The viscoelastic properties of blood clot have been studied most commonly using thromboelastography (TEG®) and thromboelastometry (ROTEM®). TEG®-based bleeding treatment algorithms recommend administering platelets to patients with low EXTEM clot strength (e.g., clot amplitude at 10 minutes [A10] <40 mm) once clot strength of the ROTEM® fibrin-based test (FIBTEM) is corrected. Algorithms based on TEG® typically use a low value of maximum amplitude (e.g., <50 mm) as a trigger for administering platelets. However, this parameter reflects the contributions of various blood components to the clot, including platelets and fibrin/fibrinogen. The platelet component of clot strength may provide a more sensitive indication of platelet deficiency than clot amplitude from a whole blood TEG® or ROTEM® assay. The platelet component of the formed clot is derived from the results of TEG®/ROTEM® tests performed with and without platelet inhibition. In this article, we review the basis for why this calculation should be based on clot elasticity (e.g., the E parameter with TEG® and the CE parameter with ROTEM®) as opposed to clot amplitude (e.g., the A parameter with TEG® or ROTEM®). This is because clot elasticity, unlike clot amplitude, reflects the force with which the blood clot resists rotation within the device, and the relationship between clot amplitude (variable X) and clot elasticity (variable Y) is nonlinear. A specific increment of X (ΔX) will be associated with different increments of Y (ΔY), depending on the initial value of X. When calculated correctly, using clot elasticity data, the platelet component of the clot can provide a valuable insight into platelet deficiency in emergency bleeding. (Anesth Analg 2015;121:868–78)

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lot amplitude is a standard parameter derived from viscoelastic methods of coagulation monitoring with thrombelastography (TEG®; Haemonetics Corp, Braintree, MA) or thromboelastometry (ROTEM®, Tem International GmbH, Munich, Germany). This variable is interpreted as a measure of clot strength. Although red blood cells make up over 90% of blood clot volume, clot strength is derived from the interaction of the fibrin network and platelets. Fibrin-based clot strength is dependent mainly on factor XIII and fibrinogen, whereas platelets contribute to overall clot strength by binding and tightening fibrin fibers. The platelet component of clot strength can be inhibited pharmacologically with, for example, a glycoprotein Ib/IIa receptor antagonist or cytochalasin D. The platelet component of clot strength is defined as the difference in shear modulus measured with and without platelet inhibition. The calculation is shown in Table 1. The platelet component of clot strength is usually expressed either dimensionless in the same way as “clot elasticity” (CE) or in units of dyne/cm² (e.g., G, which is numerically 50 times the TEG® parameter E or the equivalent ROTEM® parameter CE). Dyne is a unit of force that, although superseded by the SI system (1 dyne/cm² = 0.1 N/m² = 0.1 Pa), is still used in the scientific literature pertaining to viscoelastic coagulation assessment. It is important to note that the assessment of the platelet component to clot strength may lead to misleading results if the calculation is performed using clot amplitude instead of CE. In this article, we explore parameters used for defining platelet deficiency with TEG® and ROTEM®.

Viscoelastic Coagulation Monitoring TEG® and ROTEM® are photokymographic devices designed to measure coagulation under conditions with oscillation but without blood flow. This reflects in vivo conditions of trauma and surgery, where blood vessels are cut or disrupted; blood flow is interrupted and the clot functions to close the vessel (hemostatic clot). It should also be considered that blood is unlikely to be fully static in vivo. The oscillations that characterize the TEG® and ROTEM® devices, which reduce clot strength compared with quiescent conditions, mimic the “nonflow”/“sluggish flow” conditions of surgery and trauma.

Reprints will not be available from the authors.

From the *CSL Behring, Marburg, Germany; † Department of Anesthesiology, Perioperative Care and General Intensive Care, Paracelsus Medical University, Salzburg, University Hospital, Salzburg, Austria; ‡ Ludwig Boltzmann Institute for Experimental and Clinical Traumatology and AUVA Research Centre, Vienna, Austria; § Department of Cardiothoracic and Vascular Anesthesia and Intensive Care, IRCSS Policlinico, San Donato, Milan, Italy; ¶ ECSL Behring, Vienna, Austria; and ¶ Department of Anesthesiology and Intensive Care, AUVA Trauma Hospital of Salzburg, Austria.

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In common with many other biological tissues, blood clots have viscosity and elasticity properties. Application of stress to a blood clot results in a molecular rearrangement known as “creep,” characterizing viscosity. However, when the stress is removed, the clot’s elasticity returns to its original form. The Maxwell model takes into account a material’s viscoelastic properties in relation to stress, strain, and changes in these parameters over time. Early consideration of clot properties suggested that a blood clot could be considered to behave as a Maxwell body. However, recent porcine studies indicate that the Zener model may be more appropriate. The Zener model (also referred to as “the standard linear solid model”) is an alternative method of modeling the behavior of a viscoelastic material which, unlike the Maxwell model, includes a description of creep.

