The Hydraulic Permeability of Blood Clots as a Function of Fibrin and Platelet Density

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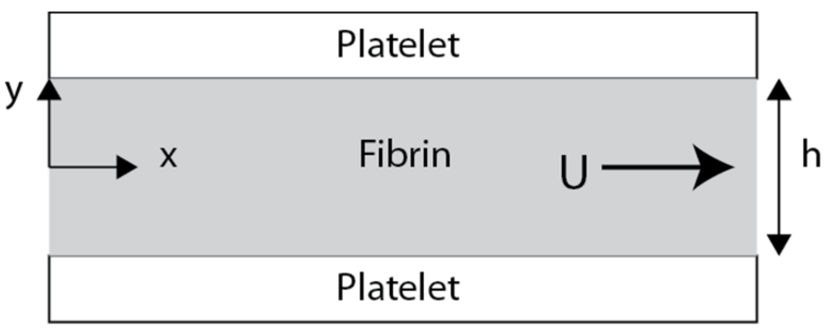
Supporting Material

Derivation of permeability between two platelet embedded in a fibrin mesh



This derivation is presented in Example 8.7 on p. 417 of Truskey et. al and is shown here in terms of the variables defined in the manuscript text [1]. Consider the case of two parallel plates separated by a distance *h* that represent two platelets with a fibrin gel between them depicted above. There is an interstitial flow of fluid with a viscosity μ and a mean velocity of U in the x-direction. The fibrin gel has a permeability k_f. The Brinkman equation for this problem reduces to:

$$\mu \frac{d^2 v_x}{dy^2} - \frac{\mu}{k_f} v_x - \frac{dP}{dx} = 0 \qquad \text{[S1]}$$

where v_x is the velocity in the x-direction and P is the pressure. Note that v_x is only a function of y and the pressure gradient is only a function of x. The boundary conditions are no-slip at the platelet surface and symmetry at the midline:

$$v_x = 0 \quad at \quad y = h/2$$
$$\frac{dv_x}{dy} = 0 \quad at \quad y = 0 \qquad [S2]$$

The solution to Eq. S1 for these boundary conditions is:

$$v_x = -\frac{k_f}{\mu}\frac{dP}{dx}\left[1 - \frac{\cosh\left(y/\sqrt{k_f}\right)}{\cosh\left(h/2\sqrt{k_f}\right)}\right] \qquad [S3]$$

The mean velocity can be calculated by:

$$U = \frac{1}{h}\int_{-h/2}^{h/2} v_x\, dy = -\frac{k_f}{\mu}\frac{dP}{dx}\left[1 - \frac{2\sqrt{k_f}}{h}\tanh\left(\frac{h}{2\sqrt{k_f}}\right)\right] \qquad [S4]$$

Finally, the total permeability between the two plates is defined by the ratio of the mean velocity and the pressure gradient ($k_t = \mu U/(dP/dx)$):

$$k_t = k_f\left[1 - \frac{2\sqrt{k_f}}{h}\tanh\left(\frac{h}{2\sqrt{k_f}}\right)\right] \qquad [S5]$$

