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REVIEW

Biomarkers in the monitoring of anticoagulant therapies: Clinical applications, diagnostic efficacy, and challenges for the clinical laboratory. Literature review

Biomarcadores en el monitoreo de terapias anticoagulantes: Aplicaciones clínicas, eficacia diagnóstica y desafíos para el laboratorio clínico. Revisión bibliográfica

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ABSTRACT

The implementation of coagulation assays enables precise evaluation of the hemostatic status of patients, which is essential for the prevention of thrombotic events such as deep vein thrombosis, pulmonary embolism, cerebrovascular accidents, and acute myocardial infarction. We conducted a literature review following the PRISMA guidelines, encompassing 78 articles published between 2019 and 2025 that focused on biomarkers for monitoring anticoagulant therapy. Of these, 38 studies met eligibility criteria by providing data on sensitivity, specificity, advantages and limitations of the biomarkers in anticoagulants patients. Results demonstrated that traditional biomarkers, including platelet count, prothrombin time, international normalized ratio, activated partial thromboplastin time, D dimer, are useful for evaluating coagulation activation but have notable limitations in patients treated with direct anticoagulants. In contrast, advanced assays, such as thrombin generation assays, allow comprehensive analysis of the entire thrombin generation process, offering a more complete assessment of the hemostatic system. The combined use of conventional biomarkers and global assays holds significant potential to markedly improve anticoagulant therapy monitoring by facilitating safe individualization of treatment and minimizing both thrombotic and hemorrhagic risk.

Keywords: Biomarkers; Anticoagulants; Monitoring; Anticoagulant Therapy.

RESUMEN

La realización de las pruebas de coagulación permite evaluar de forma precisas el estado hemostático de los pacientes, siendo esencial para la prevención de eventos trombogénicos como las trombosis venosas profunda, el tromboembolismo pulmonar, accidentes cerebrovasculares y el infarto agudo de miocardio. Se realizo una revisión bibliográfica conforme a la guía PRISMA, abarcando 78 artículos publicado entre 2019 y 2025 enfocados en biomarcadores para el monitoreo de terapias con anticoagulantes. De estos, 38 estudios fueron considerados elegibles al aportar datos sobre sensibilidad especificidad, ventajas y limitaciones de los biomarcadores en pacientes bajo tratamiento anticoagulante. Los resultados demostraron que biomarcadores convencionales como el recuento de plaquetas, tiempo de protrombina, índice internacional normalizado, tiempo parcial de tromboplastina activa y dinero D permiten evaluar la activación de la coagulación, pero presentan limitaciones notables en pacientes tratados con anticoagulantes directos. Ensayos avanzados, como los de generación de trombina, permiten analizar toda la dinámica de generación de trombina, lo que ofrece una evaluación completa del sistema hemostático. El uso combinado de biomarcadores convencionales

y ensayo globales tiene el potencial de mejorar significativamente el monitoreo terapéutico anticoagulante. Esto podría facilitar una personalización segura de la terapia, minimizar el riesgo de trombosis como de hemorragias.

Palabras claves: Biomarcadores; Anticoagulantes; Monitoreo; Terapia Anticoagulantes.

INTRODUCTION

Coagulation is a complex process involving the interaction of proteins, vascular cells, and circulating cells, similar to the role of extracellular matrix proteins in blood vessels. This intricate mechanism poses challenges for laboratory evaluation, as most biomarkers primarily assess coagulation proteins and circulating cells, leaving vascular components unexamined.[1]

Under physiological conditions, blood coagulation develops through an ordered sequence of biochemical reactions in which inactive enzymes circulating in the plasma, called proenzymes or enzyme precursors, are activated in stages. This mechanism, known as the coagulation cascade, begins after the exposure of tissue factor (TF), which, by forming a complex with factor VIIa, initiates the activation of the extrinsic pathway. The signal is then amplified by the activation of factor X (FX), whose active form (FXa), in the presence of phospholipids and calcium, transforms prothrombin (FII) into thrombin (FIIa). The latter enzyme plays a central role in converting soluble fibrinogen into fibrin, whose monomers are assembled and stabilized by factor XIIIa, generating a structural network that constitutes a stable and functional clot.[1]

