of Lublin, Poland (Ref. No.: KE:0254–244/11/2023). The principles outlined in the Declaration of Helsinki were respected.

Statistical analysis. Statistica version 13.3 was used for statistical analysis. A 5% margin of inferential error was applied, and values of $p<0.05$ were considered statistically significant. Descriptive statistics included mean values, standard deviation, confidence intervals, and range of the variables for quantitative variables and percentages for nominal variables. Spearman's correlation was used to examine the relationships between variables, the Shapiro-Wilk test was used to investigate the distribution of variables, and the Kruskal-Wallis ANOVA was used to determine the relationship between variables and the dependent variable.

RESULTS

Preoperative status. The mean age of the study cohort was 44.4 years (range: 28–56 years) and the average body weight – 70.1 kg (range: 48.0–97.0 kg). The predominant indication for DIEP flap breast reconstruction was post-oncologic deformity, accounting for 92% of cases. Among the non-oncologic patients, the main indication was prophylactic mastectomy related to BRCA1/BRCA2 gene mutations. Before reconstruction, 38% of the patients had received radiotherapy, while 77% had undergone chemotherapy. This indicates a predominance of systemic oncologic treatment compared with locoregional modalities within the group, which may influence perioperative coagulation profiles and thromboembolic risk. Unilateral reconstructions accounted for the majority of procedures (n = 21; 81%), while bilateral reconstructions were performed in 5 patients (19%). The decision regarding surgical laterality was based on oncologic indications, patient preference, and anatomical feasibility. Although bilateral reconstructions were associated with longer operative times and increased technical complexity, they did not result in a higher rate of postoperative complications in this group.

Postoperative outcomes following DIEP flap breast reconstruction are categorized as: free of complications, marginal necrosis, and flap loss. The vast majority of patients (n = 22, 85%) experienced an uneventful postoperative course without any flap-related complications. Marginal necrosis, defined as superficial tissue ischemia not requiring complete surgical revision, was observed in 3 cases (11%). Only one patient (4%) developed total flap loss due to vascular compromise, representing the most severe complication within the cohort. Notably, oncologic patients demonstrated distinct haematologic profiles compared to non-oncologic individuals. They presented with significantly lower haematocrit values (mean 36% vs. 42%; $p < 0.03$), elevated international normalized ratio (INR; 0.93 vs. 0.8; $p = 0.02$), and prolonged prothrombin time (PT; 11.4 s vs. 9.9 s; $p = 0.02$). Furthermore, EXTEM maximum clot firmness (MCF) values in the oncologic subgroup were consistently at or above normal thresholds ($p < 0.05$).

Laboratory abnormalities in individual patients included 2 cases of haemoglobin <11.5 g/dL and 2 with thrombocytopenia (<150 G/L). Activated partial thromboplastin time (APTT) deviations were observed in 7 patients: 5 exhibited shortened APTT, while 2 had prolonged values (Tab. 1). ROTEM analysis revealed abnormal EXTEM clotting time (CT) in 13 cases (8 shortened, 5 prolonged), and INTEM CT abnormalities in 6 cases. PT was shortened in 1 patient and prolonged in 3.

Table 1. Characteristics: laboratory test results before surgery

Parameters	Mean±SD	Confidence Interval (Lower CI-Upper CI)	Range (Min-Max)	SE
RBC ($\times10^6$/µl)	4.26±0.41	4.10–4.42	3.41–5.12	0.08
HGB (g/dl)	12.8±1.12	12.3–13.2	10.0–14.7	0.21
HCT (%)	37.2±3.52	35.9–38.6	29.6–44.3	0.66
MCV (fl)	88.5±4.57	86.7–90.3	82.2–99.4	0.86
MCH (pg)	31.0±2.01	30.2–31.8	28.1–34.5	0.38
RDW (%)	13.0±1.00	12.6–13.4	11.7–15.6	0.19
PLT ($\times10^3$/µl)	224±49.8	205–243	113–325	9.40
WBC ($\times10^3$/µl)	6.23±2.80	5.14–7.32	3.17–17.0	0.53
INR	0.94±0.08	0.91–0.97	0.78–1.11	0.01
APTT (s)	28.2±4.94	26.3–30.2	20.8–46.8	0.93
PT (s)	11.3±0.65	11.0–11.5	9.6–12.5	0.12
Fibrinogen (mg/dl)	269±48	247–292	163–354	10

