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Article

Combined Application of Ultrasound and Coagulation Indicators in Risk Assessment of Lower Extremity Deep Vein Thrombosis During the Perioperative Period of Hip Fracture

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Abstract: This study investigates the effectiveness of the combined application of ultrasound and coagulation indicators in assessing the risk of lower extremity deep vein thrombosis (DVT) during the perioperative period of hip fracture. Patients with hip fractures, particularly the elderly, face a high risk of DVT due to surgical trauma, prolonged immobilization, and hypercoagulability. Ultrasound, as a non-invasive imaging technique, provides real-time visualization of venous blood flow abnormalities, while coagulation indicators (such as D-dimer and fibrinogen) reflect the biological processes of thrombosis. This prospective cohort study performed ultrasound examinations and coagulation tests on perioperative patients and analyzed their combined diagnostic efficacy for DVT. The results demonstrate that integrating ultrasound with coagulation indicators enhances early DVT detection, optimizes individualized anticoagulation therapy, and reduces thrombotic complications. These findings contribute to refining perioperative DVT risk assessment systems and provide a more precise prevention and management strategy for clinical practice.

Keywords: ultrasound; coagulation indicators; deep vein thrombosis; perioperative period; hip fracture; risk assessment

1. Introduction

1.1. Background

Hip fractures are a common and severe injury, particularly among the elderly population, with their incidence rising due to the global aging trend. Patients with hip fractures often suffer from multiple comorbidities, such as cardiovascular diseases and diabetes, which significantly elevate the risk of perioperative complications. These complications not only prolong hospital stays and increase healthcare costs but also have a profound impact on patients' long-term quality of life. Among these complications, deep vein thrombosis (DVT) is one of the most frequent and potentially life-threatening conditions. DVT is primarily caused by surgical trauma, immobilization, and hypercoagulability, and it can lead to life-threatening conditions such as pulmonary embolism (PE), which is associated with high mortality rates. Even in the absence of PE, DVT may result in post-thrombotic syndrome (PTS), characterized by chronic pain, swelling, and functional impairment of the affected limb, severely compromising patients' quality of life.

1.2. Research Objectives

This study aims to explore the combined application of ultrasound and coagulation indicators in assessing the risk of DVT during the perioperative period of hip fracture. By integrating the non-invasive nature of ultrasound imaging with the sensitivity of coagulation biomarkers, the study seeks to evaluate their synergistic value in the early diagnosis and risk stratification of DVT. The ultimate goal is to provide a more accurate and efficient

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method for DVT risk assessment, guiding individualized prevention and treatment strategies.

1.3. Research Significance

The combined use of ultrasound and coagulation indicators can address the limitations of individual methods, enhancing the early detection rate of DVT, particularly for asymptomatic or early-stage cases. Early diagnosis enables timely intervention, reducing the risk of severe complications such as pulmonary embolism. Accurate DVT risk assessment allows clinicians to tailor perioperative anticoagulation therapy, balancing the prevention of thrombosis against the risk of bleeding. Optimized perioperative management can shorten hospital stays, reduce healthcare costs, and improve patient outcomes. Through early intervention and individualized treatment, this study has the potential to significantly reduce the incidence of DVT and its related complications, thereby improving the overall prognosis of hip fracture patients. The findings may provide scientific evidence to standardize and optimize perioperative DVT management in clinical practice.

2. Literature Review

2.1. Relationship Between Hip Fractures and DVT

Hip fracture patients are among the highest-risk populations for developing lower extremity deep vein thrombosis (DVT). The incidence of DVT in this group ranges from 40% to 60%, with the perioperative period being particularly critical due to factors such as surgical trauma, immobilization, and hypercoagulability. Advanced age is a significant risk factor, as elderly patients often have reduced mobility, decreased muscle mass, and underlying comorbidities such as cardiovascular disease, diabetes, and obesity. These conditions contribute to venous stasis, endothelial injury, and hypercoagulability—the three key components of Virchow's triad, which underlies the pathogenesis of DVT. Additionally, the type of anesthesia used during surgery (e.g., general vs. regional) and the duration of immobilization post-surgery further influence DVT risk. Without prophylactic measures, hip fracture patients are at a heightened risk of developing pulmonary embolism (PE), a life-threatening complication of DVT. The high morbidity and mortality associated with DVT underscore the importance of early detection and intervention in this vulnerable population [1].