On the other hand, from a therapeutic perspective, anticoagulants act by adjusts this physiological process through the specific inhibition of various factors in the cascade. Through direct or indirect influence, their primary function is to limit fibrin production to prevent the formation or progression of thrombotic events. However, it should be noted that, although their mechanisms of action do not replicate the natural course of coagulation, both hemostatic processes and anticoagulants seek to preserve the balance between clot generation and the prevention of hemorrhagic phenomena.[1]

Anticoagulants rank among the most commonly prescribed medications, serving to prevent formation of existing thrombi in conditions such as deep vein thrombosis (DVT), pulmonary thromboembolism (PTE), cerebrovascular accidents (CVA), and acute myocardial infarction (AMI).[2]

The mechanism of action of anticoagulants is based on the selective inhibition of various components of the coagulation cascade. These agents include direct thrombin inhibitors, such as heparin and its low-molecular-weight derivatives, e.g., enoxaparin and dalteparin, as well as vitamin K antagonists such as warfarin, which act by hinders with the hepatic synthesis of vitamin K-dependent coagulation factors (factors II, VII, IX, and X). Although these drugs prevent reduce the risk of thrombus formation, their use carries an increased risk of hemorrhagic events, which underscores the importance of rigorous therapeutic monitoring and individualized dosage.[2,3]

The emergence of new anticoagulants represents a challenge in the healthcare field. The use of anticoagulant therapy offers significant benefits; however, it can cause adverse effects. Vitamin K antagonists (VKAs) are the basis of oral anticoagulant treatment; the most common and most effective drug is warfarin.[3]

One of the most relevant adverse effects associated with the use of oral anticoagulants is the risk of bleeding, a complication that has been directly linked to an increase in morbidity and mortality. These hemorrhagic manifestations can range from minor bleeding, such as epistaxis or ecchymosis, to serious events such as intracranial hemorrhages, which represent a life-threatening event for the patient. In the case of heparin and its derivatives, bleeding is the most frequent adverse event. Although in numerous instances it is limited to hematomas located at the puncture site, in certain patients it can evolve into more severe hemorrhagic complications, in contexts of overdose or preexisting coagulopathies.[3]

Biomarkers within biological analysis and laboratory diagnosis play a crucial role in monitoring the efficacy and safety of anticoagulant treatment. Continuous or periodic measurement of coagulation tests allows healthcare providers to adjust dosages and manage potential complications effectively. This monitoring is essential given the variability in patient responses to different anticoagulants, including both traditional and novel agents. Among the most used biomarkers for monitoring patients on anticoagulant therapy are platelet count, prothrombin time (PT), international normalized ratio (INR), partial thromboplastin time (PTT), D-dimer (DD), and specific tests to evaluate coagulation factors, such as bleeding time and clotting time, traditional used for decades. New biomarkers have been developed that offer greater diagnostic sensitivity and specificity in disorders related to patient hemostasis.[4]

Objectives

To evaluate biomarkers applied in the management and monitoring of anticoagulated patients.

METHOD

The literature review was conducted in accordance with the PRISMA guidelines, as demonstrated in figure 1. Researchers independently performed searches across both English – language databases (PubMed, Web of Science, ScienceDirect, Nature) and Spanish- language databases (SciELO). The most relevant studies published between January 2019 and May 2025 were collected using combinations of MeSH headings and free text terms, including the following Boolean string: (patients OR anticoagulants) AND (biomarkers OR coagulation) AND (anticoagulants OR biomarkers) AND (monitoring OR anticoagulant therapies). The review was not registered, and no protocol was prepared.

