New Anticoagulants for Treatment of Venous Thromboembolism

Jeffrey I. Weitz, MD, FRCP(C), FACP, FCCP

Abstract—Treatment of venous thromboembolism (VTE) usually starts with concomitant administration of heparin or low-molecular-weight heparin (LMWH) and a vitamin K antagonist. The parenteral anticoagulant, which is given for at least 5 days, is stopped once the vitamin K antagonist produces a therapeutic level of anticoagulation. Although the introduction of LMWH has simplified the initial treatment of VTE, problems remain. LMWH must be given by daily subcutaneous (SC) injection and vitamin K antagonists require routine coagulation monitoring, which is inconvenient for patients and physicians. Recently, 3 new anticoagulants have been introduced in an attempt to overcome these limitations. These include fondaparinux and idraparinux, synthetic analogs of the pentasaccharide sequence that mediates the interaction of heparin and LMWH with antithrombin, and ximelagatran, an orally active inhibitor of thrombin. These agents produce a predictable anticoagulant response; thus, routine coagulation monitoring is unnecessary. Because they do not bind to platelets or platelet factor 4, fondaparinux and idraparinux do not cause heparin-induced thrombocytopenia (HIT). Unlike vitamin K antagonists, ximelagatran has a rapid onset of action, thereby obviating the need for concomitant administration of a parenteral anticoagulant when starting treatment. The lack of an antidote for these new agents is a drawback, particularly for idraparinux, which has a long half-life. (Circulation. 2004;110[suppl I]:I-19–I-26.)

Key Words: venous thromboembolism ■ pulmonary embolism ■ deep venous thrombosis ■ anticoagulants ■ coagulation ■ pharmacology ■ thrombosis

Venous thromboembolism (VTE), which includes deep vein thrombosis (DVT) and pulmonary embolism (PE), occurs in ≈1 in 1000 white individuals per year.1 The primary goal of initial treatment of VTE is to limit thrombus extension.2 This not only reduces the risk of PE, a complication that can be fatal, but also may minimize postphlebitic syndrome, a potentially debilitating long-term sequelae of extensive DVT.3

Anticoagulants remain the cornerstone of treatment of VTE. The landmark study by Barritt and Jordan4 established the role of anticoagulants in this setting. These investigators randomized 35 patients with clinically diagnosed PE to treatment with heparin or to no treatment. There were no fatalities in the heparin-treated group. In contrast, 25% of those untreated died of autopsy-proven PE.

Rapid anticoagulation is necessary to minimize the risk of thrombus extension and PE in patients with VTE. This concept is supported by the placebo-controlled study of Brandjes et al.,5 which randomized 120 patients with proximal DVT to treatment with heparin plus a vitamin K antagonist or to a vitamin K antagonist alone. The study was stopped prematurely because the rate of symptomatic recurrent VTE was lower in those given heparin plus a vitamin K antagonist than in those treated only with a vitamin K antagonist (6.7% and 20%, respectively; P=0.058), as was the rate of VTE extension (8.2% and 39.6%, respectively; P<0.001).

With currently available drugs, rapid anticoagulation can only be effected with parenteral anticoagulants, such as heparin or LMWH. The introduction of LMWH has simplified the initial treatment of VTE. Compared with heparin, LMWH exhibits greater bioavailability after SC injection, has a longer half-life, and produces a more predictable anticoagulant response.6 Consequently, LMWH can be given subcutaneously once or twice daily without coagulation monitoring. Meta-analyses of trials comparing SC LMWH with continuous intravenous (IV) heparin for initial treatment of VTE demonstrate that LMWH is at least as effective and safe as heparin.7,8 Because LMWH is more convenient to administer, however, it is ideally suited for outpatient treatment of VTE,9,10 an approach that reduces health care costs9–12 and improves patient satisfaction.13

