Site-Specific Intimal Wall Forces During Guide and Stent Catheter Navigation

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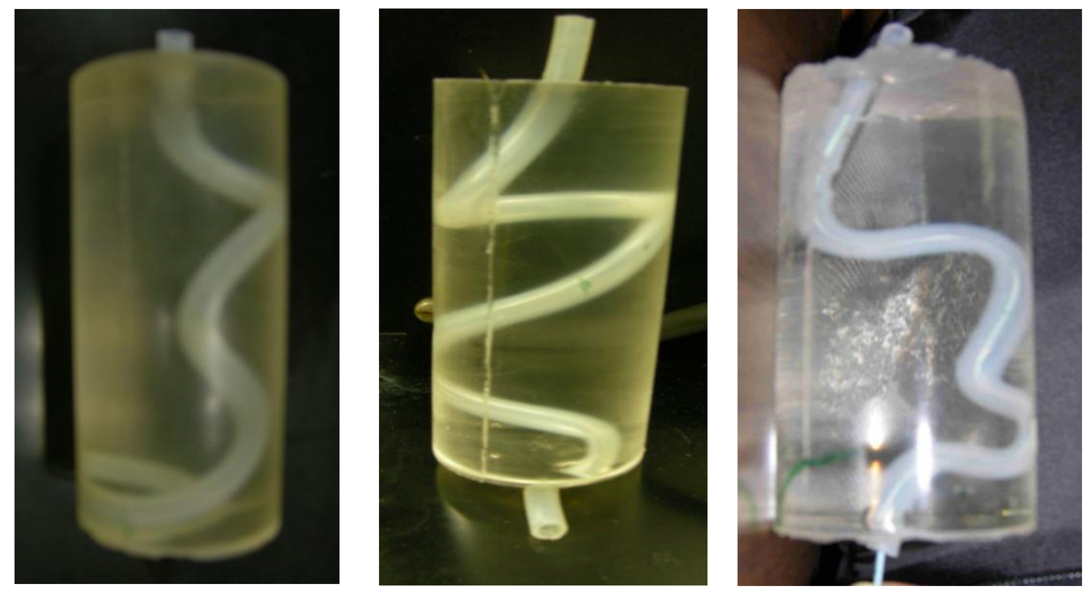
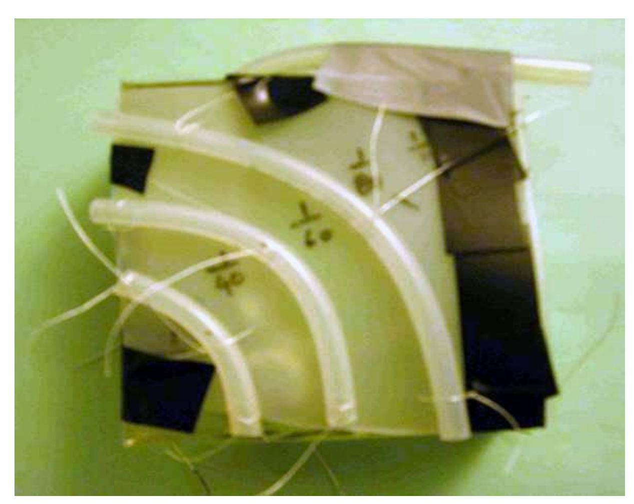
Background

Insertion and navigation of guidewires, guide catheters and stent catheters into blood vessels must be modulated to limit tissue damage and displacement of plaque deposits. In tortuous vasculature leading to sites of cerebral aneurysms, it is especially important to identify vessel locations, geometric features, and ranges of maximum and minimum forces associated with catheter advance and retreat. **The purpose of this work was to determine the variable tip and normal forces as guide and stent catheters were navigated through curvilinear blood vessel phantoms, as well as over preserved blood vessel surfaces.** The resulting data can be used to calibrate haptic training devices, to limit excessive force application during subsequent clinical procedures.