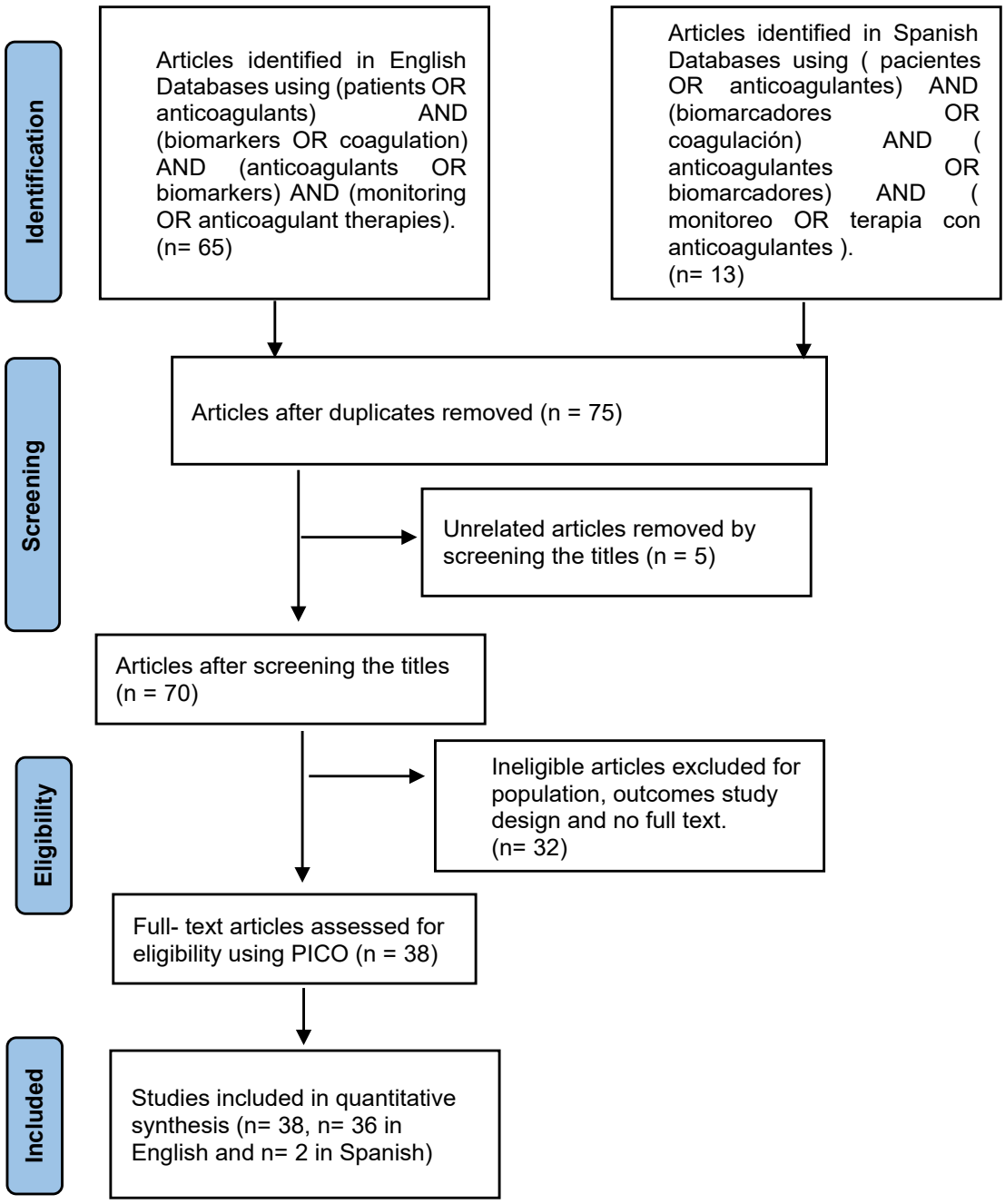

Figure 1. PRISMA flow diagram

To define the search strategies and selection criteria, inclusion and exclusion criteria were applied to the collections; see figure 2 for the PICO questions. Subsequently, researchers independently screened the titles, abstracts, and full texts, excluding studies that did not meet the inclusion criteria, as shown in figure 1.