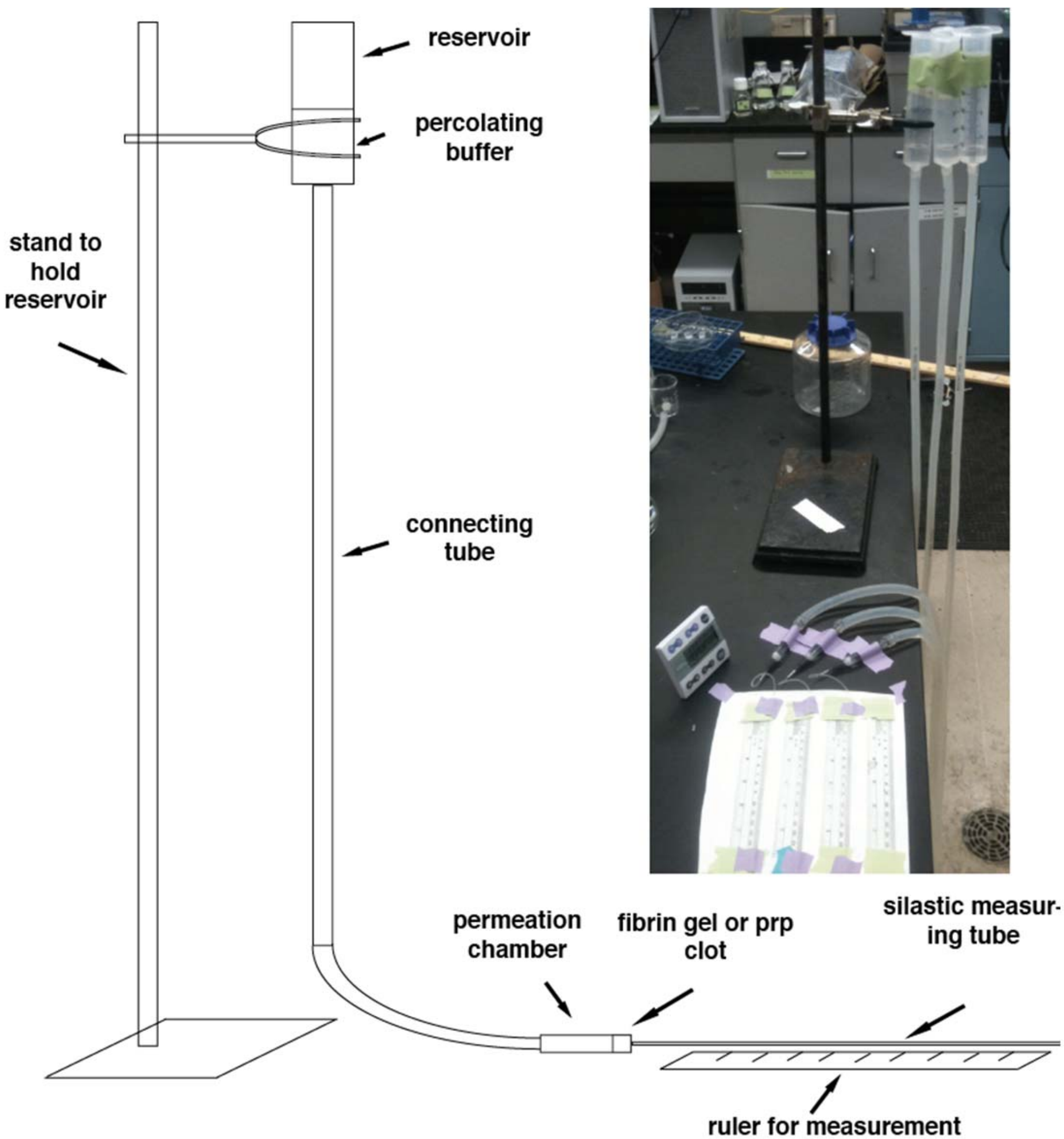


Figure S1. Experimental set-up for measuring clot permeability. A reservoir containing TBS supported by a ring stand and clamp was connected to the top of the permeation chamber via an 8 mm ID Tygon® connecting tube. 0.76 mm ID silastic tubing was connected to the bottom of the chamber via a blunt 16 gauge needle. The volumetric flow rate of buffer through the fibrin gel or platelet rich clot was calculated by measuring the displacement of the air-buffer interface in the tubing at regular time intervals. (Insert) Image showing permeability measurements of 156 mg/ml fibrin gels.

