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

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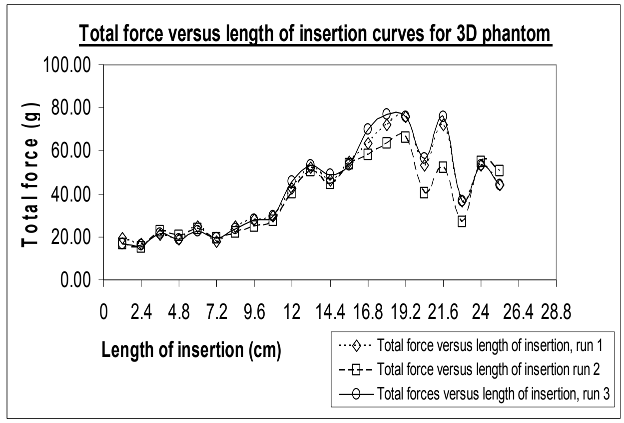
Statement of Purpose: Insertion and navigation of guidewires, guide catheters and stent catheters into blood vessels must be modulated to limit tissue damage and displacement of plaque deposits. Especially in tortuous vasculature leading to sites of cerebral aneurysms, it is important to identify vessel locations, geometric features and ranges of maximum and minimum forces associated with catheter advance and retreat. The purpose of this work was to employ a modified reciprocating friction device to monitor the variable tip and normal forces experienced as guide and stent catheters were navigated through curvilinear blood vessel phantoms and over preserved blood vessel surfaces. These data can calibrate haptic training devices to limit excessive force application during subsequent clinical procedures.

Methods: Clinically utilized guidewires, guide catheters, and stent catheters were selected from studies at the Toshiba Stroke Research Center of SUNY Buffalo (1), and their frictional forces monitored in triplicate during simulated endovascular insertions using 1Hz, 12mm reciprocating contact motions against saline-lubricated lumenal walls of vein grafts for arterial reconstruction (2,3) and 6 different soap-water-lubricated silicone phantoms of tortuous blood vessel paths, coupled to a device previously applied to measure "blinking" friction in tissue-tissue articulations (4). One phantom mimicked the path of an actual human carotid siphon, as reconstructed from CT images, and in all phantoms the catheters were advanced over pre-inserted guidewires in repeatable paths documented by rotational angiography. Three phantoms were curved in only one plane, and three others were tortuous in 3 dimensions. In one 3-D phantom, results were also obtained when an arterial graft was first inserted into the tortuous path before catheter testing.

Results: Coefficient of Friction (CoF) measurements determined for 4 different guide catheters against the lumenal walls of saline-lubricated arterial grafts gave values between 0.3 and 0.5 over a range of normal forces from 30 grams to 300 grams. Measurements for these same catheters contacting the inner walls of the soap-water-lubricated silicone phantom tubing gave CoF values from 0.2-0.4. Stent catheter (Guidant Multi-Link Rx Penta Coronary Stent System) tests yielded average CoF values of 0.37 against saline-lubricated arterial graft lumenal walls and 0.34 against soap-water-lubricated silicone phantom tubing inner walls. Negotiation of the various guide and stent catheters through 2-dimensional silicone phantoms, with radius of curvature varying from 1 in 20mm to 1 in 60mm, showed frictional forces to systematically increase with increase of curvature, peaking at the central locations of the curved segments and lowest at the entrance and exit sites. Negotiation of catheters through the 3-D tortuous phantoms, in reciprocating 12 mm increments from entrance to exit, produced frictional force increases as highly curved segments were entered and significantly lower resistive forces as curved segments were occupied by the catheter body distal to the tip, as shown in the following Figure.



Frictional forces varied from 10 -100 grams over the traverse lengths of the silicone phantoms, implicating normal wall forces of about 20-200 grams applied from the bending and tip contact points of the advanced catheter segments. Frictional forces were lower in an arterial graft first inserted into the tortuous silicone phantom path, suggesting that wall compliance should be accounted for in addition to CoF. Tip forces always remained below 10 grams. Frictional force showed highest values at sites of highest tortuosity and adjacent to points of initial guide wire contact with the vessels' interior walls.

Conclusions: Coefficient of Friction measurements established sufficient similarity between articulating contacts of guide and stent catheters with the interior walls of saline-lubricated preserved blood vessels (arterial grafts) and soap-water-lubricated silicone phantoms to employ the phantoms as reasonable surrogates for the tortuous vasculature that must be negotiated during endovascular procedures. Measurements of the resistive frictional forces as these catheters were advanced through the phantom 3-D convolutions showed maximum values approaching 100 grams at the entrances to regions of maximum curvature, with relief of those forces after catheter tip exit from the curved zones. The average forces are in substantial excess of those shown earlier to produce endothelial damage (5).

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Acknowledgment: NIH Grant # R01-EB 02916