Figure 2. PICO research question	
P	Patients under treatment with anticoagulants.
I	What biomarkers can effectively assess coagulant treatment?
C	Compared conventional and sophisticated methods
O	What would be the effectiveness and challenges of using biomarkers in the diagnosis of pathologies in the clinical laboratory?
Question: for patients on anticoagulant therapy, what biomarkers would be used to assess the efficacy of the treatment, comparing conventional methods with sophisticated methods? What would be the effectiveness and challenges of using biomarkers in diagnosing pathologies in clinical laboratories?	

RESULTS

Biomarkers are tools that measure and evaluate physiological processes, both in healthy individuals and those with pathologies. Their usefulness ranges from identifying the risk of developing a disease to monitoring therapeutic response in patients undergoing treatment.[5,6]

As a result, biomarkers play a fundamental role in the diagnosis of underlying conditions. Their use allows us to identify coagulopathies and coagulation factor deficiencies that might otherwise go undetected without detailed analysis. This is crucial for the development of more precise and safer therapeutic strategies for patients.[5,6,7]

The most used biomarkers for monitoring patients on anticoagulant therapy include:

The platelet count at the time of venous thromboembolism (VTE) diagnosis serves as a pivotal biomarker for assessing bleeding risks associated with anticoagulant therapy. In a cohort exceeding 37 000 patients administered vitamin K antagonists, a non-linear U-shaped correlation was delineated between the initial platelet count and the incidence of major bleeding: patients exhibiting both extremely low and exceedingly high platelet levels demonstrated a heightened occurrence of severe bleeding, with mortality rates from bleeding being particularly elevated within the low platelet count subset.[8,9]

Moreover, various non-thromboembolic factors may influence platelet counts at the initiation of antithrombotic therapy. The administration of chemotherapy typically results in thrombocytopenia. Conversely, reactive thrombocytosis is frequently observed following significant surgical interventions, such as splenectomies. It is paramount to exclude pseudotrombocytopenias, which can arise from the use of EDTA tubes, through the evaluation of a blood smear and platelet counting in citrate tubes to avert erroneous diagnoses and unwarranted therapeutic measures.[8,9]

The PT and aPTT are coagulation tests used to assess the hemostatic status of patients with possible coagulation factor deficiencies. The PT assesses the time required for plasma to clot after the addition of calcium and thromboplastin, allowing for the analysis of the function of the extrinsic coagulation pathway, including factors VII, X, V, II, and fibrinogen deficiency. Meanwhile, the aPTT measures the time required for plasma to clot after the addition of phospholipids and calcium, assessing the function of the intrinsic coagulation pathway, including factors VIII, IX, XI, and XII.[6,10,11]

The PT test has a sensitivity of 85–90 % for detecting deficiencies in extrinsic pathway factors. In contrast, the aPTT is used to detect coagulation inhibitors of the intrinsic pathway and shows a sensitivity of 70–80 % for identifying disorders related to this pathway.[6,10,11]

International Normalized Ratio (INR) is a crucial metric for monitoring patients on anticoagulants, particularly vitamin K antagonists (VKAs) like warfarin. It is derived from the prothrombin time (PT) of the patient compared to a control PT, adjusted by the International Sensitivity Index (ISI) of the thromboplastin used. This standardization allows for consistent monitoring across different laboratories and patient populations.[12,13]

Portable INR devices provide reliable, accurate measurements from capillary or venous blood, yielding values comparable to laboratory assays. Point of care INR tests match standard laboratory techniques in precision. Test strips contain lyophilized reagents. On applying a blood sample, reagents dissolve and coagulation activators initiate thrombin generation. The device starts with a timer at the same moment. Thrombin cleaves a peptide substrate, producing an electrochemical signal. The interval until the first signal appears is processed by an algorithm that converts it into the standard INR, which the device displays.[12,13]