2.2. Application of Ultrasound in DVT Diagnosis

Ultrasound imaging is the most widely used diagnostic tool for DVT due to its non-invasive nature, accessibility, and real-time imaging capabilities. The technique relies on high-frequency sound waves to visualize blood flow and detect thrombus formation in deep veins. Compression ultrasonography (CUS) is the most common method, where the inability to compress a vein under ultrasound pressure indicates the presence of a thrombus. Doppler ultrasound, which assesses blood flow velocity and direction, is often used in conjunction with CUS to improve diagnostic accuracy. Ultrasound is highly sensitive and specific for detecting symptomatic DVT, particularly in the proximal veins of the lower extremities (e.g., femoral and popliteal veins). However, its effectiveness is limited in cases of asymptomatic or distal DVT (e.g., in the calf veins), where thrombi may be smaller or less obstructive. Furthermore, postoperative patients may present challenges such as swelling, pain, or restricted mobility, which can hinder the quality of ultrasound imaging. Despite these limitations, ultrasound remains a cornerstone of DVT diagnosis due to its practicality, cost-effectiveness, and lack of radiation exposure [2].

2.3. Role of Coagulation Indicators in DVT Risk Assessment

Coagulation indicators play a crucial role in assessing the risk of DVT. Common coagulation indicators include D-dimer, fibrinogen, PT, and APTT, which reflect the body's coagulation status and provide laboratory evidence for DVT diagnosis. These biomarkers

are particularly useful in the perioperative period of hip fracture patients, where the risk of DVT is significantly elevated due to factors such as immobility, surgical trauma, and hypercoagulability.

D-dimer, a fibrin degradation product, is one of the most widely used biomarkers for DVT screening. Elevated D-dimer levels indicate increased fibrinolytic activity, often associated with thrombotic events. However, its specificity is limited in postoperative settings due to the influence of surgical trauma and inflammation. Fibrinogen, a key protein in the coagulation cascade, reflects hypercoagulability and is often elevated in patients with DVT. Other indicators, such as PT and APTT, provide insights into the extrinsic and intrinsic coagulation pathways, respectively, but are more commonly used to monitor anticoagulation therapy rather than diagnose DVT.

Table 1 summarizes the common coagulation indicators, their normal ranges, clinical significance, and application in DVT diagnosis [3].

Table 1. Summary of Common Coagulation Indicators and Their Clinical Significance.

Coagulation Indicator	Normal Range	Significance of Elevation	Application in DVT Diagnosis
D-dimer	<0.5 mg/L	Reflects fibrinolytic activity; elevated levels indicate thrombosis or increased fibrinolysis.	Used to rule out DVT: Normal D-dimer levels can largely exclude DVT; elevated levels require further imaging confirmation.
Fibrinogen	2.0–4.0 g/L	Reflects coagulation function; elevated levels indicate hypercoagulability or inflammatory response.	High fibrinogen levels are associated with increased DVT risk but have low specificity.
Prothrombin Time (PT)	11–13.5 seconds	Reflects extrinsic coagulation pathway function; prolonged PT indicates coagulation factor deficiency or anticoagulant therapy (e.g., warfarin).	Used to monitor anticoagulation therapy but has limited direct role in DVT diagnosis.
Activated Partial Thromboplastin Time (APTT)	25–35 seconds	Reflects intrinsic coagulation pathway function; prolonged APTT indicates coagulation factor deficiency or heparin therapy.	Used to monitor heparin therapy but has limited direct role in DVT diagnosis.
Platelet Count	100–300 × 10^9/L	Thrombocytopenia indicates increased bleeding risk; thrombocytosis may be associated with hypercoagulability.	Thrombocytosis may be associated with increased DVT risk but has low specificity.

2.4. Limitations of Existing Research

Despite advances in diagnostic techniques, current approaches to DVT risk assessment in hip fracture patients have significant limitations. Ultrasound, while effective for detecting symptomatic proximal DVT, often misses asymptomatic or distal thrombi, which can still pose a risk of progression or embolization. Additionally, the quality of ultrasound imaging can be compromised in postoperative patients due to factors such as pain, swelling, or limited mobility. On the other hand, coagulation biomarkers, particularly D-dimer, lack specificity and can yield false-positive results in the presence of trauma,

surgery, or inflammation. The reliance on a single diagnostic method often results in incomplete or inaccurate risk assessment, highlighting the need for a combined approach that integrates imaging and laboratory biomarkers. Furthermore, there is a lack of standardized protocols for perioperative DVT management in hip fracture patients, with variations in prophylactic measures, diagnostic timing, and treatment strategies. These gaps in research and clinical practice underscore the importance of developing more comprehensive and accurate diagnostic strategies, as well as evidence-based guidelines for DVT prevention and management in this high-risk population [4].