In addition to factor XIII, platelets and fibrin/fibrinogen are recognized as the key determinants of whole blood clot strength. After platelets have bound to fibrin via the glycoprotein IIb/IIIa receptor, the clot contracts through the action of cytoplasmic motility proteins inside platelets, such that fluid (serum) is expelled. With TEG® and ROTEM®, the oscillation period is 10 seconds (6 full oscillations per minute) compared with 9 seconds (6.7 oscillations per minute) with Hartert’s apparatus. The principles of the TEG® apparatus and that designed by Hartert are that the angle of rotation is the same for both devices (4°45′) and the TEG® oscillation period is 10 seconds (6 full oscillations per minute) compared with 9 seconds (6.7 oscillations per minute) with Hartert’s apparatus. The principles of the ROTEM® device are similar to those of TEG®, although with ROTEM® the oscillation period is 12 seconds (5 full oscillations per minute) and the central pin, instead of the plunger, was recorded via deflection of a light beam, with a 100-mm deflection representing the maximal rotation of 4°45′ (the scale of 0–100 mm was chosen arbitrarily). Hartert used the symbol $\varepsilon$ to denote CE. In 1960, he used the same symbol to denote shear modulus of the clot and defined its relationship with clot amplitude as shown by the equation in Table 1. The equation was written slightly differently by the same author in 1962 (Table 1). Importantly, the equation shows that the relationship between deflection of the light beam (subsequently defined as clot amplitude) and shear modulus is not linear. The symbol $\varepsilon$ was used synonymously with G in the 1962 publication. This is confusing, because within the same publication Hartert calculated the shear modulus of a clot with amplitude 2.5 cm to be 5000 dyne/cm². This is the basis for today’s calculation of G (defined as shear elastic modulus strength in units dyne/cm²) from clot amplitude (A) (Table 1).

Today, the principles of using either TEG® or ROTEM® remain similar to the early work of Hartert. Whole blood or plasma is placed into a cup, although unlike in Hartert’s experiments reagents, such as celite or kaolin, are added to stimulate coagulation. Similarities between the current TEG® apparatus and that designed by Hartert are that the angle of rotation is the same for both devices (4°45′) and the TEG® oscillation period is 10 seconds (6 full oscillations per minute) compared with 9 seconds (6.7 oscillations per minute) with Hartert’s apparatus. The principles of the ROTEM® device are similar to those of TEG®, although with ROTEM® the oscillation period is 12 seconds (5 full oscillations per minute) and the central pin, instead of the plunger, was added to a cup, and a plunger (pin) was immersed in the blood. The apparatus was designed so that rotation of the plunger was recorded via deflection of a light beam, with a 100-mm deflection representing the maximal rotation of 4°45′ (the scale of 0–100 mm was chosen arbitrarily). Hartert used the symbol $\varepsilon$ to denote CE. In 1960, he used the same symbol to denote shear modulus of the clot and defined its relationship with clot amplitude as shown by the equation in Table 1. The equation was written slightly differently by the same author in 1962 (Table 1). Importantly, the equation shows that the relationship between deflection of the light beam (subsequently defined as clot amplitude) and shear modulus is not linear. The symbol $\varepsilon$ was used synonymously with G in the 1962 publication. This is confusing, because within the same publication Hartert calculated the shear modulus of a clot with amplitude 2.5 cm to be 5000 dyne/cm². This is the basis for today’s calculation of G (defined as shear elastic modulus strength in units dyne/cm²) from clot amplitude (A) (Table 1). Numerically, G (dyne/cm²) has a value 50 times that of Hartert’s parameter G with arbitrary units.

| Coagulation property | Equation | Equation |
|----------------------|----------|----------|
| **Platelet component** | Platelet component = (100 × AT)/(100 − AT) − (100 × AF)/(100 − AF) [Equation used today, for correct calculation of platelet component from clot amplitude] | $A_t$ represents amplitude (total), without platelet inhibition; $A_f$ represents amplitude under platelet inhibition (F denotes fibrin). |
| **Shear modulus** | $\varepsilon = (100 \times a)/(100 − a)$ [Source: Hartert, 1960] | $\varepsilon$ represents clot amplitude |
| | $G = (100 \times s)/(100 − s)$ [Source: Hartert & Schaeder, 1962] | $G$ has arbitrary units |
| | $G = (5000 \times A)/(100 − A)$ [Equation used today] | $A$ represents clot amplitude |
| **Clot elasticity** | CE = (100 × A)/(100 − A) | $G$, defined as shear elastic modulus strength (dyne/cm²) |
| **Maximum clot elasticity** | MCE = (100 × MCF)/(100 − MCF) | MCF stands for maximum clot firmness (i.e., the peak value of clot amplitude) |
| **Clot elasticity attributable to platelets** (i.e., platelet component) | $CE_{platelet} = CE_{EXTEM} − CE_{FIBTEM}$ | $CE_{EXTEM}$ represents clot amplitude |
| | $MCE_{platelet} = MCE_{EXTEM} − MCE_{FIBTEM}$ | $MCE_{FIBTEM}$ represents clot amplitude |