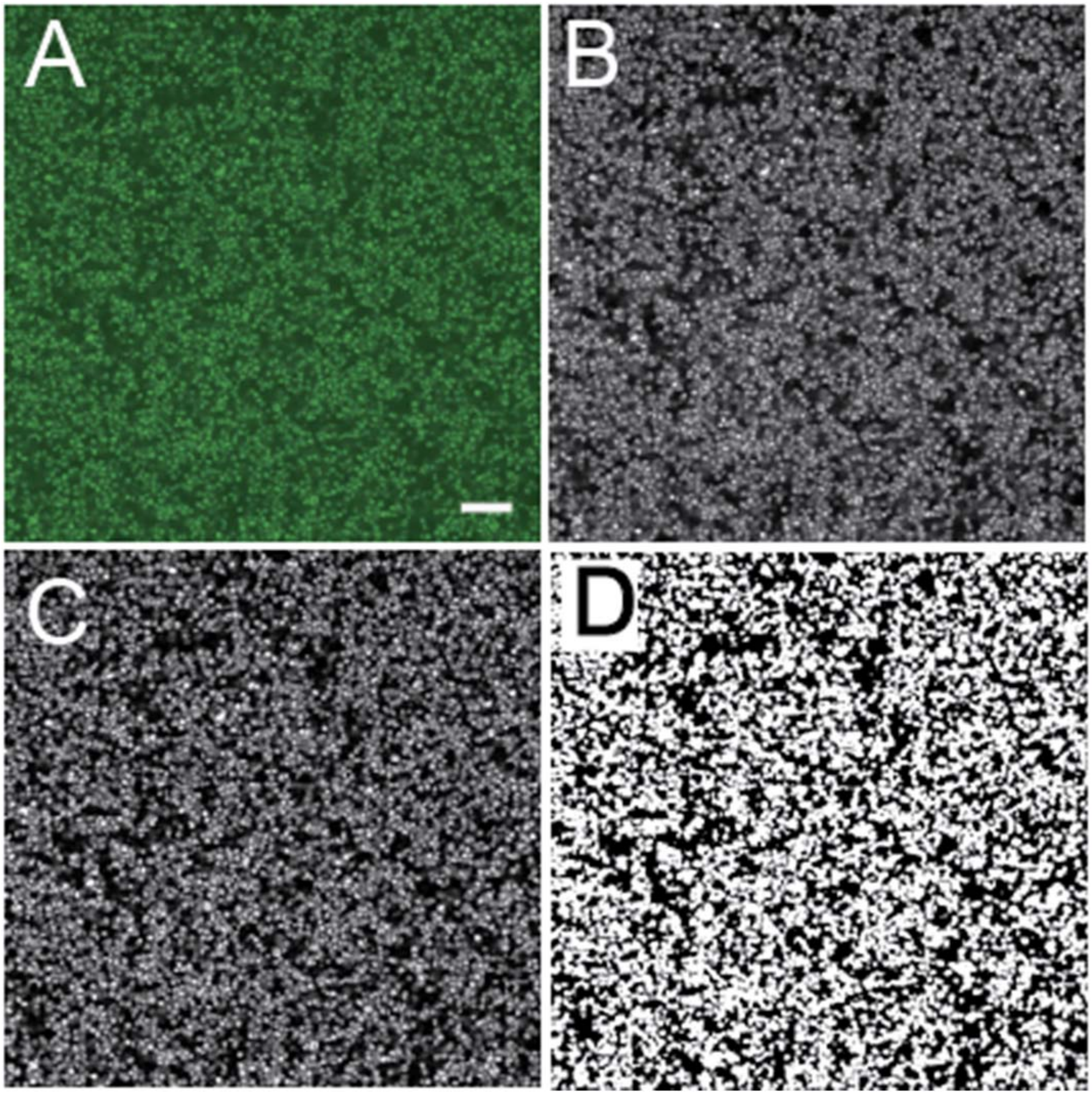


Figure S2. Image analysis for obtaining measured platelet area fractions. (A) Original 600x magnified confocal image showing only the platelets (green) of a PRC at a density of 4×10^7 platelet/μL. Scale bar = 20 μm. (B) Original image converted to 8-bit grayscale with ImageJ software. (C) Greyscale image after subtraction of the background using the Sternberg rolling ball method with a rolling ball radius of 10 μm. (D) Final image after thresholding with a threshold value of 5. Area fraction of platelets = 0.45.