After initial treatment with heparin or LMWH, ongoing anticoagulant therapy is needed to prevent recurrent VTE.14,15 Extended therapy usually involves administration of a vitamin K antagonist,2 although long-term LMWH may be a better choice in cancer patients with VTE.16 A 3-month course of anticoagulant treatment is adequate for patients with VTE complicating a transient risk factor, such as surgery. In contrast, more extended therapy is needed in...
patients with unprovoked VTE. Long-term anticoagulation therapy is problematic because vitamin K antagonists are not easy to administer. Routine coagulation monitoring is essential to ensure that a therapeutic response is obtained because vitamin K antagonists have a narrow therapeutic window. Thus, a subtherapeutic response does not effectively reduce the risk of thrombosis, whereas excessive anticoagulation increases the risk of bleeding. Furthermore, interactions with a range of drugs can reduce or enhance the anticoagulant effects of vitamin K antagonists, as can variable intake of foods containing vitamin K. In addition, genetically determined polymorphisms in the cytochrome P4502C9 enzyme influence the metabolism of vitamin K antagonists. These phenomena contribute to the need for routine coagulation monitoring. Even when coagulation monitoring is performed, patients using vitamin K antagonists have a therapeutic anticoagulant response less than half the time, a situation that places them at risk for complications.

Recently, 2 new parenteral and 1 novel oral anticoagulant have been evaluated in patients with VTE. Parenteral agents with longer half-lives than heparin or LMWH have the potential to simplify initial or extended treatment of VTE, whereas rapidly acting oral anticoagulants provide an opportunity for streamlined therapy by eliminating the need for parenteral agents for initial VTE treatment and by obviating the requirement for coagulation monitoring and dose adjustment. Focusing on new drugs that have been evaluated in patients with VTE, this article reviews their pharmacology, outlines the potential advantages of these agents over existing anticoagulants, describes the results of clinical trials evaluating new anticoagulants for treatment of VTE, provides perspective as to strengths and potential drawbacks of these new agents, and identifies their evolving role in VTE management.

**Pharmacology of New Anticoagulants**

The new anticoagulants that have been evaluated for the treatment of VTE include 2 parenteral antithrombin-dependent inhibitors of activated factor X (factor Xa), fondaparinux and idraparinux, and ximelagatran, the first oral direct thrombin inhibitor. By targeting factor Xa, fondaparinux and idraparinux block thrombin generation. In contrast, ximelagatran inhibits thrombin, the enzyme that catalyzes the conversion of fibrinogen to fibrin (Figure 1). Thrombin also activates platelets and amplifies its own generation by feedback activation of factors VIII and V, key cofactors in factor Xa and thrombin generation, respectively. The pharmacology of fondaparinux, idraparinux, and ximelagatran is briefly discussed.

**Fondaparinux**

A synthetic analog of the antithrombin-binding pentasaccharide sequence found on heparin or LMWH (Figure 2), fondaparinux binds antithrombin with high affinity. Once bound, fondaparinux evokes conformational changes in the reactive center loop of antithrombin that enhance its reactivity with factor Xa. Fondaparinux is a catalytic inhibitor; thus, after promoting the formation of the factor Xa/antithrombin complex, fondaparinux dissociates from antithrombin and is available to activate additional antithrombin molecules.

With excellent bioavailability after SC administration and a plasma half-life of 17 hours, fondaparinux is administered subcutaneously once daily. Systemic fondaparinux is excreted unchanged via the kidneys. Therefore, fondaparinux must be used with caution in patients with renal insufficiency.

When given SC in fixed doses, fondaparinux produces a predictable anticoagulant response. Consequently, routine coagulation monitoring is unnecessary. If necessary, fondaparinux can be monitored with antifactor Xa levels using a chromogenic assay. Fondaparinux has no effect on routine tests of coagulation, such as the activated partial thromboplastin time or activated clotting time. (Figure 2)

Figure 1. Sites of action of fondaparinux, idraparinux, and ximelagatran. Coagulation is initiated by the tissue factor/factor VIIa (TF/VIIa) complex, which activates factors IX and X. Activated factor X (Xa) converts small amounts of prothrombin (II) to thrombin (IIa), which then feeds back to activate factors VIII and V, key cofactors in coagulation. The process is propagated by activated factor IX (IXa), which together with activated factor VIII (VIIIa) assembles on the surface of activated platelets to form intrinsic tenase, a complex that efficiently activates factor X. Xa, together with activated factor V (Va), assembles on the surface of activated platelets to form prothrombinase. This complex generates a burst of thrombin that, in the final stage of the coagulation process, converts fibrinogen to fibrin. By inhibiting factor Xa in an antithrombin-dependent fashion, fondaparinux and idraparinux block thrombin generation. In contrast, ximelagatran undergoes bioconversion to melagatran, which then blocks thrombin activity by binding directly to the active site of the enzyme.