Mean – arithmetic mean; Lower CI – lower bound of the confidence interval; Upper CI – upper bound of the confidence interval; Min – minimum value; Max – maximum value; SD – standard deviation; SE – standard error of the mean; Red Blood Cells (RBC), Haemoglobin (HGB), Haematocrit (HCT), Mean Corpuscular Volume (MCV), Mean Corpuscular Haemoglobin (MCH), Red Cell Distribution Width (RDW), Platelets (PLT), White Blood Cells (WBC), International Normalized Ratio (INR), Activated Partial Thromboplastin Time (APTT), Prothrombin Time (PT)

Table 2. Characteristic: thromboelastometric results on the day of surgery and postoperative day

Parameters	Surgery day		Postoperative day 1	
	Mean± SD	Range (Min-Max)	Man± SD	Range (Min-Max)
EXTEM CT (s)	55.0±8.3	40–81	56.9±7.4	44–72
EXTEM CFT (s)	83.3±19.5	59–125	83.8±20.8	49–124
EXTEM MCF (mm)	61.5±4.8	53–73	61.5±5.6	52–72
EXTEM ML (%)	14.8±4.8	2–23	14.9±5.2	4–25
EXTEM LI30 (%)	98.9±1.3	95–100	98.8±1.4	96–100
EXTEM LI45 (%)	93.9±2.9	87–99	93.1±3.2	86–98
EXTEM LI60 (%)	89.8±4.0	83–101	89.7±5.7	80–101
INTEM CT (s)	188±47.6	106–296	207±72.5	122–357
INTEM CFT (s)	77.2±24.9	23–129	80.1±22.4	42–126
INTEM MCF (mm)	59.5±4.7	52–70	59.4±5.3	50–71
INTEM ML (%)	14.3±3.8	8–21	14.8±5.1	2–23
INTEM LI30 (%)	97.2±2.9	90–100	96.6±2.1	93–99
INTEM LI45 (%)	92.4±3.5	84–97	91.1±3.7	85–101
INTEM LI60 (%)	90.2±5.0	82–101	89.9±7.2	80–101
FIBTEM CT (s)	53.1±9.5	34–81	52.3±6.7	43–66
FIBTEM CFT (s)	300±419	76–1634	255±278	54–920
FIBTEM MCF (mm)	20.7±11.3	9–60	20.6±7.0	10–35
FIBTEM ML (%)	4.3±5.5	0–19	1.1±2.3	0–9
FIBTEM LI30 (%)	99.0±2.1	93–100	99.8±0.8	97–100
FIBTEM LI45 (%)	97.9±3.7	86–100	99.5±1.5	94–100
FIBTEM LI60 (%)	98.4±3.3	88–100	100±0.7	98–101

EXTEM Clotting Time (CT), EXTEM Clot Formation Time (CFT), EXTEM Maximum Clot Firmness (MCF), EXTEM Maximum Lysis (ML), EXTEM Lysis Index at 30 minutes (LI30), EXTEM Lysis Index at 45 minutes (LI45), EXTEM Lysis Index at 60 minutes (LI60), INTEM Clotting Time (CT), INTEM Clot Formation Time (CFT), INTEM Maximum Clot Firmness (MCF), INTEM Maximum Lysis (ML), INTEM Lysis Index at 30 minutes (LI30), INTEM Lysis Index at 45 minutes (LI45), INTEM Lysis Index at 60 minutes (LI60), FIBTEM Clotting Time (CT), FIBTEM Clot Formation Time (CFT), FIBTEM Maximum Clot Firmness (MCF), FIBTEM Maximum Lysis (ML), FIBTEM Lysis Index at 30 minutes (LI30), FIBTEM Lysis Index at 45 minutes (LI45), FIBTEM Lysis Index at 60 minutes (LI60).

Despite these findings, all patients had fibrinogen levels within normal laboratory limits before surgery. However, FIBTEM CT was prolonged in 6 cases, indicating altered fibrin polymerization kinetics.

Thromboelastometric analysis was conducted several hours before surgery to inform perioperative coagulation management. The comprehensive profile of ROTEM parameters is presented in Table 2. A comparative study between conventional coagulation tests (CCTs) and ROTEM/TEG-derived parameters is shown in Figure 4. Preoperative anticoagulation was administered prophylactically 12 hours before surgery, while intraoperative unfractionated heparin dosing was tailored individually based on preoperative ROTEM findings, patient body weight, and intraoperative bleeding tendencies (Tab. 3).