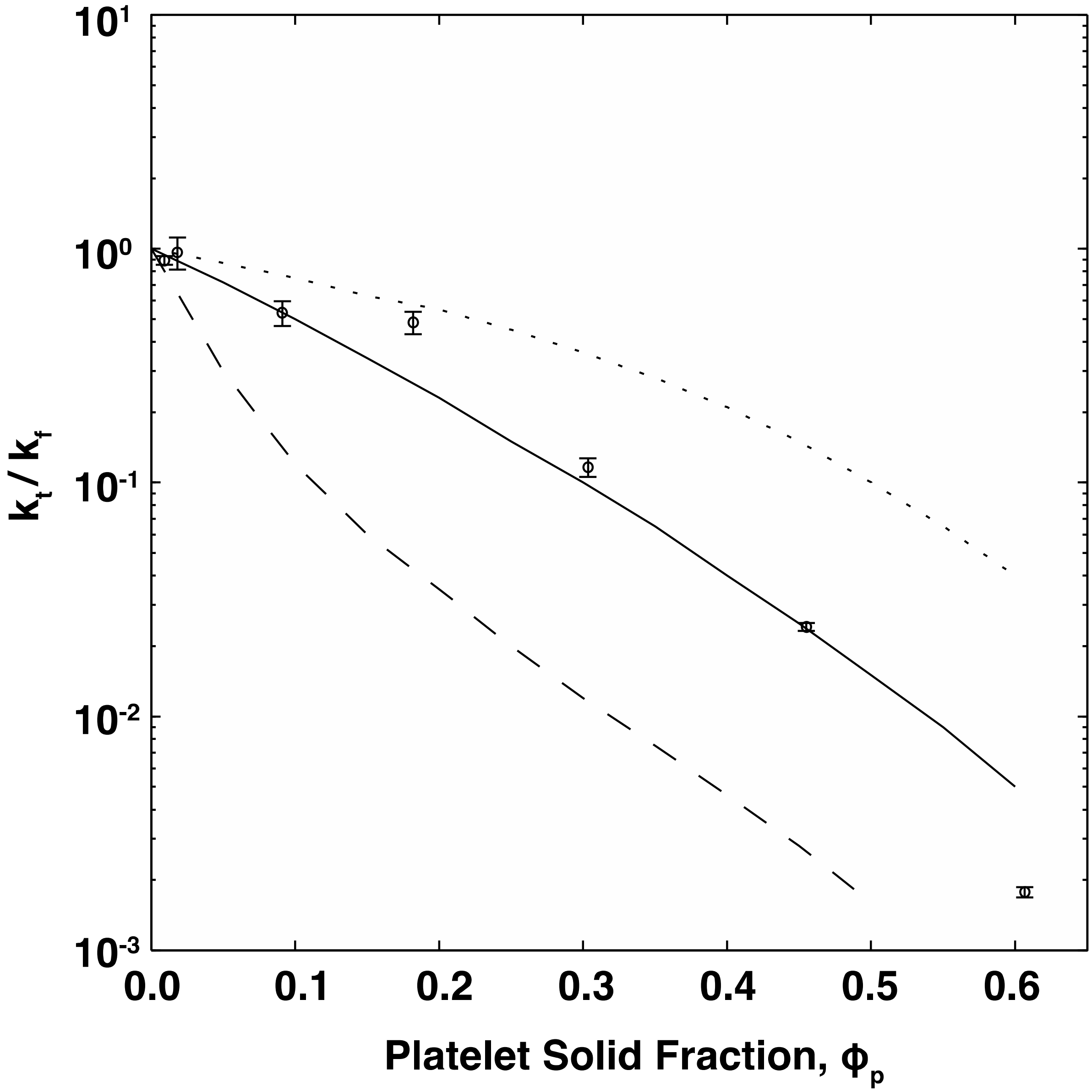


Figure S3. Solutions for the normalized permeability of the Brinkman equation from Ethier [2]**.** The total permeability, k_t, is normalized by the permeability of the fine fraction, k_f. In our case, the fine fraction refers to the fibrin. Each line represents a different ratio between the fine fraction permeability and the square of the radius of the coarse objects (k_f/a_{coarse}^2): 10 (− −), 1 (—), and 0.1 (···). The measured permeability (O) best fits the solution for $k_f/a_{coarse}^2 = 1$.