D-dimer is produced as a result of the degradation of fibrin clots formed by the action of thrombin and degraded by plasmin. Its presence indicates widespread activity of the body's coagulation and fibrinolysis processes and is useful in detecting hypercoagulable states and the risk of DVT and PE. Its disadvantage is that it is a nonspecific test; it can be elevated in various pathological processes, such as DVT and PE.[6,14,15]

Another biomarker used is fibrinogen, a plasma protein essential for blood clotting. It is produced in the liver and transformed into fibrin, which forms a network or mesh at the wound site to stop blood flow. In trauma situations, the concentration of this protein in the blood can increase up to four times its usual value, which

under normal conditions is 200 to 400 mg/dL. This means that, in trauma situations, levels can reach up to 1600 mg/dL. Measuring fibrinogen is useful for evaluating hemorrhagic and thrombotic disorders and is also considered a proinflammatory marker in traumatic or inflammatory processes. It is specific for the final stage of coagulation.[6,16]

Thrombin-binding factor (TGA) is a key enzyme in blood coagulation, responsible for converting fibrinogen into fibrin, which facilitates clot formation. Elevated TGA levels are considered a marker of thrombogenic risk and are useful for assessing a patient's overall hemostatic status and predicting the recurrence of deep vein thrombosis (DVT). This test is notable for its sensitivity in detecting minimal coagulation abnormalities in both hypercoagulable and hypo coagulable states. It is also a valuable tool for optimizing dosage in anticoagulant therapy.[17,18,19,20]

Thrombin time (TT) is used to assess the transformation of fibrinogen into fibrin after thrombin uptake. It is one of the biomarkers used to detect FBG abnormalities, as well as the presence of thrombin inhibitors, fibrin formation, and its polymerization process. It evaluates thrombin activity on fibrinogen with high specificity in detecting fibrinogen and heparin levels, including their functionality.[17,21,22]

Factors II and X (FII, FX) biomarkers are essential proteins in the blood coagulation process, playing a critical role in clot formation and hemostasis. Factor II, also known as prothrombin, is activated as thrombin in the common coagulation pathway. This process is mediated by the action of factor Xa, synthesized in the liver and dependent on vitamin K. Deficit of this protein may increase the risk of bleeding, while its hyperactivity is associated with an increased risk of thrombosis.[23,24]

On the other hand, factor X, or Stuart-Prower factor, has functional activity in the common coagulation pathway. When activated, it forms factor Xa, which is essential in the conversion of prothrombin into thrombin. This factor is activated by the action of thromboplastin, converting into Xa. Like Factor II, it is synthesized in the liver and is dependent on vitamin K. Both factors are sensitive to alterations in vitamin K production, whether in anticoagulant therapies with vitamin K antagonists or physiological processes.[23,24]

One of the most used biomarkers today is chromogenic factor X (CFX), used in coagulation tests to measure factor X activity. Unlike other tests, CFX does not depend on thromboplastin or fibrinogen, avoiding interactions that can generate erroneous results, such as elevated INR. CFX generates a colorimetric signal that facilitates the detection of deficiencies or alterations in coagulation factors and has a high sensitivity of approximately 90 % to detect diseases related to factor X and variations in treatments with vitamin K antagonist anticoagulants. Anticoagulants such as warfarin inhibit the production of factor X in the liver, so CFX can also be used to indirectly evaluate warfarin-induced anticoagulation in situations where the interaction with thromboplastin or fibrinogen could interfere with the INR results.[25,26,27]

Anti-Xa and anti-IIa chromogenic activity is another relevant biomarker, especially in the monitoring of heparin therapies. This analysis allows the evaluation of anticoagulant effectiveness by providing information on the activity of coagulation factors X and II. It is especially useful when quantitative data are required, since anti-Xa levels can vary depending on the anticoagulant used. Reference values for anti-Xa depend on the type of anticoagulant used, but therapeutic levels of anti-Xa with low molecular weight heparin are generally considered to be between 0,5 and 1,2 U/mL. Anti-IIa, on the other hand, has a higher specificity for thrombin inhibition, facilitating direct assessment of anticoagulant action.[17,28,29,30]