Figure 2. Structures of fondaparinux and idraparinux. Fondaparinux is a synthetic analog of the natural pentasaccharide found in heparin and LMWH heparin. To enhance its affinity for antithrombin, idraparinux is 0-methylated and 0-sulfated.
Idraparinux
A second-generation synthetic pentasaccharide, idraparinux is more negatively charged than fondaparinux (Figure 2). Consequently, idraparinux binds to antithrombin with an affinity higher than that of fondaparinux.33 Because it binds antithrombin so tightly, idraparinux has a plasma half-life similar to that of antithrombin, ≈80 hours. With this long half-life, idraparinux is administered SC on a once-weekly basis. Like fondaparinux, idraparinux exhibits excellent bioavailability after SC injection and produces a predictable anticoagulant response, thereby obviating the need for routine coagulation monitoring.33

Ximelagatran
The first oral, direct thrombin inhibitor, ximelagatran is a prodrug of melagatran (Figure 3), a 429-dalton dipeptide that fits within the active-site cleft of thrombin and blocks the enzyme’s interactions with its substrates.34 Thus, melagatran is a stoichiometric inhibitor of thrombin that forms a reversible 1:1 complex with the enzyme. Melagatran exhibits poor bioavailability after oral administration. Ximelagatran, which has a molecular mass of 474, was developed to overcome this problem. With the addition of an ester and a hydroxyl group to the carboxyl and amidine groups of melagatran, respectively, ximelagatran is more lipophilic than melagatran. Consequently, ximelagatran is readily absorbed in the small intestine.34 Plasma levels of ximelagatran peak in the small intestine 30 minutes after drug ingestion (Figure 4). Although ximelagatran has no intrinsic anticoagulant activity, it is rapidly converted to melagatran via 2 intermediates. The bioavailability of melagatran after administration of oral ximelagatran is ≈20%. Plasma levels of melagatran peak 2 hours after ximelagatran ingestion; melagatran circulates with a half-life of 3 hours in healthy volunteers and 4 to 5 hours in patients. Because melagatran has a relatively short half-life, ximelagatran is administered orally twice daily.34

Ximelagatran produces a predictable anticoagulant response after fixed oral dosing. The half-life of melagatran does not vary among ethnic groups35 and is not influenced by obesity36 or mild to moderate hepatic insufficiency.37 Ximelagatran does not interact with drugs that are metabolized by cytochrome P450 isozymes CYP2C19, CYP2C9, or CYP3A4.34

At least 80% of systemic melagatran is eliminated unchanged via the kidneys. The half-life of melagatran is slightly prolonged in the elderly, likely reflecting their reduced creatinine clearance.38 Coagulation monitoring is unnecessary for ximelagatran because it produces a predictable anticoagulant response.34 Like all direct thrombin inhibitors, ximelagatran prolongs the activated partial thromboplastin time and international normalized ratio (INR). However, its effect on these tests is not dose-dependent and the extent of prolongation depends on the reagent used for testing. If monitoring is required, the ecarin clotting time, a test that has yet to be standardized, provides the best estimate of drug concentration.

Potential Advantages of New Anticoagulants
Fondaparinux was developed to replace heparin or LMWH for initial treatment of VTE, whereas idraparinux and ximelagatran were designed to compete with vitamin K antagonists. Because of their rapid onset of action, however, idraparinux and ximelagatran also may be useful for initial treatment of VTE, as well as for extended therapy.