In 1948, Hartert introduced a viscoelastic device for measuring the shear modulus of a blood clot. Whole blood was added to a cup, and a plunger (pin) was immersed in the blood. The apparatus was designed so that rotation of the plunger was recorded via deflection of a light beam, with a 100-mm deflection representing the maximal rotation of 4°45′ (the scale of 0–100 mm was chosen arbitrarily). Hartert used the symbol $\varepsilon$ to denote CE. In 1960, he used the same symbol to denote shear modulus of the clot and defined its relationship with clot amplitude as shown by the equation in Table 1. The equation was written slightly differently by the same author in 1962 (Table 1). Importantly, the equation shows that the relationship between deflection of the light beam (subsequently defined as clot amplitude) and shear modulus is not linear. The symbol $\varepsilon$ was used synonymously with G in the 1962 publication. This is confusing, because within the same publication Hartert calculated the shear modulus of a clot with amplitude 2.5 cm to be 5000 dyne/cm². This is the basis for today’s calculation of G (defined as shear elastic modulus strength in units dyne/cm²) from clot amplitude (A) (Table 1). Numerically, G (dyne/cm²) has a value 50 times that of Hartert’s parameter G with arbitrary units.

In a discussion of Hartert’s work, Copley stated that the name Hartert gave for his method—thromboelastography—was ill-chosen and even misleading, because the term “thrombus” is reserved for intravascular clotting, whereas blood clot in Hartert’s device is formed in vitro. Copley suggested the term “coagulograph” or “blood clot elastograph” for Hartert’s apparatus; these suggestions were reiterated by Evans et al. in 2006.
cup, is rotated so that resistance to its rotation is measured (resistance increases as the clot forms). With both TEG® and ROTEM®, the principal measurement is clot amplitude, which shows the extent to which rotation is either triggered (TEG®) or resisted (ROTEM®) by clot formation. The scale for clot amplitude with both TEG® and ROTEM® generally ranges from 0 to 100 mm, with the maximal value chosen arbitrarily. Both elasticity and viscosity of the forming blood clot contribute to the clot amplitude.24

As with Hartert’s original device, clot amplitude has a nonlinear relationship with elasticity (Fig. 1). Although the scale for elasticity ranges between zero and infinity, it would have been possible to configure the TEG® or ROTEM® device to display elasticity as the primary reading instead of amplitude. Had this approach been adopted (Fig. 2), calculation of the platelet component from TEG® or ROTEM® results would have been more straightforward from the beginning. Such adjustment could now be implemented by modifying the device software. Thus, future presentation of the platelet component as a primary TEG®/ROTEM® parameter, as shown in Figure 2, is conceivable.

With the TEG® device, the cup rotates both clockwise and counterclockwise, with movement that can be described as oscillatory. Amplitude is derived from rotation of the plunger, occurring as the blood forms a bond between these 2 parts of the apparatus. The clockwise and counterclockwise rotation angles of the plunger are recorded, and the central point at which the plunger remains before the clot is formed represents no rotation. With the ROTEM® device, it is the plunger that rotates (oscillates); the cup remains stationary and the rotation angle is decreased as the clot forms. As with TEG®, clot amplitude is calculated from the maximal rotation angle of the plunger. There is a question with both devices whether clot amplitude represents the difference between the central point and the full rotation in one direction or the difference between full rotation in one direction versus full rotation in the opposite direction. With Hartert’s device, the maximal rotation was 4°45′, representing 2°22.5′ clockwise from the resting point and the same rotation counterclockwise. Therefore, the 100-mm maximal deflection represented 50 mm in each direction from the resting point. The ROTEM® device provides measurements from a single point in the rotation cycle (i.e., maximal rotation in one direction). The measured deflection from the resting point is doubled to obtain clot amplitude (A), and the generation of traces showing both positive and negative deflection is artificial. With TEG®, readings are taken more frequently, so that values are obtained for rotation in both directions. Consequently, Figure 2 could be represented differently with TEG®; the curves above and below the x-axis would have equal weighting, and the y-axis scale could go downward to −50 and upward to +50. However, clot amplitude with TEG® (A) represents both positive and negative deflection, meaning that, in practice, TEG® clot amplitude values correspond to those of ROTEM® (although differences in cup size/geometry and in assay components mean that values are not directly comparable between the 2 devices).