3. Methods

3.1. Study Population

3.1.1. Inclusion Criteria

Patients diagnosed with hip fracture (e.g., femoral neck fracture, intertrochanteric fracture) and scheduled for surgical intervention (e.g., internal fixation, hemiarthroplasty, or total hip arthroplasty).

Age ≥ 18 years, with no upper age limit, to include elderly patients who are at the highest risk of DVT.

Patients or their legal representatives provided written informed consent to participate in the study.

Availability of complete medical records and willingness to comply with follow-up assessments.

3.1.2. Exclusion Criteria

Preoperative diagnosis of DVT, pulmonary embolism (PE), or other thrombotic disorders.

Severe hepatic or renal dysfunction (e.g., Child-Pugh class C or end-stage renal disease on dialysis), which may affect coagulation biomarker levels.

Recent use of anticoagulant or antiplatelet medications (within the past 3 months), as these may alter coagulation profiles.

Inability to undergo ultrasound examination due to physical limitations (e.g., severe obesity, open wounds, or casts on the lower extremities).

Pregnancy or lactation, as these conditions may influence coagulation parameters.

3.1.3. Patient Characteristics

Demographic data: Age, gender, body mass index (BMI), and smoking status.

Clinical data: Type of hip fracture, time from injury to surgery, surgical approach, anesthesia type (general or regional), and duration of surgery.

Comorbidities: Hypertension, diabetes mellitus, cardiovascular disease, chronic obstructive pulmonary disease (COPD), and history of malignancy.

Preoperative mobility status: Ambulatory status (independent, with assistance, or bedridden) and use of assistive devices (e.g., walker, cane).

3.2. Study Design

This study employed a prospective cohort design to evaluate the combined application of ultrasound and coagulation indicators in assessing the risk of DVT during the perioperative period of hip fracture. The study was conducted in a tertiary care hospital over a period of 24 months. Patients were enrolled consecutively upon admission and followed up until 7 days postoperatively. The study protocol was approved by the institutional review board (IRB), and all procedures adhered to the principles of the Declaration of Helsinki.

The research design flowchart is shown in Figure 1. It illustrates the complete process from patient admission to follow-up completion, including preoperative and postoperative assessments (Days 1, 3, and 7) with ultrasound and coagulation tests.

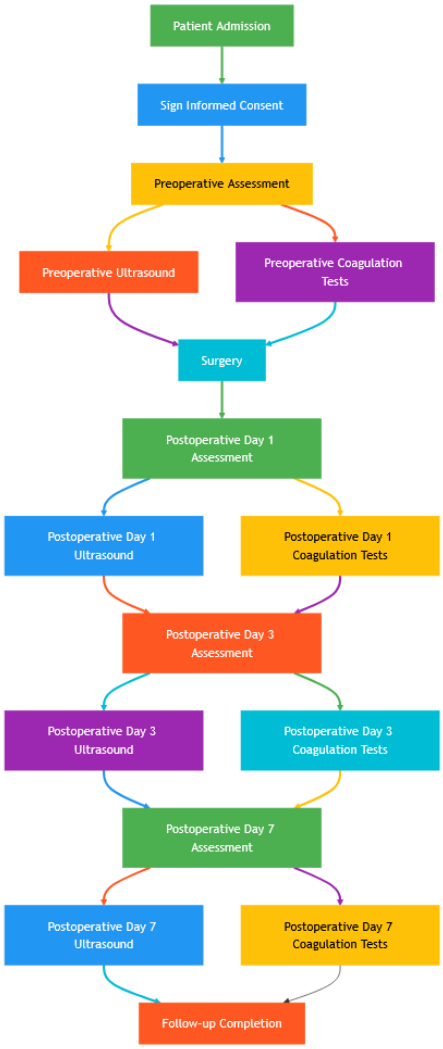

Figure 1. Research Design Flowchart.

3.3. Data Collection

3.3.1. Ultrasound Examination

Timing: Ultrasound examinations were performed at four time points: preoperatively (within 24 hours of admission) and postoperatively on days 1, 3, and 7.

Method: A standardized protocol using color Doppler ultrasound was followed. The deep venous system of both lower extremities, including the femoral, popliteal, and posterior tibial veins, was examined. Compression ultrasonography (CUS) was used to assess vein compressibility, while Doppler imaging evaluated blood flow velocity and direction.

Results: The presence, location, and extent of thrombus were recorded. Veins were classified as fully compressible, partially compressible, or non-compressible. Abnormal blood flow patterns, such as absence of flow or reflux, were also documented.