Ecarin (ECT) is another biomarker that converts prothrombin to meizothrombin, which can be inhibited by direct thrombin inhibitors but not by heparin. The accuracy of clotting time determined by ECT can be affected by fibrinogen and prothrombin deficiencies. It is particularly useful for measuring the functional activity of direct thrombin inhibitors (DTIs), making it advantageous for the specific monitoring of patients with thrombosis treated with dabigatran.[31,32]

Vitamin K, a group of fat-soluble substances essential for several biological processes, plays a crucial role in blood coagulation. It is specific for the activity of vitamin K-dependent factors II, VII, IX, and X, as well as proteins C and S, making it essential for preventing coagulopathies and bleeding.[33,34]

Protein C and S biomarkers are equally important for maintaining the balance between coagulation and fibrinolysis, both of which are necessary to prevent excessive clot formation and to eliminate those that have already formed. Protein C, when activated, prevents excessive coagulation by inhibiting factors Va and VIIIa.[35,36] Protein S, in turn, acts as a cofactor for protein C, enhancing its ability to inhibit these factors.[37]

Plasminogen is an inactive enzyme that converts to plasmin and is responsible for dissolving blood clots through the process of fibrinolysis. When plasminogen is activated, it is transformed into plasmin, which breaks down the fibrin network and eliminates clots.[17,38]

Table 1. Summary of biomarkers used in patients receiving anticoagulant treatment

Authors	Biomarkers	Clinical Correlation	Specificity.	Sensitivity.	Advantages	Disadvantages
Gauer RL WDJ.[8] Di Micco P, Monreal M[9]	Platelet counts	Identification of certain instances of thrombocytopenia that may manifest in patients undergoing anticoagulant therapy, particularly in cases of heparin induced thrombocytopenia.	……	Exhibit low sensitivity.	……	It lacks specificity for a singular pathological condition, as the reduction in platelet levels may be attributable to various factors that can precipitate a pathological state.
Vera O. Vallejos A,[2] Bello A, et al.[3]	Thromboplastin time (PT).	Monitoring of patients on anticoagulant therapy at risk of bleeding.	Evaluates the extrinsic pathway, including factors VII, X, V, and II.	It has a high sensitivity of 85 - 90 %.	For patients on anticoagulant therapy. Greater efficacy at risk of bleeding and thrombosis.	It is an unstable biomarker in patients who consume vitamin K. It evaluates the extrinsic pathway.
Ayuso Murillo D, et al.[12] Wermine K, et al.[13]	International Normalized Ratio (INR)	Serves to evaluate the efficacy of vitamin K antagonists.	It demonstrates enhanced specificity, particularly in individuals receiving Warfarin therapy.	……	A prognostic indicator in relation to hemorrhagic and thrombotic risks.	Evaluates exclusively the extrinsic coagulation pathway.
Perifanis V, et al.[4] Ou FS, et al.[5]	Active partial thromboplastin time (aPTT)	In unfractionated heparin anticoagulant therapies. Inhibitor detection.	Specific to the intrinsic pathway, including factors VIII, IX, XI, and XII.	Detection of alterations in factors in the intrinsic pathway, coagulation inhibitors, sensitivity 70-80 %.	Monitoring in anticoagulant therapies with heparin.	It is not useful in monitoring oral anticoagulant therapies such as warfarin, nor does it evaluate the extrinsic pathway.
Perifanis V, et al[4] Nabila N, et al.[6] Ballestri S, et al.[7]	Thrombin Time (TT)	Measures the conversion of fibrinogen to fibrin. Detects fibrinogen abnormalities and the presence of thrombin inhibitors.	Evaluates the activity of thrombin on fibrinogen.	They have a high level of fibrinogen and inhibitors such as thrombin and heparin.	Evaluates the functional activity of fibrinogen and heparin detection.	It is exclusive to the final stage of coagulation. It is not particularly useful in monitoring anticoagulant therapies.
Marin MJ, et al. Winter WE, et al.[10,11]	D-dimer (DD)	Marker for assessing coagulation and fibrinolysis. Standard test for deep vein thrombosis (DVT) and pulmonary thromboembolism (PT)	It is not specific for a particular pathological process, but it rules out the presence of thrombotic diseases.	It has a high sensitivity in the presence of degraded fibrin.	Rules out the presence of DVT and PT and provides a marker for monitoring DIC.	It is elevated in different pathological processes.
Ayuso Murillo D, et al.[12] Wermine K, et al.[13]	Vitamin K	Risk of coagulopathies and bleeding.	Specific to the activity of vitamin K-dependent factors II, VII, IX, and X.	Its sensitivity is based on dietary variations.	Evaluates coagulation disorders related to vitamin K deficiency.	It is not frequently used in cynicism.