Postoperative status. Postoperative anticoagulation with low-molecular-weight heparin (LMWH) was individually adjusted based on perioperative thromboelastometric profiles, allowing for tailored haemostatic management. The extent of perioperative blood loss was indirectly assessed by quantifying the number of packed red blood cell (PRBC) units transfused on the day of surgery and the first postoperative day. During hospitalization, 15 out of 26 patients (57.7%) required transfusion support. Blood products were administered in 5 patients intraoperatively or on the day of surgery, and in an additional 5 patients on the first postoperative day. The mean number of PRBC units transfused per patient during this immediate perioperative period was 1.7. The maximum number of units transfused per patient on either the day of surgery or the following day did not exceed 4 units. Significantly, the cumulative transfusion requirement during the entire hospital stay did not exceed 6 units per patient (Tab. 4).

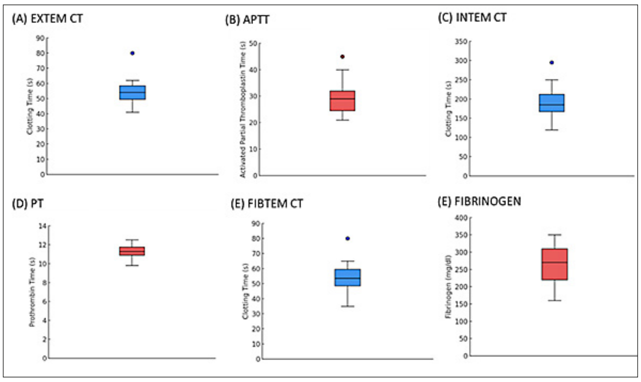

Figure 4. Comparison of coagulation parameters obtained using visco-elastic testing (TEG/ROTEM) and conventional coagulation tests (CCTs). Panels A–C present clotting time values derived from EXTEM CT, APTT, and INTEM CT, respectively, highlighting different activation pathways in the coagulation cascade. Panel D shows Prothrombin Time (PT), a standard marker of extrinsic pathway function. Panels E and F illustrate the FIBTEM CT and plasma fibrinogen concentration (mg/dl), respectively, providing insight into fibrin polymerization and overall clot stability. Boxplots display the distribution of each parameter, including median values, interquartile ranges, and outliers. ROTEM-based assessments (A, C, E) demonstrated broader variability and detected individual deviations in clotting profiles that were not fully captured by conventional assays (B, D, F)

Table 3. Characteristic: antithrombotic prophylaxis

Parameters		Patients on medication	Mean± SD	Range (Min-Max)
Dose of unfractionated heparin during surgery (USP Units)		26	2648±766	1500–4250
Day of surgery	enoxaparin (mg)	6	46.7±14.9	20.0–60.0
	nadroparin (U.I. anti–Xa)	18	3705±1691	1900–7600
	unfractionated heparin (USP Units)	3	2000±1323	1000–3500
Day 1 post-op.	enoxaparin (mg)	3	40.0±16.3	20.0–60.0
	nadroparin (U.I. anti–Xa)	20	3990±1805	1900–7600
	unfractionated heparin (USP Units)	1	25000±0.0	25000–25000
Evening of day 1 post-op.	enoxaparin (mg)	6	56.7±7.5	40.0–60.0
	nadroparin (U.I. anti–Xa)	17	3990±1843	1900–7600
	unfractionated heparin (USP Units)	1	25000±0.0	25000–25000

Table 4. Characteristic: blood units transfused during the hospitalization. The majority of patients (58%) received blood transfusions during hospitalization

Parameters	No. of patients who received blood transfusions	Statistics on the number of blood units transfused to patients	
		Mean± SD	Range (Min-Max)
Day of surgery	5	0.4±1.0	0–4
Day 1 post-op.	5	0.4±1.0	0–4
During entire hospitalization	15	1.7±2.0	0–6

These findings suggest that individualized anticoagulation guided by thromboelastometry may contribute to improved perioperative hemostatic control and a reduction in overall transfusion needs.

DISCUSSION

Thromboelastography (TEG) and rotational thromboelastometry (ROTEM) are increasingly regarded as valuable point-of-care tools for perioperative haemostatic assessment in microsurgical procedures. These visco-elastic assays provide comprehensive, real-time data encompassing all phases of coagulation—from clot initiation through stabilization to fibrinolysis—which makes them particularly useful for detecting hypercoagulable states associated with increased risk of flap pedicle thrombosis. Early identification of such states allows for prompt implementation of targeted anticoagulation strategies and enhanced intraoperative monitoring, potentially reducing the risk of free flap failure [14–16].