3.3.2. Coagulation Biomarker Testing

Timing: Blood samples were collected at the same time points as ultrasound examinations (preoperative and postoperative days 1, 3, and 7).

Indicators:

The following coagulation biomarkers were measured:

D-dimer: A marker of fibrinolysis, with elevated levels indicating thrombotic activity.

Fibrinogen: A key protein in the coagulation cascade, reflecting hypercoagulability.

Prothrombin Time (PT) and Activated Partial Thromboplastin Time (APTT): Measures of the extrinsic and intrinsic coagulation pathways, respectively.

Platelet count: To assess thrombocytopenia or thrombocytosis, which may influence coagulation.

Methods: Blood samples were collected in citrate tubes and analyzed using standardized laboratory techniques. Quality control measures were implemented to ensure accuracy and reproducibility.

3.4. Diagnostic Criteria for DVT

The diagnosis of DVT was established using a combination of clinical, imaging, and laboratory criteria.

3.4.1. Clinical Assessment

Symptoms such as unilateral leg swelling, pain, warmth, or erythema were documented.

Clinical probability scores (e.g., Wells score) were calculated to stratify patients into low, moderate, or high-risk categories.

3.4.2. Imaging Criteria

Ultrasound: Non-compressibility of a vein or absence of blood flow on Doppler imaging was considered diagnostic of DVT.

Venography: For cases with inconclusive ultrasound findings, venography was performed as the gold standard. Filling defects or abrupt cutoffs in contrast opacification were diagnostic of DVT.

3.4.3. Laboratory Criteria

Elevated D-dimer levels (>500 ng/mL) in the absence of other causes (e.g., infection, trauma) supported the diagnosis of DVT.

3.5. Statistical Analysis

3.5.1. Descriptive Statistics

Continuous variables (e.g., age, D-dimer levels) were expressed as mean ± standard deviation (SD) or median (interquartile range, IQR), depending on data distribution.

Categorical variables (e.g., gender, fracture type) were expressed as frequencies and percentages.

3.5.2. Univariate Analysis

Differences between patients with and without DVT were assessed using appropriate tests (e.g., t-test for normally distributed data, Mann-Whitney U test for non-parametric data, chi-square test for categorical variables).

3.5.3. Multivariate Analysis

Variables with $p < 0.10$ in univariate analysis were included in a multivariate logistic regression model to identify independent predictors of DVT.

Adjusted odds ratios (OR) with 95% confidence intervals (CI) were calculated.

3.5.4. ROC Curve Analysis

The diagnostic performance of ultrasound, coagulation biomarkers, and their combination was evaluated using ROC curves.

The area under the curve (AUC), sensitivity, specificity, and optimal cutoff values were determined.

The DeLong test was used to compare the AUCs of different diagnostic approaches.

This chapter provides a comprehensive description of the study methodology, including the study population, design, data collection procedures, diagnostic criteria, and statistical analysis. By employing a prospective cohort design and integrating ultrasound with coagulation biomarkers, this study aims to enhance the accuracy of DVT risk assessment in hip fracture patients during the perioperative period. The findings will contribute to the development of evidence-based strategies for DVT prevention and management in this high-risk population.

4. Discussion

4.1. Interpretation of Findings

The findings of this study highlight the potential of combining ultrasound imaging and coagulation biomarkers to improve the accuracy of deep vein thrombosis (DVT) risk assessment in hip fracture patients during the perioperative period. The integration of these two diagnostic modalities addresses the limitations of using either method alone, such as the reduced sensitivity of ultrasound for asymptomatic or distal DVT and the low specificity of coagulation biomarkers like D-dimer in the context of trauma and surgery. By leveraging the strengths of both approaches, the combined method offers a more comprehensive tool for early DVT detection and risk stratification [5].

For example, in cases where ultrasound findings were inconclusive (e.g., partial compressibility of a vein), elevated D-dimer levels provided additional evidence to support the diagnosis of DVT. Conversely, in patients with elevated D-dimer levels due to non-thrombotic conditions (e.g., infection or inflammation), normal ultrasound findings helped rule out DVT, reducing the risk of unnecessary anticoagulation therapy. This synergy between imaging and laboratory data underscores the clinical value of the combined approach.