Ahmad U, et al.[16] Cohen H, et al.[17]	Chromogenic factor X (CFX)	Determines the function of factor X, providing information on the common pathway and coagulopathies.	It is specific to the functionality of the coagulation process, detecting factor X deficiency, and monitoring therapies.	Its sensitivity is 90 % and is determined in congenital or acquired diseases of this factor and in variations in treatments with vitamin K antagonist anticoagulants.	Efficiently assesses factor X activity. Contributes to the diagnosis of coagulopathies. Monitoring anticoagulant therapies. Useful in patients with DIC.	Very limited test. Results are affected by certain anticoagulants.
Depasse F, et al.[18] Binder NB, et al.[19].	Factors II and X (FII, FX)	Vitamin K-dependent factors, essential for coagulation.	FII: Determine the functional activity of prothrombin. FX: Specific to the common pathway and variability of vitamin K-dependent factors.	Sensitive to alterations in vitamin K production, whether in anticoagulant therapies with vitamin K antagonists or physiological processes.	They evaluate the common pathway and allow for monitoring of anticoagulant therapies. They can specifically differentiate these coagulation factors.	Likewise, they are expensive tests.
Sidonio RF, et al.[20] Mackie I, et al.[21] Binder NB, et al.[22]	Anti-Xa and Anti-IIa chromogenic activity	Essential tests for monitoring anticoagulant therapies.	Anti-Xa: Determines the action of anticoagulants. Anti-ILA: Specific for thrombin inhibition, evaluating the direct action of anticoagulants.	It has a high sensitivity, which allows for the effective evaluation of the usefulness of anticoagulants.	Specific monitoring in anticoagulated patients.	Limited and unavailable test. It only assesses specific inhibitors and does not show overall coagulation status.
Batsuli G, et al.[23] Peyvandi F, et al.[24]	Ecarina	They evaluate thrombin activity in the presence of ecarin, useful for determining the effectiveness of anticoagulants.	Specific for measuring the functional activity of direct thrombin inhibitors (DTIs).	.....	Specific monitoring of patients with debigatran.	Test that is difficult to access in routine laboratories.
Greenmyer JR, et al.[25] Menegatti M, et al.[26] Mohsenian S, et al.[27]	Thrombin generation (TGA)	Determines the capacity of plasma to generate thrombin.	Specific to provide general information on coagulation factors and general hemostatic status.	Sensitive to minimal variations in coagulation, whether hyper - or hypocoagulability.	Complete overview of overall coagulation status. Allows adjustment of anticoagulant therapies.	It's expensive. It doesn't replace traditional testing.
McRae HL, et al.[28] Amiral J, et al.[29]	Protein C and S activity.	Useful in congenital or hereditary deficiencies.	Specific for measuring the functionality of protein C that inactivates factors Va and VIIIa.	Sensitive to congenital or acquired deficiencies of protein C.	Its deficiency is a key factor in regulating coagulation. It determines the risk of thrombosis. It contributes to the monitoring of thrombophilia.	Anticoagulants such as heparin and warfarin affect protein C activity. This test is difficult to access.