### Parameters for Assessing Platelet Contribution to Clot Strength

**ROTEM®**

Results from 2 ROTEM® tests are used to guide platelet administration: EXTEM and FIBTEM. The EXTEM test provides a measure of clot strength with extrinsic activation of whole blood coagulation via tissue factor. Both

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**Table 2. Major Parameters Associated with Thrombelastography and Thromboelastometry**

| Coagulation property | TEG® parameter | ROTEM® parameter | Parameter used by Hartert |
|----------------------|----------------|------------------|--------------------------|
| Clot strength        | A (amplitude at any specific time) [mm] | A (amplitude at any specific time [A5, A10, etc. = amplitude at 5 min, 10 min, etc.] [mm]) | a or s (amplitude at any specific time) |
| Clot elasticity      | MA (maximum amplitude) [mm] | MCF (maximum clot firmness) [mm] | ma |
|                      | G (shear elastic modulus at any specific time) [dyne/cm²] | CE (clot elasticity at any specific time) [dimensionless] | G′ or ε (clot elasticity at any specific time) [dimensionless] |
|                      | E (normalized G parameter at any specific time) [dimensionless] | EMX (E at maximum amplitude) [dimensionless] | mε (maximum clot elasticity) [dimensionless] |

*The user manual for TEG® states that E and EMX have units dyne/cm², but it may be argued that these parameters should be considered as dimensionless.*

*G was used by Hartert to represent dimensionless clot elasticity, a departure from conventional use of G to represent shear elastic modulus.*
Calculating the Platelet Component with TEG® and ROTEM®

The platelet component is calculated from the elastic strength, meaning that EXTEM alone does not provide a specific measure of the platelet contribution to clot strength. The FIBTEM test is the same as EXTEM but with the addition of cytochalasin D to prevent platelets from contributing to the clot strength. By comparing results from the EXTEM and FIBTEM tests, a specific assessment of the contribution of platelets to clot strength (platelet component) can be obtained.

The platelet component is calculated from the elasticity results. First, CE (a dimensionless quantity) is obtained from clot amplitude (A) as shown in Table 1. MCE is calculated in the same way from maximum clot firmness (MCF) (Table 1). After such conversion, the platelet component can be calculated from EXTEM and FIBTEM results (Table 1). It is important that the calculation of platelet component be performed using elasticity (e.g., CE, MCE) as opposed to clot amplitude (e.g., A, MCF) because of the nonlinear relationship between clot amplitude and CE, MCE, as indicated in Figure 1 and Table 3. Unlike amplitude, CE may be considered a reflection of the force with which the blood clot resists rotation within the device. Where there is a nonlinear relationship between 2 variables X and Y, a specific increment of X (ΔX) will be associated with different increments of Y (ΔY), depending on the initial value of X. Therefore, an increment ΔX from baseline X cannot be considered as equivalent to the same increment ΔX from baseline X'. The European Society of Anaesthesiology guidelines for the management of perioperative bleeding highlight the fact that MCE and G have a curvilinear relationship with maximum amplitude (MA) and MCF. An illustration of the comparison between platelet component, correctly calculated from CE (in this case, EXTEM- and FIBTEM-MCE values) and incorrectly calculated from clot amplitude (MCF values), is presented in Table 3. This theoretical model shows that, across a range of platelet counts (from 10,000 to 100,000/μL), ΔMCF remains unchanged, whereas ΔMCE increases with platelet count. Therefore, it is clear that ΔMCF is not appropriate for calculating the platelet component.

In the literature, there are publications where the contribution of platelets to clot strength has been calculated appropriately (i.e., using CE; Table 4). However, as also shown in Table 4, there are numerous examples where unsuitable methodology has been used, with calculations based on clot amplitude. Where the overall conclusions of a publication are based on possible incorrect calculation of platelet component (i.e., where the subtraction is performed using values for clot amplitude as opposed to CE), the findings should be interpreted with caution until the calculations have been repeated using correct methodology.

**TEG®**

With the TEG® device, the standard kaolin-activated TEG® assay is most commonly used in relation to assessing the platelet contribution to clot strength. However, there is also a commercially available TEG® assay with platelet inhibition (Functional Fibrinogen assay), which is based on the same principle as FIBTEM. The platelet component of clot strength may be calculated by comparing elasticity results from the Functional Fibrinogen assay and from a standard assay without platelet inhibition. For example, the platelet component could be calculated as E (elasticity) obtained using the RapidTEG™ (Haemonetics Corp) assay minus E obtained using the Functional Fibrinogen assay, where E is a “normalized G parameter”, calculated in exactly the same way as Hartert’s shear modulus $\mu$ (Table 1). [Note that G is shear elastic modulus strength, with units dyne/cm² (Table 1)]. The parameter E may be considered as equivalent to the CE parameter of ROTEM®. The units of E are commonly referred to as dyne/cm². However, CE is considered dimensionless and, because E is calculated in the same way as CE, we would argue that E should also be considered dimensionless. A is the equivalent of the ROTEM® parameter A (clot amplitude, in mm). For maximum values, EMX