3-D phantoms used in the experiments

The phantom on the right was designed to mimic a human carotid siphon, as reconstructed from CT images of a patient



2-D phantoms, each with a different radius of curvature

Materials

Guidewires, Guide Catheters, Stent Catheters: from collection of clinically used devices, Toshiba Stroke Research Center[1]

Blood Vessel Phantoms: 6 different silicone (Sylgard) devices; **2-D** (curved in one plane, only, 3.2mm I.D., with radius of curvature varying from 1 in 20mm to 1 in 60mm) and **3-D** (tortuous, 3.2-4.6mm I.D.; one 3-D phantom mimicked the path of an actual human carotid siphon, as reconstructed from CT images); custom-designed and constructed by the Toshiba Stroke Research Center[1] – *lubricated with soapy water to ease insertion of steel guide wire through phantom*

Blood Vessels: preserved human umbilical vein grafts with known, blood-compatible surface properties[2,3] ; inserted in large-diameter phantom – *saline-lubricated during friction experiments*

Methods

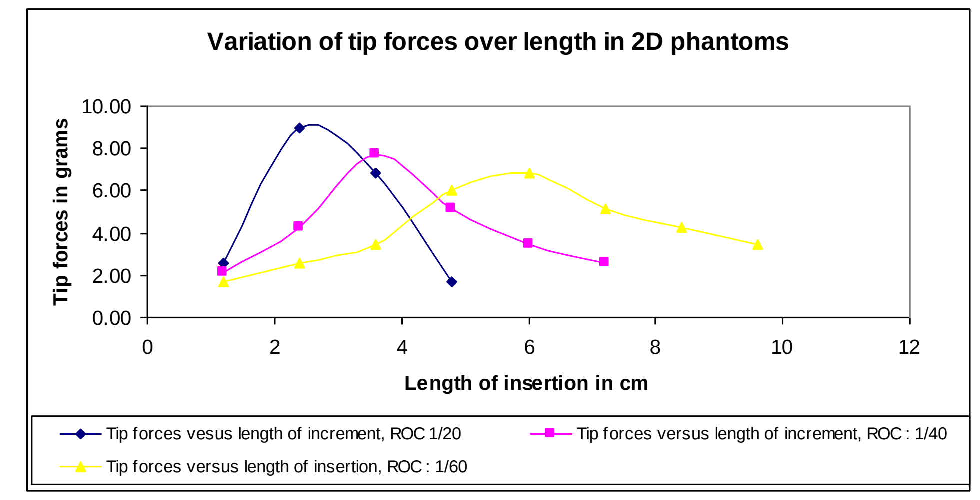
Frictional forces of catheters were monitored during simulated endovascular insertions.

- phantom or blood vessel (in phantom): in fixed position away from reciprocating stage
- guidewire pre-inserted in phantom
- catheter: fixed to strain gauge linkage, and moved via contact with reciprocating stage (1Hz, 1.2cm translation)
- strain gauge calibrated; 5g frictional force determined for free catheter (no insertion)
- catheter inserted a specific distance into phantom (or blood vessel) → forces during reciprocation recorded → reciprocation stopped to advance catheter 1.2cm into the phantom (or blood vessel) → forces during reciprocation measured at new location → repeated for up to 24 locations (up to 28.8 cm total insertion length); fewer measurements were made in the 2-D phantoms
- 3 replicate experiments for each condition

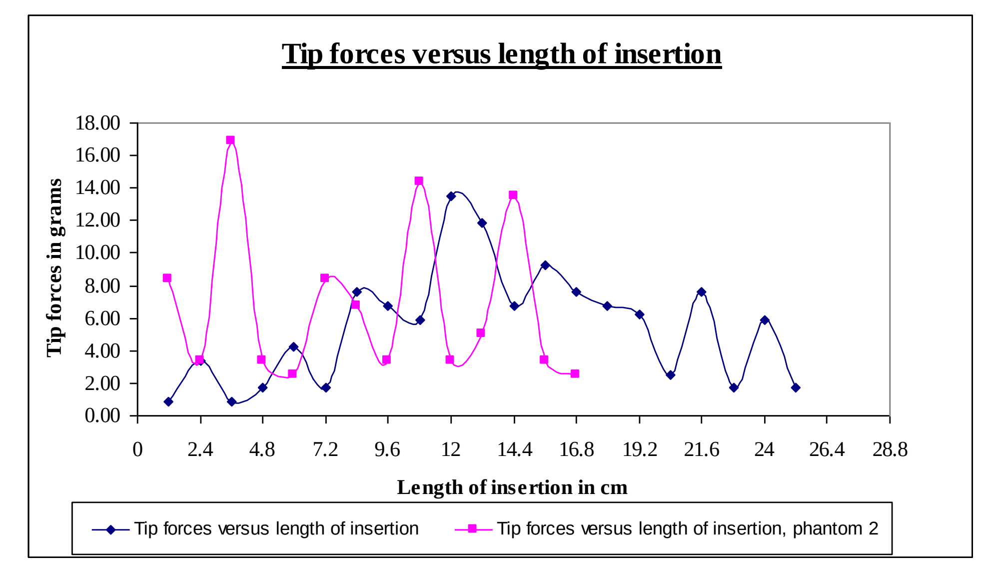
References

1. Sengupta et al. (2007) Int J Computer-Assisted Radiol Surg 2:138-145. **2.** Baier et al. (1980) Vasc Surg 14:145-157. **3.** Dardik et al. (2002) J Vasc Surg 35:64-71. **4.** Fry (1968) Circulation Res 22:165-197.