DISCUSSION

The U-shaped association between the initial platelet counts at the commencement of anticoagulation and the risk of major bleeding underscores the notion that neither low nor excessively high platelet counts ensure protection. Patients presenting with critically low platelet counts are often concomitant with severe comorbidities, including advanced malignancies and liver or renal insufficiency, which predispose them to bleeding and partially elucidate the elevated incidence of fatal bleeding, in contrast to studies that exclusively incorporated patients with established thrombocytopenia.[9] These findings reinforce the imperative that, in clinical settings, anticoagulation should be approached with circumspection in individuals with diminished platelet counts, particularly within the oncological framework.[8,9]

Conversely, pseudotrombocytopenias resulting from EDTA represents an analytical artifact whose recognition is crucial, as the patient does not face an actual risk of bleeding; however, they may be subjected to unnecessary interventions if this condition is not accurately excluded through smear examination and counting in citrate tubes.[8,9]

PT and aPTT continue to be essential for assessing extrinsic and intrinsic coagulation pathways. These tests are used due to their ability to detect coagulation factor deficiencies. However, they have limitations in patients receiving direct oral anticoagulants (DOACs), where ecarin-based tests have demonstrated greater specificity.[11] The importance of standardizing these tests to minimize discrepancies in results and improve their clinical reliability.[33]

INR is an extremely reproducible biomarker between laboratories, but its reliability is limited to patients anticoagulated with vitamin K antagonists (AVK) for at least six months. It is not reliable in patients at initiation AVK therapy, or in those with advanced liver disease, disseminated intravascular coagulation (DIC), or congenital or acquired deficiencies of vitamin K dependent coagulation factors.[12,13]

On the other hand, DD, although a nonspecific biomarker, is useful in the detection of hypercoagulable states, such as the risk of DVT and PE. Highlight its role in the early identification of thrombotic events, although they warn that its elevation in inflammatory or infectious states can generate false positives.[16] Emphasize that, although DD is a valuable tool in the evaluation of thrombotic diseases, its interpretation should be done with caution. Elevated levels can also be associated with other conditions, such as kidney failure or neoplasia.[15] This variability in its specificity highlights the importance of complementing it with other tests to improve its diagnostic accuracy.

Thrombin generation has established itself as a comprehensive biomarker for assessing both hypercoagulable and hypocoagulable states. Highlight that its predictive capacity for DVT recurrence surpasses that of conventional tests, providing a more precise approach for adjusting anticoagulant doses.[19] TGA enables detailed monitoring of coagulation but is also useful in patients with bleeding disorders, as it helps identify minimal variations in thrombotic activity, facilitating more personalized therapeutic adjustments.[20] Chromogenic biomarkers, such as anti-Xa and anti-IIa, have proven to be valuable tools in monitoring heparin and DOAC therapies. These tests provide a more accurate assessment of anticoagulant activity, overcoming some limitations of traditional methods.[30] Even so, the lack of standardization of these tests remains a challenge, underscoring the need to improve their reproducibility and clinical applicability.[33]

From a clinical perspective, the combination of conventional biomarkers and more advanced testing provides a more complete view of a patient's hemorrhage status. This allows for personalized adjustment of anticoagulant doses, reducing both the risk of bleeding and thrombotic events. Furthermore, monitoring vitamin K-dependent factors, such as factors II and X, facilitates the optimization of treatments with vitamin K antagonists, such as warfarin.[26]

This study contributes to the development of clinical strategies that optimize the monitoring of anticoagulant therapies, providing crucial data on the efficacy and safety of biomarkers. The implementation of these methods in clinical practice promotes an evidence-based approach, improving the quality of care and patient safety.

CONCLUSIONS

Biomarkers are key tools for optimizing the monitoring of patients on anticoagulant therapy, as they allow for a more accurate assessment of hemostatic status, thereby increasing therapeutic safety and clinical efficacy in preventing thromboembolic and hemorrhagic events. The incorporation of advanced methodologies, such as thrombin generation assays (TGA) and chromogenic tests, has significantly expanded diagnostic and therapeutic monitoring capabilities, especially in patients receiving direct-acting oral anticoagulants (DOACs), facilitating safer and more effective individualization of treatment.

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