### Table 1. Comparison of Fondaparinux and Idraparinux with LMWH

<table>
<thead>
<tr>
<th>Feature</th>
<th>Fondaparinux</th>
<th>Idraparinux</th>
<th>LMWH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Factor Xa</td>
<td>Factor Xa</td>
<td>Factor Xa and thrombin</td>
</tr>
<tr>
<td>Route of administration</td>
<td>SC</td>
<td>SC</td>
<td>SC</td>
</tr>
<tr>
<td>Half-life (h)</td>
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<td>4</td>
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<tr>
<td>Endothelial cell binding</td>
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<td>Some</td>
</tr>
<tr>
<td>Protein binding</td>
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<td>None</td>
<td>Some</td>
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<tr>
<td>Clearance</td>
<td>Renal</td>
<td>Renal</td>
<td>Renal</td>
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<tr>
<td>HIT</td>
<td>No</td>
<td>No</td>
<td>Rare</td>
</tr>
<tr>
<td>Antidote</td>
<td>None</td>
<td>None</td>
<td>Partial neutralization with protamine sulfate</td>
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LMWH indicates low-molecular-weight heparin; SC, subcutaneous; HIT, heparin-induced thrombocytopenia.
The new anticoagulants have potential advantages over existing agents. Focusing first on the parenteral agents, both fondaparinux and idraparinux have properties that distinguish them from LMWH (Table 1), the anticoagulant that is rapidly replacing heparin for initial VTE treatment. Whereas the bioavailability of LMWH after SC injection is 80% to 90%, fondaparinux and idraparinux exhibit almost complete bioavailability. In addition, there is less between-patient variability in the anticoagulant response with fondaparinux and idraparinux than with LMWH. These differences reflect the fact that fondaparinux and idraparinux are homogeneous preparations of synthetic pentasaccharide units that bind only to antithrombin. In contrast, LMWH preparations are composed of heparin fragments that range in molecular weight from 1000 to 10,000 daltons. Only 15% to 20% of these fragments possess a pentasaccharide sequence. Longer chains can bind nonspecifically to endothelial cells and various plasma proteins. Pentasaccharide-independent binding of heparin chains to endothelial cells reduces bioavailability because these cellular binding sites must be saturated before the LMWH chains can enter the circulation and interact with antithrombin. Binding to plasma proteins, the levels of which differ between patients, explains the between-patient variability in the anticoagulant response to LMWH. Although fondaparinux and idraparinux have greater bioavailability than LMWH and produce a more predictable anticoagulant response, it is unclear whether these properties endow the new anticoagulants with clinical advantages over LMWH.

Fondaparinux and idraparinux have half-lives of 17 and 80 hours, respectively. In contrast, LMWH has a half-life of only 4 to 5 hours. Despite its relatively short half-life, LMWH is effective when given once daily for VTE treatment, although uncertainty remains as to whether once-daily LMWH is as effective as twice-daily dosing. A potential explanation for the extended antithrombotic activity of LMWH is its capacity to induce the release of tissue factor pathway inhibitor (TFPI) from the vasculature. An endogenous anticoagulant, TFPI limits the initiation of coagulation by inhibiting tissue factor-bound factor VIIa in a factor Xa-dependent fashion. In contrast to LMWH, neither fondaparinux nor idraparinux induces TFPI release. However, the long half-lives of fondaparinux and idraparinux may preclude the need for this additional anticoagulant mechanism.

Although LMWH can induce HIT, the risk of HIT is lower with LMWH than with heparin. In contrast, fondaparinux and idraparinux do not cause HIT because they do not bind to platelets or platelet factor 4 (PF4). Thus, HIT is triggered by antibodies directed against the heparin/PF4 complex. Fondaparinux and idraparinux do not bind to platelets. Therefore, they do not cause platelet activation and subsequent PF4 release. Likewise, because these agents do not bind to PF4, they do not induce the conformational changes in PF4 that render it antigenic. These properties endow fondaparinux and idraparinux with a safety advantage over heparin and LMWH and may render these new agents useful for HIT treatment, a possibility that requires evaluation in clinical trials.

Osteoporosis can occur after long-term treatment with heparin or LMWH. The risk of this complication should be lower with fondaparinux and idraparinux because shorter heparin chains cause less bone loss than longer chains in cell culture systems and in laboratory animal models. For extended treatment, therefore, fondaparinux and idraparinux may be safer than heparin or LMWH.