![Figure 1. Relationships of clot amplitude (e.g., A) with clot elasticity (e.g., E for TEG®, CE for ROTEM®) and shear modulus (G). Because a specific increment of clot amplitude is associated with different increments of clot elasticity or shear modulus, depending on the initial value of clot amplitude, the relationship between amplitude and elasticity or shear modulus is nonlinear. In A, the single curvilinear line can show relationships of clot amplitude with both G and clot elasticity as CE, we would argue that E should also be considered dimensionless. A is the equivalent of the ROTEM® parameter A (clot amplitude, in mm). For maximum values, EMX...](image-url)
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(E at maximum amplitude, equivalent to MCE) would be used instead of E, in which case MA would be used instead of A. As an illustration of the need to use CE, Chandler stated that an increase in thrombelastograph clot amplitude from 50 to 67 mm (34% increase) corresponds with a 2-fold increase in CE. Thus, the principles discussed earlier in relation to ROTEM apply to TEG in the same way. Although the platelet component of clot strength can be derived from E or EMX, its calculation from G values may also be considered. The calculation of G by using the constant “5000,” and subsequent interpretation of G as an absolute value for shear elastic modulus may be flawed, however, for the following reasons: First, the strain imparted by the TEG device is large enough to modify clot structure (i.e., the strain is too large for a linear viscoelastic response to be maintained). Second, the constant 5000 was derived from experiments reported by Hartert and Schaeder in 1962, and it is possible that differences in geometry or oscillation speed between today’s devices and that used by Hartert may mean that the value of 5000 should be redetermined experimentally using today’s devices. Until such experiments have been performed, using an elasticity parameter that does not rely on a constant (i.e., E) may, arguably, be considered preferable. Despite these considerations, as indicated earlier, G is mathematically a simple multiple of CE (E.g., $G = 50 \times E$). This means that the mathematical approach for calculating the platelet component from G would be the same as that with E. However, we are not aware of published reports where the platelet component, based on TEG data, has been correctly calculated and used to guide treatment for perioperative or trauma-related bleeding. As with ROTEM, calculation of the platelet component requires data from the EXTEM and FIBTEM assays. With TEG, the RapidTEG and Functional Fibrinogen assays could be used for this purpose; the procedure for calculating the platelet component would be the same. A = clot amplitude; CE = clot elasticity; EXTEM = ROTEM® extrinsically activated test; FIBTEM = ROTEM® test designed to assess fibrin-based clotting; MCE = maximum clot elasticity; MCF = maximum clot firmness.

(E at maximum amplitude, equivalent to MCE) would be used instead of E, in which case MA would be used instead of A. As an illustration of the need to use CE, Chandler stated that an increase in thrombelastograph clot amplitude from 50 to 67 mm (34% increase) corresponds with a 2-fold increase in CE. Thus, the principles discussed earlier in relation to ROTEM apply to TEG in the same way. Although the platelet component of clot strength can be derived from E or EMX, its calculation from G values may also be considered. The calculation of G by using the constant “5000,” and subsequent interpretation of G as an absolute value for shear elastic modulus may be flawed, however, for the following reasons: First, the strain imparted by the TEG device is large enough to modify clot structure (i.e., the strain is too large for a linear viscoelastic response to be maintained). Second, the constant 5000 was derived from experiments reported by Hartert and Schaeder in 1962, and it is possible that differences in geometry or oscillation speed between today’s devices and that used by Hartert may mean that the value of 5000 should be redetermined experimentally using today’s devices. Until such experiments have been performed, using an elasticity parameter that does not rely on a constant (i.e., E) may, arguably, be considered preferable. Despite these considerations, as indicated earlier, G is mathematically a simple multiple of CE (E.g., $G = 50 \times E$). This means that the mathematical approach for calculating the platelet component from G would be the same as that with E. However, we are not aware of published reports where the platelet component, based on TEG data, has been correctly calculated and used to guide treatment for perioperative or trauma-related bleeding. As with ROTEM, calculation of the platelet component requires data from the EXTEM and FIBTEM assays. With TEG, the RapidTEG and Functional Fibrinogen assays could be used for this purpose; the procedure for calculating the platelet component would be the same. A = clot amplitude; CE = clot elasticity; EXTEM = ROTEM® extrinsically activated test; FIBTEM = ROTEM® test designed to assess fibrin-based clotting; MCE = maximum clot elasticity; MCF = maximum clot firmness.

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Table 3. Theoretical Data to Illustrate the Difference Between the Platelet Component (Based On the Difference in MCE Between EXTEM and FIBTEM) and the Difference in MCF Between EXTEM and FIBTEM

| Platelet count (μL) | FIBTEM MCF (mm) | FIBTEM MCE | EXTEM MCF (mm) | EXTEM MCE | MCE contributors: fibrin, platelets | MCF contributors: fibrin, platelets | ΔMCF (EXTEM – FIBTEM) (platelet component) |
|---------------------|-----------------|------------|----------------|------------|-----------------------------------|------------------------------------|-------------------------------|
| 100,000             | 40              | 67         | 70             | 233        | 40.0%, 60.0%                       | 25.0%, 75.0%                       | 30                           |
| 50,000              | 20              | 25         | 50             | 100        | 40.0%, 60.0%                       | 25.0%, 75.0%                       | 30                           |
| 35,000              | 15              | 18         | 45             | 82         | 33.3%, 66.7%                       | 22.0%, 78.0%                       | 30                           |
| 30,000              | 10              | 11         | 40             | 67         | 25.0%, 75.0%                       | 16.4%, 83.6%                       | 30                           |
| 20,000              | 5               | 5          | 35             | 54         | 14.3%, 85.7%                       | 9.3%, 90.7%                        | 30                           |
| 10,000              | 0               | 0          | 30             | 43         | 0.0%, 100.0%                       | 0.0%, 100.0%                       | 30                           |

*MCE = (100 × MCF)/(100 − MCF).

