Tortuous Iliac Systems—A Significant Burden to Conventional Cannulation in the Visceral Segment: Is There a Role for Robotic Catheter Technology?

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ABSTRACT

Purpose: To attempt to quantify the effect of varying degrees of iliac tortuosity on maneuverability and "torquability" of endovascular catheters in the visceral segment, comparing conventional and robotic cannulation techniques.

Materials and Methods: In a fenestrated endograft within a pulsatile phantom, 10 experienced operators cannulated the renal arteries via three different access vessels of varying iliac tortuosity with the use of conventional and robotic techniques. All procedures were performed in the angiography suite and recorded for blinded video assessment for quantitative (time, catheter-tip movements) and qualitative metrics (operator performance scores).

Results: In total, 120 cannulations were observed. With increasing iliac tortuosity, median time and number of catheter movements required for renal cannulation with conventional techniques increased in stepwise fashion for mild, moderate, and severe iliac tortuosity (times, 7.6 min [interquartile range (IQR), 4.6–9.3 min] vs 6.9 min [4.2–11.4 min] vs 17.7 min [13.3–22.6 min], respectively; movements, 184 [IQR, 110–351] vs 251 [207–395] vs 569 [409–616], respectively). Median renal cannulation times were significantly reduced with the use of the robotic system irrespective of mild, moderate, or severe tortuosity (times, 1.4 min [IQR, 1.1–1.9 min] vs 3 min [2.3–3.3 min] vs 2.8 min [1.5–3.9 min], respectively; movements, 19 [IQR, 14–27] vs 46 [43–58] vs 45 [40–66], respectively; $P < .005$). Overall operator performance scores improved significantly with the use of the robotic system irrespective of iliac tortuosity severity.

Conclusions: In cases of moderate to severe iliac tortuosity, conventional catheter manipulation and control becomes an issue. The improvement in positional control and predictability seen with advanced catheter designs may be amplified in cases of severe iliac tortuosity.

ABBREVIATIONS

EIA = external iliac artery, IC3ST = Imperial College Complex Endovascular Cannulation Scoring Tool, IQR = interquartile range, L1 = central luminal distance from aortic bifurcation to iliac bifurcation, L2 = straight-line distance from aortic bifurcation to iliac bifurcation, τ = iliac tortuosity index

The presence of hostile iliac anatomy is a challenge to successful endovascular intervention in the aorta and its branches. Adequate iliofemoral access, endograft delivery, and successful branch cannulation and stent placement are all influenced by aortic and iliac tortuosity.

Many of the problems associated with access and endograft delivery that previously rendered some patients with tortuous iliac anatomy unsuitable for endovascular intervention (1,2) because of the high risk of hemorrhage, rupture, and dissection (3–5) have been tackled by the development of smaller and more flexible delivery systems. However, in complex endovascular procedures such as fenestrated and branched endografting, unfavorable iliac anatomy can impact significantly on the performance of the conventional endovascular catheters used for selective catheterization as an independent variable (6–10). Both these factors may subsequently compromise successful and safe target vessel cannulation.

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This study aims to quantify the effect of varying degrees of iliac tortuosity on the ability to maneuver and apply torque to endovascular catheters during target vessel cannulation in the visceral segment in fenestrated endografting, and examines the advantages of robotic cannulation techniques.

MATERIALS AND METHODS

Robotic System

The robotically steerable catheter system used in the present study (Hansen, Mountain View, California) consists of a workstation with an instinctive motion controller, which is a three-dimensional hand-operated joystick that enables the operator to remain seated and away from the radiation source. This intuitive catheter system can replicate the hand movement of the operator, delivering control in three dimensions with seven degrees of freedom. The remote catheter manipulator by the angiographic table delivers the robotic catheter and receives position commands from the instinctive motion controller to control the catheter's pull wires, ultimately determining the position of the catheter tip in a master/slave fashion. The robotic catheter itself comprises a multidirectional inner guide (11-F outer diameter, 8.5-F inner diameter) within a unidirectional outer 14-F guide (inner, 11 F), with full rotational ability and a workspace defined by a bend of as much as 270° and a 10-cm extension.