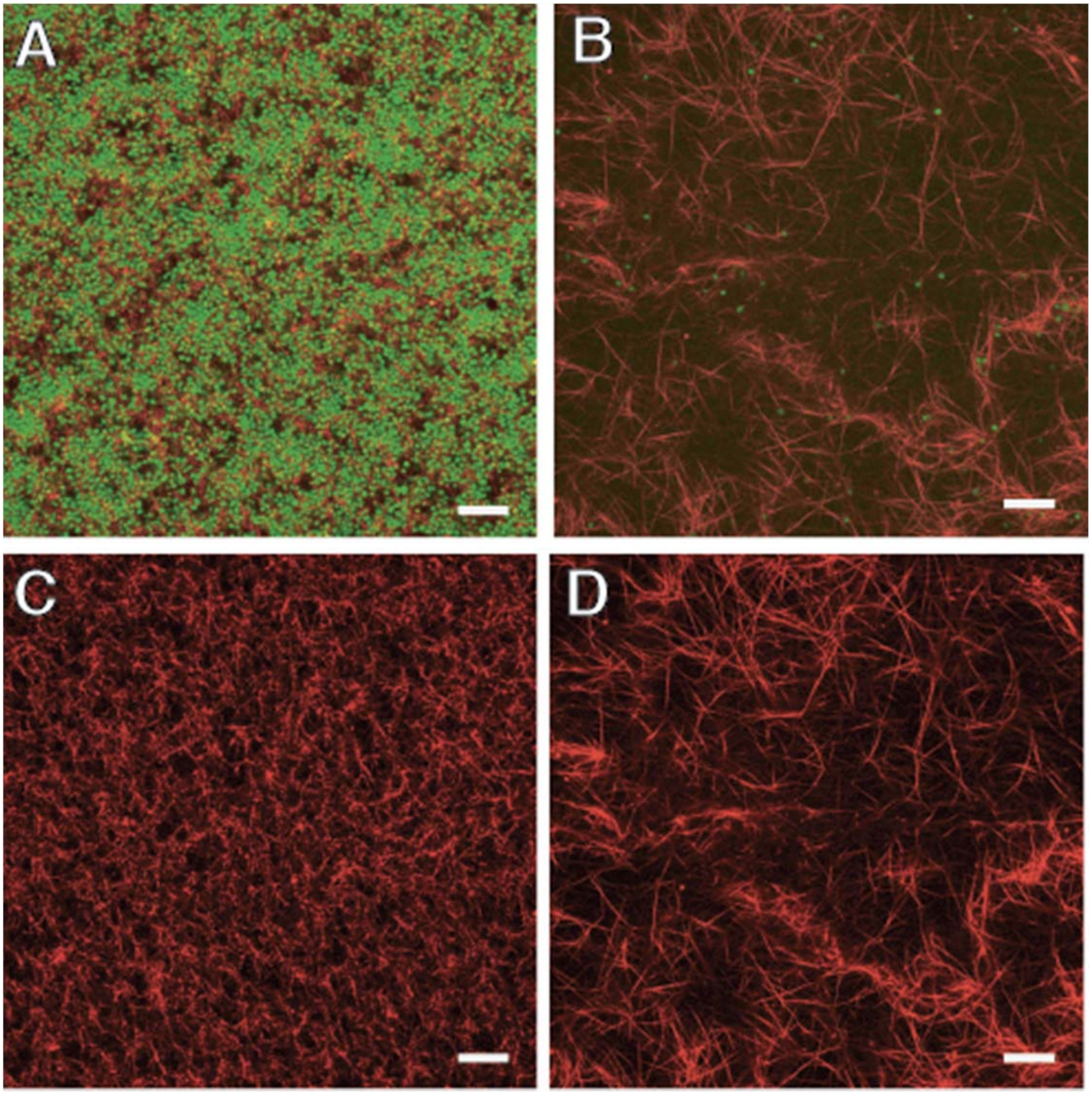


Figure S4. The effect of platelets on fibrin fiber morphology. The presence of platelet (A, C) leads to shorter fibrin fibers compared to platelet poor plasma (B, D). The volume fraction of platelets (A) is 0.61. Platelets are labeled green and fibrin(ogen) is labeled red. Scale bar = 20 μm

Supporting References

1. Truskey GA, Yuan F, Katz DF. Transport Phenomena in Biological Systems. 2nd ed. Prentice Hall; 2009.

2. Ethier CR. Flow Through Mixed Fibrous Porous Materials. AIChE J. 1991;37(8):1227–36.