EXTEM = ROTEM® extrinsically activated test; FIBTEM = ROTEM® test designed to assess fibrin-based clotting; MCE = maximum clot elasticity; MCF = maximum clot firmness.
### Table 4. Methods Used in the Literature for Calculating the Platelet Component

| Publication          | Device          | Method for calculating the platelet component | Term used                                      | Δ calculated? |
|----------------------|-----------------|-----------------------------------------------|-----------------------------------------------|---------------|
| Barua et al. 2010    | TEG             | GP = GWB − GF                                  | Contribution of platelet function to clot strength | Yes           |
|                     |                 | (GP = contribution of platelets to clot strength; GWB = whole blood clot strength; GF = clot strength with abciximab) |                                              |               |
| Cartwright et al. 2015 | ROTEM         | Platelet elasticity component = (EXTEM-MCE − FIBTEM-MCE) | Platelet elasticity component | Yes           |
| Chandler et al. 2001 | TEG            | Platelet-dependent clot strength = ESMtotal − ESMplatelet-independent | Platelet-dependent clot strength | Yes           |
|                     |                 | [ESM = elastic shear modulus = (5000 × AMP)/ (100 − AMP)] |                                              |               |
| Dekker et al. 2014   | ROTEM           | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet component/platelet contribution | No            |
| Djabir et al. 2013   | ROTEM           | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet component                           | Yes           |
| Haizinger et al. 2006 | roTEG or ROTEM  | Platelet component = EXTEM-MCE − FIBTEM-MCE   | Platelet component                           | Yes           |
| Kettner et al. 1999  | TEG             | ΔGMA = (5000 × standard MA)/(100 − standard MA) − (5000 × abciximab MA)/(100 − abciximab MA) | Platelet function/contribution of platelets to clot strength | No (not shown in figures/tables but correlation with platelet count is presented in Table 1) |
| Lang and von Depka 2006 | ROTEM         | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet component                           | Yes           |
| Lang et al. 2009     | ROTEM           | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet component                           | Yes           |
| Mahla et al. 2001    | roTEG           | Gp = Gt − Gc                                   | Contribution of platelets to G                | Yes           |
|                     |                 | [G = (5000 × MA)/(100−MA); Gp = contribution of platelets to G; Gt = total G; Gc = G attributable to soluble components of the coagulation pathway] |                                              |               |
| Nielsen et al. 2000  | TEG             | Gp (%) = (Gp − Gc)/Gc × 100                   | G caused by platelet function                 | Yes           |
|                     |                 | [G = (5000 × MA)/(100−MA); Gp = G caused by platelet function; Gc = total G; Gc = G caused by soluble components of coagulation] |                                              |               |
| Nielsen and Geary 2000 | TEG            | Gp = Gt − Gc                                  | Contribution of platelets to G                | Yes           |
|                     |                 | [G = (5000 × MA)/(100−MA); Gp = contribution of platelets to G; Gt = total G; Gc = G attributable to soluble components of the coagulation pathway] |                                              |               |
| Pérez-Ferrer et al. 2015 | ROTEM         | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet contribution to clot strength        | Yes           |
| Schöchl et al. 2012  | ROTEM           | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet component                           | Yes           |
| Solomon et al. 2013  | ROTEM           | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet component                           | Yes           |
| Solomon et al. 2013  | ROTEM           | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet component                           | No            |
| Torres et al. 2013   | ROTEM           | MCEplatelet = MCEEXTEM − MCEFIBTEM             | Platelet component                           | Yes           |