Aortic Model

A silicone-based, transparent, computed tomography (CT)–reconstructed anthropomorphic phantom representing a thoracoabdominal aortic aneurysm was used (Elastrat Sàrl, Geneva, Switzerland). The aorta was dilated throughout its length (5.2-cm visceral segment diameter), with marked aneurysmal dilation of the infrarenal segment (8.1-cm maximum diameter). A four-vessel fenestrated stent-graft was constructed from a standard thoracic graft (42 mm × 10 mm; Medtronic, Santa Rosa, California). The fenestration dimensions for the renal arteries were 12 mm for the right renal artery and 8 mm for the left renal artery. The endograft was deployed in fixed suspension via strings to simulate the partial deployment of a custom-made fenestrated stent-graft. The strings were adjusted before each procedure to prevent misalignment. The phantom was filled with a blood-mimicking water/glycerol mixture (60:40 by volume concentration) and circulated by using a pulsatile blood pump, providing physiologically realistic blood-flow waveforms.

Tortuosity Index

To assess the effect of varying degrees of iliac tortuosity on the performance of conventional versus robotic endovascular cannulation of the renal arteries, three access vessels on the pulsatile phantom were chosen: the right external iliac artery (EIA), the left EIA, and the left internal iliac artery. For each access vessel, the central luminal distance from the aortic bifurcation to the iliac bifurcation (ie, L1) and the straight-line distance from the aortic bifurcation to the iliac bifurcation (ie, L2) measured in a plane perpendicular to the central lumen line were calculated from volume-rendered CT reconstructions of the phantom. The iliac tortuosity index (τ) was calculated as the ratio of L1 to L2 (Fig 1).

The value of τ was scored as shown in Table 1 based on consensus reporting criteria (2,11,12); the corresponding values for the iliac angle are also shown. The access vessel measurements are summarized in Table 2.

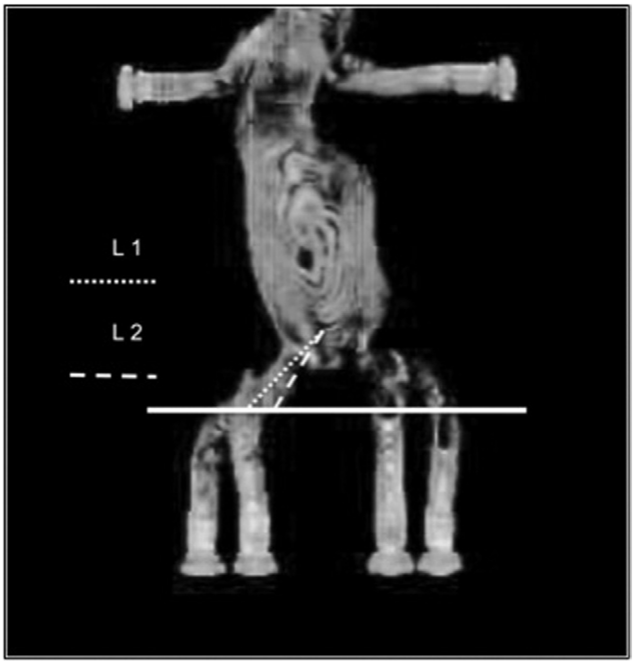

Figure 1. The aortic phantom and calculation of τ. For each access vessel within the phantom, L1 and L2, measured in a plane perpendicular to the central lumen line, were calculated from volume-rendered CT reconstructions of the phantom. The L1/L2 ratio was used to calculate τ, as shown here for the right EIA.

Table 1. Iliac Tortuosity Index Scoring

Score	Description	Iliac Tortuosity Index (τ)	Iliac Angle (φ)
0	Absent	$\tau \leq 1.25$	$160° < \varphi < 180°$
1	Mild	$1.25 < \tau \leq 1.5$	$121° < \varphi < 159°$
2	Moderate	$1.5 < \tau \leq 1.6$	$90° < \varphi < 120°$
3	Severe	$\tau \geq 1.6$	$\varphi < 90°$

Study Protocol

Ten experienced operators (five vascular surgeons and five interventional radiologists, all with significant experience with fenestrated stent-grafting and all of whom had served as lead operator for more than 200 cases) were recruited to