As an orally active anticoagulant, ximelagatran has potential advantages over vitamin K antagonists (Table 2). Vitamin K antagonists have a delayed onset of action. Thus, these agents act as anticoagulants by interfering with vitamin K-dependent, post-translational modification of the vitamin K-dependent clotting factors, an essential step in the synthesis of functional coagulation proteins. The antithrombotic effect of vitamin K antagonists most probably reflects reductions in the functional levels of prothrombin and factor X, a process that requires 4 to 5 days of treatment. Because of their slow onset of action, initial therapy with vitamin K antagonists is usually supported by overlapping treatment with a parenteral anticoagulant in patients with established thrombosis, or in those at high risk for thrombosis. In contrast, ximelagatran has a rapid onset of action, thereby obviating the need for concomitant administration of a parenteral anticoagulant when starting treatment.

As mentioned earlier, vitamin K antagonists have a narrow therapeutic window. Furthermore, genetic differences in metabolism and multiple drug and food interactions affect the
anticoagulant response to vitamin K antagonists. These factors contribute to the need for routine coagulation monitoring, which is inconvenient for patients and physicians. In contrast, ximelagatran, with a wider therapeutic window than vitamin K antagonists and no food or drug interactions, can be given without coagulation monitoring. Building on their unique properties, fondaparinux, idraparinux, and ximelagatran have been compared with conventional anticoagulant regimens in VTE patients.

Clinical Trials With New Anticoagulants
Fondaparinux and ximelagatran have completed phase III clinical trials for treatment of VTE. Idraparinux has completed phase II evaluation, and phase III clinical trials are underway. The results of these trials are discussed.

Fondaparinux
Fondaparinux has been evaluated for treatment of VTE in 2 phase III clinical trials. In the MATISSE-DVT study, 2205 patients with DVT were randomized, in a double-blind fashion, to receive either fondaparinux (in dosages of 5, 7.5, or 10 mg SC once daily depending on body weight) or enoxaparin (1 mg/kg SC twice daily) for at least 5 days, followed by a minimum of a 3-month course of treatment with a vitamin K antagonist. At 3 months, rates of recurrent symptomatic VTE with fondaparinux or enoxaparin were 3.9% and 4.1%, respectively, whereas rates of major bleeding were 1.1% and 1.2%, respectively. In the open-label MATISSE PE trial, 2213 patients with PE were randomized to receive either fondaparinux (in dosages of 5, 7.5, or 10 mg SC once daily depending on body weight) or heparin (by continuous IV infusion) for 5 days, followed by a minimum of a 3-month course of therapy with a vitamin K antagonist. At 3 months, rates of recurrent symptomatic VTE with fondaparinux or heparin were 3.8% and 5.0%, respectively, whereas rates of major bleeding were 1.3% and 1.1%, respectively. The results of the MATISSE studies suggest that fondaparinux is as effective as LMWH or unfractionated heparin for initial VTE treatment. Furthermore, fondaparinux is easier to administer than unfractionated heparin.

Idraparinux
In a phase II, dose-finding trial, idraparinux was compared with warfarin for treatment of patients with proximal DVT. In this trial, 659 patients were treated for 5 to 7 days with enoxaparin and then randomized to receive once-weekly SC idraparinux (2.5, 5.0, 7.5, or 10 mg) or warfarin for 12 weeks. The primary efficacy end point, changes in compression ultrasound and perfusion lung scan findings, was similar in all idraparinux groups and did not differ from that in the warfarin group. There was a clear dose response for major bleeding in patients given idraparinux with an unacceptably high rate of major bleeding in those given the 10-mg dose. Two patients, both of whom were in the 5-mg idraparinux group, experienced fatal bleeds. Patients given the lowest dose of idraparinux had less bleeding than those randomized to warfarin (P=0.029). Based on these data, ongoing phase III trials are comparing SC idraparinux monotherapy (at a dose of 2.5 mg SC once weekly) with 5 to 7 days of enoxaparin, followed by at least 3 months of warfarin therapy for treatment of patients with DVT or PE.