The overall complication rate in this study was low (15%), which may reflect the clinical benefits of individualized anticoagulation management guided by thromboelastometric data. Despite this, the broader use of TEG/ROTEM remains subject to debate, mainly due to limited high-quality evidence and the absence of standardized protocols for predicting thrombotic events in free flap surgery. Conventional coagulation tests (CCTs)—including activated partial thromboplastin time (aPTT), prothrombin time (PT), international normalized ratio (INR), and fibrinogen levels—are not designed to capture the dynamic nature of clot formation and lysis. They fail to provide real-time information and have shown no statistically significant correlation with free flap outcomes, unlike perioperative TEG/ROTEM parameters [14–16]. Patients undergoing DIEP flap breast reconstruction represent a subgroup with particularly high thromboembolic risk, especially in oncologic settings. TEG/ROTEM profiling may offer predictive value in this population, supporting intraoperative and postoperative anticoagulation decisions, particularly in the critical 0–72-hour window when most thrombotic events occur. Importantly, TEG/ROTEM measurements appear to be more sensitive than CCTs in identifying hypocoagulability following heparin administration [14–18].

Parker et al. [19] demonstrated the clinical relevance of thromboelastometric monitoring by identifying the functional fibrinogen-to-platelet ratio (FPR) as a predictive marker of thrombotic events in free flap surgery. In their cohort, an FPR ≥42 yielded 89% sensitivity and 75% specificity for thrombosis prediction, with malignancy-associated hypercoagulability playing a key role. Early detection via TEG/ROTEM facilitated timely anticoagulation or surgical intervention, thereby reducing flap failure rates. Similarly, Kolbenschlag et al. [20] confirmed the utility of ROTEM in perioperative risk stratification. Elevated maximum clot firmness (MCF) values—indicative of a hypercoagulable state—were significantly associated with thromboembolic events and higher rates of flap loss. Their findings highlight the prognostic potential of pre- and intraoperative ROTEM data. Zavlin et al. [21] further supported this concept by evaluating the TEG-G parameter, representing clot tensile strength (measured in dyn/cm²). They found that postoperative elevations in TEG-G—within 48 hours of surgery—were associated with thrombotic complications, while traditional parameters (platelet count, aPTT, PT) failed to detect these changes. This underscores the added diagnostic value of viscoelastic assays in microsurgical settings.

Nevertheless, the predictive accuracy of TEG/ROTEM is not universally supported. Wikner et al. [22], in a prospective cohort of 35 patients, reported no significant association between ROTEM parameters and adverse surgical outcomes (thrombosis, bleeding, or flap loss). Ekin et al. [23] reached similar conclusions, finding no correlation between pre- or postoperative TEG values and flap complications. Interestingly, they identified statistical associations between INR, aPTT, and flap loss, although they questioned their clinical significance.

The findings of the presented study contribute to the ongoing discussion. The elevated EXTEM MCF values observed in oncologic patients suggest increased clot firmness consistent with a hypercoagulable state. Such alterations may result from malignancy-related mechanisms, including procoagulant activity of tumor cells, inflammatory cytokine release, platelet activation, endothelial dysfunction, and the effects of chemo- and radiotherapy [24].

Taken together, the current literature highlights the absence of standardized perioperative anticoagulation protocols in DIEP flap surgery. Despite heterogeneity in practice, many institutions incorporate TEG/ROTEM to guide individualized thromboprophylaxis. While further large-scale, prospective studies are needed to establish definitive predictive thresholds, existing evidence supports the potential of TEG/ROTEM to improve perioperative decision-making, reduce thrombotic complications, and optimize outcomes in microsurgical breast reconstruction.

Limitations of the study. This was a retrospective analysis of a medical database, for which limited data were available. There was also a limited number of cases collected for a single-centre study.

CONCLUSIONS

Thromboelastography proved more effective than routine laboratory tests in detecting preoperative coagulopathies. Anticoagulation was tailored based on thromboelastographic findings, patient weight, and intraoperative bleeding, resulting in low complication rates—only 1 flap loss and 3 cases of marginal necrosis. No early thromboses were observed. While adequate prophylaxis reduces thrombotic risk, overtreatment may increase bleeding. The mean perioperative transfusion requirement was low (0.4 units), supporting the utility of thromboelastography in optimizing haemostatic balance and improving outcomes in microsurgical breast reconstruction.

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