**Publications with inappropriate methodology for calculating the platelet component**

| Publication          | Device          | Method for calculating the platelet component | Term used                                      | Δ calculated? |
|----------------------|-----------------|-----------------------------------------------|-----------------------------------------------|---------------|
| Bontekoe et al. 2014 | TEG             | MA-PLTs = MA (CK test) − MA-fibrinogen (CFF test) | Contribution of platelets to MA               | Yes           |
| Cui et al. 2009     | TEG             | MAplatelet = MAEXTEM − MAfibrinogen           | Functional platelet component of clot strength | Yes           |
|                     |                 | [MA = absolute strength and elasticity of the clot; MAfibrinogen = contribution of functional fibrinogen to clot strength; MAplatelet = functional platelet component of clot strength] |                                              |               |
| Cui et al. 2010     | TEG             | MAplatelet = MAEXTEM − MAfibrinogen           | Functional platelet component of clot strength | Yes           |
|                     |                 | [MA = absolute strength and elasticity of the clot; MAfibrinogen = contribution of functional fibrinogen to clot strength; MAplatelet = functional platelet component of clot strength] |                                              |               |
| Faybik et al. 2006  | TEG             | MAfibrinogen = MAEXTEM − MAfibrinogen         | Contribution of platelets to clot firmness     | Yes           |
|                     |                 | [MA = contribution of platelets to clot firmness; MAfibrinogen = MA from standard TEG® assay; MAfibrinogen = MA from abciximab-modified TEG®] |                                              |               |
| García-Monteavaro et al. 1986 | TEG    | MAplatelet = MAIPP − MAAPP                  | Platelet thrombodynamic action                | Yes           |
| Godier et al. 2010   | ROTEM           | MCFplatelet = MCFEXTEM − MCFFIBTEM            | Platelet component                            | Yes           |

(Continued)
## Table 4. Continued

| Publication                      | Device  | Method for calculating the platelet component | Term used                                      | Δ calculated? |
|----------------------------------|---------|-----------------------------------------------|------------------------------------------------|---------------|
| Gottmukka et al. 1999            | TEG     | MA$_{\text{plt}}$ = MA$_{\text{whole blood}}$ – MA$_{\text{fib}}$  
                          |         | Contribution of platelets to clot strength    | Yes             |
| Greilich et al. 1997            | TEG     | MA$_{\text{abcixibam}}$ = MA$_{\text{abcixibam}}$ – MA$_{\text{whole blood}}$ | Platelet contribution to clot strength         | Yes           |
| Harnett et al. 2002             | TEG     | MA$_{\text{platelet}}$ = MA$_{\text{whole blood}}$ – MA$_{\text{fibrinogen}}$  
                          |         | Contribution of platelets to MA              | Yes             |
| Oswald et al. 2010              | ROTEM   | MCF$_{\text{platelet}}$ = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Monaca et al. 2014              | ROTEM   | MCF$_{\text{platelet}}$ = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Harnett et al. 2005             | TEG     | MA$_{\text{whole blood}}$ – MA$_{\text{abcixibam}}$ | Platelet function                             | Yes           |
| Reid et al. 1998                | TEG     | MA$_{\text{platelet}}$ = MA$_{\text{whole blood}}$ – MA$_{\text{fibrinogen}}$  
                          |         | Contribution of platelets to clot strength    | No              |
| Harnet et al. 2013              | TEG     | MA$_{\text{platelet}}$ = MA$_{\text{whole blood}}$ – MA$_{\text{fibrinogen}}$  
                          |         | Contribution of platelets to clot strength    | Yes             |
| Schramko et al. 2015            | ROTEM   | MCF$_{\text{platelet}}$ = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Niemi et al. 2006               | ROTEM   | MCF$_{\text{platelet}}$ = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Olde Engberink et al. 2014      | ROTEM   | MCF$_{\text{platelet}}$ = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Ostrowski et al. 2013           | TEG     | MA$_{\text{platelet}}$ = MA$_{\text{TEG}}$ – MA$_{\text{Fib}}$  
                          |         | Platelet contribution to clot strength        | Yes (in the text, MA$_{\text{TEG}}$ and MA$_{\text{Fib}}$ presented in Table 2) |
| Oswald et al. 2010              | ROTEM   | Platelet component = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Rahe-Meyer et al. 2010          | ROTEM   | Platelet component = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Reid et al. 1998                | TEG     | MA$_{\text{abcixibam}}$ = MA$_{\text{abcixibam}}$ – MA$_{\text{TEG}}$  
                          |         | Platelet component                            | Yes           |
| Schramko et al. 2009            | ROTEM   | Platelet component = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Schramko et al. 2015            | ROTEM   | MCF$_{\text{platelet}}$ = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet MCF                                   | Yes           |
| Sivula et al. 2009              | ROTEM   | MCF$_{\text{platelet}}$ = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |
| Tynngård et al. 2014            | ROTEM   | Platelet component = MCF$_{\text{EXTEM}}$ – MCF$_{\text{FIBTEM}}$ | Platelet component                            | Yes           |

AMP = amplitude; EXTEM = ROTEM$^*$ extrinsically activated test; FIBTEM = ROTEM$^*$ test designed to assess fibrin-based clotting; FF = TEG$^*$ Functional Fibrinogen test; MA = maximum amplitude; PLT = platelet; PPP = platelet-poor plasma; PRP = platelet-rich plasma; TEG$^*$ = TEG$^*$ kaolin-activated assay.
Calculating the Platelet Component with TEG® and ROTEM®

assay involves up to 4 cuvettes. The first assesses citrated blood as in the standard method to determine the strength of the fully activated clot. The second cuvette is heparinized and contains reptilase plus factor XIIIa to measure strength of the full fibrin clot in the absence of platelet activation. The third and fourth cuvettes, also heparinized, measure the effects of adenosine diphosphate (ADP) and arachidonic acid stimulation on platelet aggregation. The platelet mapping assay was designed to provide an insight into the inhibitory effects of clopidogrel and aspirin. Conceivably, it could be used to guide platelet administration in a perioperative setting for patients who are bleeding without having taken platelet-inhibiting drugs. However, the results are explorative for using the platelet component to guide the transfusion of platelets in the treatment of coagulopathic bleeding.