Ximelagatran
The double-blind, phase III THRIVE treatment study randomized 2491 patients with acute DVT to receive either oral ximelagatran (36 mg twice daily) alone for 6 months or enoxaparin (1 mg/kg SC twice daily for a minimum of 5 days), followed by warfarin (target INR of 2.0 to 3.0) for 6 months. The primary end point, objectively documented recurrent VTE, occurred in 2.1% and 2.0% of patients given ximelagatran and enoxaparin/warfarin, respectively. Rates of major bleeding were similar in the ximelagatran and enoxaparin/warfarin groups (1.3% and 2.2%, respectively), as were the all-cause mortality rates (2.3% and 3.4%, respectively; P=NS). These results suggest that oral ximelagatran is as effective as conventional anticoagulant treatment with enoxaparin followed by warfarin in preventing recurrent VTE in patients with acute DVT. However, unlike enoxaparin or dalteparin, ximelagatran can be given orally, and in contrast to warfarin, ximelagatran does not require coagulation monitoring or dose adjustment. Consequently, ximelagatran has the potential to streamline treatment.

Ximelagatran also has been evaluated for the long-term secondary prevention of recurrent thrombosis in patients with VTE. An open-label, phase III study (THRIVE III) randomized 1233 patients who had completed a 6-month course of anticoagulant therapy for treatment of VTE to oral ximelagatran (24 mg twice daily) or placebo for an additional 18 months. The primary end point, objectively documented recurrent VTE, occurred in 2.8% of patients given ximelagatran and in 12.6% of those randomized to placebo (hazard ratio 0.16; P<0.001). Major bleeding rates were similar between the ximelagatran and placebo groups (1.1% versus 1.3%, respectively; hazard ratio 1.16), and there were no fatal or intracranial bleeds. Hence, data from this study indicate that lower-dosage ximelagatran (24 mg twice daily) can effectively prevent recurrent VTE.

Potential Role of New Anticoagulants in VTE Treatment
The introduction of LMWH provided a major advance in initial VTE treatment. With once- or twice-daily SC administration and no need for coagulation monitoring, LMWH paved the way for out-of-hospital treatment. New anticoagulants have the potential to further streamline VTE treatment and to offer potential safety advantages over existing agents. Based on the results of the MATISSE-DVT and MATISSE-PE trials, fondaparinux can be used in place of LMWH or heparin for initial treatment of VTE. Although more convenient to administer than heparin, like LMWH, fondaparinux must be given daily by SC injection. However, fondaparinux may be safer than heparin or LMWH because it does not cause HIT.

Idraparinux and ximelagatran have the potential to be used as sole therapy for VTE treatment. In the case of idraparinux, a single SC injection at the time of VTE diagnosis circumvents the need for daily SC injections of LMWH for the initial
5 to 7 days of treatment. Thereafter, once-weekly SC idraparinux can be used in place of a vitamin K antagonist. With no need for routine coagulation monitoring and dose adjustment, idraparinux is more convenient to administer than vitamin K antagonists. Although promising, the efficacy and safety of idraparinux for VTE treatment remains to be established in the ongoing phase III trials.

Like idraparinux, ximelagatran also can be used for both initial and extended VTE treatment. Ximelagatran has the advantage of oral bioavailability, thereby obviating the need for SC injections, and in contrast to vitamin K antagonists, ximelagatran does not require coagulation monitoring or dosage adjustment. Based on the results of the THRIVE treatment trial,55 ximelagatran alone (at a dosage of 36 mg twice daily) appears to be as effective and safe as conventional treatment with LMWH followed by warfarin for DVT treatment.

The data from the THRIVE III study66 indicate that a lower-dosage ximelagatran regimen (24 mg twice daily) prevents recurrent VTE. This study highlights the fact that patients with unprovoked VTE have a rate of recurrent VTE of 7% to 10% per year when anticoagulant therapy is stopped.17–24 When given in dosages sufficient to produce a target INR of 2.0 to 3.0, warfarin reduces this risk by >90%, but is associated with an average rate of major bleeding of 2% per year, of which 10% are fatal.17–24 A lower-intensity warfarin regimen (target INR 1.5 to 1.9) is less effective at preventing recurrent VTE than usual-intensity warfarin (target INR 2.0 to 3.0) in this setting and does not appear to reduce the risk of bleeding.57 Although effective, warfarin is inconvenient because of the need for routine coagulation monitoring and dosage adjustment. Ximelagatran has the potential to overcome this barrier.