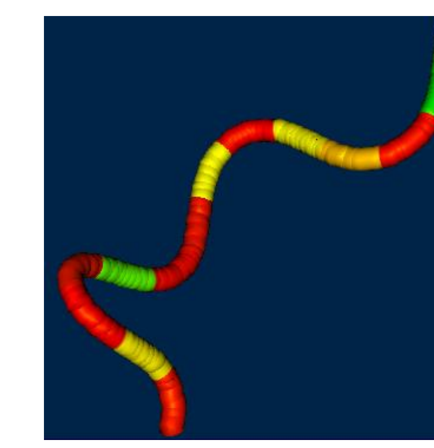
Results

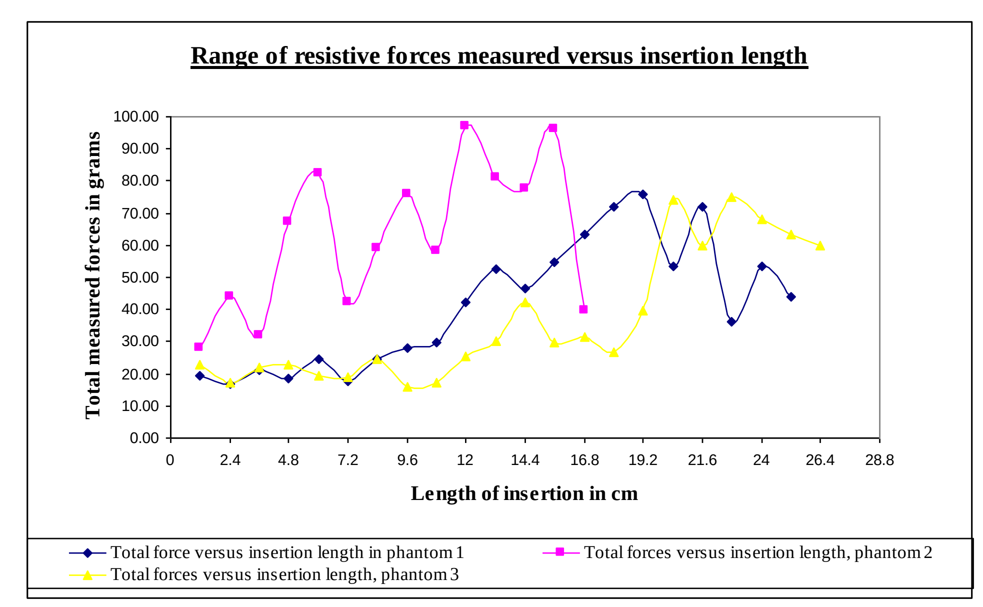


2-D phantoms: Catheter tip forces decreased with decreasing curvature. Forces were greatest at the central locations of 2-D phantoms.



3-D phantoms: Catheter tip forces varied from approximately 1 to 17g, peaking at the highly curved sections of the phantoms.





3-D phantoms: total frictional forces varied from 10 to 100g, implicating normal wall forces of approx. 20-200g applied from the bending and tip contact points of the advanced catheter segments. Lower resistive forces were noted as curved segments were occupied by the catheter length behind the tip.

Frictional forces were lower in the preserved vein graft (first inserted into a 3-D phantom path), suggesting that wall compliance should be accounted for, in addition to coefficient of friction.

Conclusions

- **Location-dependent tip and catheter frictional forces can be identified in surrogates for the tortuous vasculature negotiated during endovascular procedures.** *This conclusion is based on measured similarities between the coefficients of friction of catheters in contact with saline-lubricated preserved blood vessels, and in contact with soapy-water-lubricated silicone phantoms [coefficients = 0.3 to 0.5].*
- **The average resistive frictional forces during advance of catheters through the phantoms in this study were in excess of forces shown by others to produce endothelial damage.** *This conclusion is based on measured maximum forces of nearly 100g, much larger than forces reported by Fry (1968) to damage endothelium.[4]*

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