Response to letter: How much will a catheter tip expand in aspiration thrombectomy?

We thank Liu and Kallmes for their interest and valuable observations, which might help to improve the understanding of our study.[1]

Our findings show, in all catheters, an increased aspiration effective force as compared with the expected theoretical force corresponding to the labeled catheter diameter.[2] This is an objective and evidenced finding.

We agree with Liu and Kallmes that the reasons for these differences are probably basically due to two different factors:

- Catheter tip distensibility
- Clot–catheter friction.

The proportional impact of each factor might certainly be discussed. Both causes are also correlated, because a higher distensibility leads to a larger clot–catheter interaction surface. In our study, after adjusting for tip distensibility, an almost straight correlation is found between the measured force and the effective inner diameter (ID) for all catheters. This is very revealing and hard to believe that it is a coincidence if friction forces exert a higher effect.

Liu and Kallmes point out several flaws that might have been committed in our experiments but should also be aware that:

- Our experiments were carried out under specific temperature conditions that might favor catheter tip distensibility as compared with other conditions in which Liu and Kallmes experiments seem to be performed.
- We wonder whether our clot analogs, despite having the same dimensions and materials, might have a different degree of curing and therefore be considerably stiffer. This is an important feature since clot compressibility might dramatically influence the observed catheter distensibility.
- Liu and Kallmes state that clots are prone to deforming when interacting with catheters with distal marker bands. However, we mentioned in our article that the most distensible part is the distal tip above the radiopaque band, comprising the catheter liner and outer jacket layers.

Considering the mentioned points and to be more accurate in our assumptions, we performed some additional experiments to confirm that the 15–25% of the increase in catheter tip ID (ΔID), calculated from the cone's geometrical equation, was mainly due to tip expansion. First, we 3D-printed several cylinders of 5×5 mm (diameter x height) with Elastic 50A resin and postprocessed the samples following the same steps as for the clot analog: we washed them in isopropyl alcohol for 10 min and postcured them at 60°C for 20 min. Next, we performed strain-controlled compression tests on these cylindrical samples (n=3) at room temperature. Tests were programmed to cause a maximum deformation of 20% to target values in the range of ΔID. The slopes of the stress–strain curves obtained from the experiments determined the intrinsic stiffness of the material used as clot analog: 5.27±0.14 MPa. Then, we conducted the same compression tests (n=3) directly on the React 68's tip to find its stiffness: 1.97±0.28 MPa. That means that the stiffness of the clot analog is 2.67-fold (or 267 %) higher than that of the tip. Additionally, the force required to cause a 19.15% strain on this catheter's tip was 409.60±39.78 mN, in line with the results presented in our article. Hence, we concluded that due to the differences in stiffness between both interacting parts and the match between the applied forces and the strains, the interaction between our clot and the catheter tip is a combination of major tip distension and minor, if any, clot contraction.

The objective of our study was to demonstrate that the catheter tip distensibility plays a major role in clot–catheter interaction, and while it is certain that the friction force is not residual, our estimation of effective ID still remains valid for the total measured force.

Finally, in consideration of the tip stiffness of commercially available aspiration catheters, most physiological clots, especially those considered soft or moderately stiff, will contract to be aspirated when interacting with the catheter tips. However, there are cases where large clots as stiff as the catheter tip cannot be completely ingested. Therefore, there is a need to consider the biomechanics of the target clot to adapt the device's tip distensibility in the development of novel aspiration catheters and optimize the efficiency of a direct aspiration first pass technique for this situation.

In closing, we thank Liu and Kallmes for their attention to our study and concur with the importance of inspiring the community to better understand the differences in thrombectomy device features in order to improve future developments and procedure outcomes. We invite Liu and Kallmes to contact us directly and will be pleased to make in situ demonstrations when the health situation makes it possible. That would allow sharing of information and experimental conditions, enabling us to reach common conclusions after fruitful discussions.

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