**Potential Limitations of New Anticoagulants**

What are the drawbacks of these new anticoagulants? Like all anticoagulants, the major side effect of these new drugs is bleeding. To counteract this problem, a safe rapidly-acting antidote is desirable. Unfortunately, none of these new agents has an antidote. When rapid reversal is required because of major bleeding or the need for urgent surgery, the lack of an antidote is more problematic for agents with a long half-life, such as idraparinux, than for those with a short half-life, such as ximelagatran. Although procoagulants, including recombinant factor VIIa, may reverse the anticoagulant effects of fondaparinux, idraparinux, or ximelagatran in animals or healthy volunteers,38–61 the effect of these agents on anticoagulant-induced bleeding has yet to be addressed. Furthermore, recombinant factor VIIa is not available in all hospitals and the drug is expensive, particularly if repeated doses are needed. Although not well studied, dialysis is likely to clear melagatran, but not fondaparinux or idraparinux.

A side effect unique to ximelagatran is elevation of liver enzymes. Overall, ≈6% (range, 5% to 10%) of patients treated with long-term ximelagatran have a transient increase in alanine aminotransferase levels to over 3 times the upper limit of normal. Typically, this occurs between 1 and 6 months after the start of treatment. Concomitant elevation of bilirubin levels is found in only 0.4% of patients. The increase in serum alanine aminotransferase is generally asymptomatic and reversible, regardless of whether ximelagatan treatment is continued or stopped. Although this phenomenon appears to be benign, more data on patients treated long-term are needed. Until this information is available, ximelagatran will need to be restricted to patients with normal or near normal hepatic function at baseline. Furthermore, it is likely that testing of liver function will need to be performed when initiating ximelagatran treatment and during the first 6 months of therapy. Although less problematic than the routine coagulation monitoring and dosage adjustments needed with vitamin K antagonists, the requirement for liver function test monitoring may limit the convenience of ximelagatran.

Cost is a consideration with any new drug. Fondaparinux is more expensive than LMWH, and idraparinux and ximelagatran are likely to cost more than vitamin K antagonists, even with their attendant cost of coagulation monitoring. Therefore, cost-effectiveness analyses will be required to determine the extent to which these new treatments reduce health care costs. Patient convenience also deserves consideration. By obviating the need for routine coagulation monitoring, agents such as idraparinux or ximelagatran can improve the quality of life for individuals with limited access to anticoagulation clinics.

Finally, compliance with these new drugs may be difficult to assess in the absence of coagulation monitoring. Attention to packaging and ongoing supervision of patients will help minimize this problem.

**Conclusions and Future Directions**

New anticoagulants have the potential to further refine VTE treatment. Still unknown, however, is the role of these agents in selected high-risk VTE patients, such as those with cancer, and their safety in pregnancy. With its short half-life and oral bioavailability, ximelagatran could prove more convenient than LMWH in cancer patients with VTE, provided that its safety can be established in those with hepatic metastases and abnormal liver function tests. Fondaparinux also may prove useful in this setting, although its longer half-life may complicate timing of invasive procedures.

The safety of these new anticoagulants in pregnancy has yet to be established. In placental perfusion studies, synthetic pentasaccharides do not cross the placental barrier.62 Consequently, these agents deserve evaluation in pregnant women. More information is needed about the safety of ximelagatran in pregnancy and in nursing mothers. Minute amounts of melagatran are found in breast milk,63 but the clinical significance of this finding is uncertain because melagatran is poorly absorbed from the gastrointestinal tract.

Fondaparinux, idraparinux, and ximelagatran are the first of a number of new anticoagulants. Other orally active inhibitors of thrombin and factor Xa are undergoing development. Clinical trials are needed to determine whether any of these newer agents will be more effective or safer than those currently available. The introduction of these new anticoagulants expands the treatment options for VTE and will likely transform initial and long-term management.
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