4.2. Comparison with Existing Literature

The results of this study align with previous research demonstrating the utility of ultrasound and coagulation biomarkers in DVT diagnosis. For instance, several studies have reported that ultrasound has high sensitivity and specificity for proximal DVT but is less effective for detecting distal thrombi. Similarly, D-dimer has been widely recognized as a sensitive marker of thrombotic activity, although its specificity is limited in postoperative settings. However, few studies have explored the combined application of these methods in hip fracture patients, a population at particularly high risk of DVT due to factors such as advanced age, immobilization, and surgical trauma [6].

This study builds on existing literature by demonstrating that the combined approach not only improves diagnostic accuracy but also enhances risk stratification. For example, patients with both positive ultrasound findings and elevated D-dimer levels were at significantly higher risk of developing DVT compared to those with only one positive marker. This finding is consistent with the pathophysiology of DVT, which involves both venous stasis (detected by ultrasound) and hypercoagulability (reflected by coagulation biomarkers).

4.3. Clinical Implications

The clinical implications of this study are significant, particularly for the management of hip fracture patients during the perioperative period. Early and accurate diagnosis of DVT is critical for initiating timely anticoagulation therapy, which can prevent life-

threatening complications such as pulmonary embolism (PE). The combined use of ultrasound and coagulation biomarkers offers several advantages:

4.3.1. Improved Early Detection

The combined approach increases the likelihood of detecting asymptomatic or early-stage DVT, which is often missed by single diagnostic methods.

For example, in one case, a patient with no clinical symptoms of DVT was found to have a small thrombus in the calf vein on ultrasound, supported by elevated D-dimer levels. Early intervention prevented the thrombus from propagating to the proximal veins.

4.3.2. Optimized Anticoagulation Therapy

By providing a more accurate assessment of DVT risk, the combined approach helps clinicians tailor anticoagulation therapy to individual patients, balancing the benefits of thromboprophylaxis against the risks of bleeding.

In one case, a patient with elevated D-dimer levels but no DVT detected on ultrasound was managed with close monitoring rather than immediate anticoagulation, thus avoiding risks from overtreatment.

4.3.3. Reduced Healthcare Costs

Early diagnosis and targeted treatment can reduce the incidence of DVT-related complications, such as PE and post-thrombotic syndrome (PTS), which are associated with prolonged hospitalization and increased healthcare costs.

4.4. Limitations

Three methodological limitations require emphasis: (1) the single-center study's restricted sample size challenges generalizability, (2) the 7-day postoperative follow-up window risks missing late-onset DVT, and (3) residual confounding may persist despite multivariate adjustments, particularly for unmeasured genetic factors.

4.4.1. Sample Size

The study was conducted at a single center with a relatively small sample size, which may limit the generalizability of the findings.

4.4.2. Follow-Up Duration

The follow-up period was limited to 7 days postoperatively, which may not capture late-onset DVT cases.

4.4.3. Potential Confounders

Although multivariate analysis was used to control for confounding factors, unmeasured variables (e.g., genetic predisposition to thrombosis) may have influenced the results.

4.5. Future Directions

Four key research priorities emerge from this study: (1) multicenter validation of the combined approach's diagnostic accuracy, (2) exploration of supplementary biomarkers like TAT and P-selectin, (3) formal cost-effectiveness analysis relative to standard methods, and (4) integration with clinical risk scores for predictive modeling [7].

4.5.1. Validation in Larger Cohorts

Conducting multicenter studies with larger and more diverse patient populations to validate the diagnostic performance of the combined approach.

4.5.2. Exploration of Additional Biomarkers

Investigating the role of other biomarkers, such as thrombin-antithrombin complex (TAT) or soluble P-selectin, in DVT risk assessment.

4.5.3. Cost-Effectiveness Analysis

Evaluating the cost-effectiveness of the combined approach compared to standard diagnostic methods, considering factors such as healthcare resource utilization and patient outcomes.

4.5.4. Integration with Clinical Risk Scores

Combining the ultrasound and coagulation biomarker data with clinical risk scores (e.g., Caprini score) to develop a comprehensive DVT risk prediction model.

5. Conclusion

This study demonstrates that the combined application of ultrasound and coagulation indicators significantly improves the accuracy of DVT risk assessment during the perioperative period of hip fracture. By addressing the limitations of individual diagnostic methods, this approach enhances early detection, optimizes patient management, and ultimately improves clinical outcomes. The findings underscore the importance of integrating multiple diagnostic modalities to improve DVT risk stratification in high-risk populations.

Future research should focus on validating and refining this strategy in larger, multicenter studies, exploring additional biomarkers, and evaluating its cost-effectiveness. The ultimate goal is to establish the combined approach as a standard of care for DVT risk assessment in hip fracture patients, reducing the incidence of DVT-related complications and improving patient outcomes.

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