At present, the platelet component of blood clot strength is not commonly used as a direct basis for treatment decisions. Instead, low whole blood clot strength (extrinsic activation), in the presence of adequate fibrin-based clot strength, is the typical criterion for administering platelets. The European Society of Anaesthesiology guidelines for the management of perioperative bleeding state that “adequate TEG® Functional Fibrinogen test/FIBTEM clot strength in the presence of decreased overall clot strength in bleeding patients may indicate platelet deficiency,” although specific thresholds for administering platelets are not provided. In a ROTEM®-based coagulation management algorithm for cardiovascular surgery patients, platelets are administered if EXTEM A10 is ≤40 mm and FIBTEM A10 is >10 mm. That is, these ROTEM® parameters suggest reduced overall clot strength in the setting of an adequate fibrinogen contribution to the clot. In a similar treatment algorithm for trauma-related bleeding, it is recommended that platelets are transfused if EXTEM CA10 <40 mm when FIBTEM CA10 >12 mm. Few bleeding management algorithms based on TEG® results have been published. In one example, platelet transfusion was based only on MA, a parameter with limited sensitivity to platelets. In the future, it is possible that platelet component, calculated from the difference in CE between the whole blood clot and the fibrin-based blood clot, could be integrated as one of the standard parameters of ROTEM® and that it might be validated against clinical parameters. The platelet component could then be used directly as a basis for quantitative treatment decisions.

**Relationships Between Viscoelastic Coagulation Parameters and Platelet Count and Platelet Function**

Correlations between EXTEM clot amplitude or CE and platelet count have been reported. In a prospective study involving patients undergoing cardiac surgery, EXTEM A5 significantly correlated with platelet count (Pearson correlation = 0.74; P < 0.001). Analyses on platelet-rich plasma samples from healthy volunteers demonstrated a positive correlation between changes in MCE and platelet count (r² = 0.88; P < 0.001). In trauma patients, a statistically significant but weak correlation has been reported between ROTEM® platelet component (defined as MCEEXTEM − MCEFIBTEM) and platelet count (correlation coefficient = 0.44; P < 0.001). A more recent animal study also reported significant (P < 0.05) moderate correlation between these parameters. 

**Platelet Component and Bleeding Management**

The platelet component derived from ROTEM® and TEG® analysis provides a measurement of the contribution that platelets make to the strength of the whole blood clot. This is different from both platelet count and platelet function (measured by aggregometry). Nonetheless, there may be potential for using the platelet component to guide the transfusion of platelets in the treatment of coagulopathic bleeding.

In this review, we provide evidence that the platelet component of clot strength should be calculated using CE as opposed to clot amplitude parameters from TEG® or ROTEM® analysis. This is because CE, unlike clot amplitude, reflects the force with which the blood clot resists rotation within the device, and the relationship between clot amplitude and CE is nonlinear. The platelet component has the potential to provide valuable insight into the clinical importance of a minor contribution of platelets to CE in emergency bleeding and might therefore help to guide treatment with platelet concentrate. However, this is conditional on the platelet component being calculated correctly. Certainly, clinical validation studies are needed to refine the interpretation of TEG® and ROTEM® results for the management of clinical bleeding.

**CONCLUSIONS**

In this review, we provide evidence that the platelet component of clot strength should be calculated using CE as opposed to clot amplitude parameters from TEG® or ROTEM® analysis. This is because CE, unlike clot amplitude, reflects the force with which the blood clot resists rotation within the device, and the relationship between clot amplitude and CE is nonlinear. The platelet component has the potential to provide valuable insight into the clinical importance of a minor contribution of platelets to CE in emergency bleeding and might therefore help to guide treatment with platelet concentrate. However, this is conditional on the platelet component being calculated correctly. Certainly, clinical validation studies are needed to refine the interpretation of TEG® and ROTEM® results for the management of clinical bleeding.

**DISCLOSURES**

Name: Cristina Solomon, MD, MBA.

**Contribution:** This author helped design the study and wrote the manuscript.

**Attestation:** Cristina Solomon approved the final manuscript and attests to the integrity of the data presented. Cristina Solomon is the archival author.

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E 5. Solomon C, Rahe-Meyer N, Sørensen B. Fibrin formation

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2. Khurana S, Mattson JC, Westley S, O’Neill WW, Timmis GC,

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Name: Marco Ranucci, MD.

Contribution: This author helped prepare and critically revised the manuscript for important intellectual content.

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