Morphometric analysis of torso arterial anatomy with implications for resuscitative aortic occlusion

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BACKGROUND: Hemorrhage is a leading cause of death in military and civilian trauma. Despite the importance of the aorta as a site of hemorrhage control and resuscitative occlusion, detailed knowledge of its morphometry is lacking. The objective of this study was to characterize aortic morphometry in a trauma population, including quantification of distances as well as diameters and definition of relevant aortic zones.

METHODS: Center line measures were made (Volume Viewer) from contrast computed tomography (CT) scans of male trauma patients (18–45 years). Aortic zones were defined based on branch arteries. Zone I includes left subclavian to celiac; Zone II includes celiac to caudal renal; Zone III includes caudal renal to aortic bifurcation. Zone lengths were calculated and correlated to novel and definitive measure of torso extent (symphysis pubis to sternal notch).

RESULTS: Eighty-eight males (mean [SD], 28 [4] years) had CT scans for the study. The median (interquartile range) lengths (mm) of Zones I, II, and III were 210 mm (202–223 mm), 33 mm (28–38 mm), and 97 mm (91–103 mm), respectively. Median aortic diameters at the left subclavian, celiac, and lowest renal arteries were 21 mm (20–23 mm), 18 mm (16–19 mm), and 15 mm (14–16 mm), respectively, and the terminal aortic diameter was 14 mm (13–15 mm). The correlation for descending aortic length (all zones) against torso extend was $r = 0.454$.

CONCLUSION: This study provides a morphometric analysis of the aorta in a male population, demonstrating consistency of length and diameter while defining distinct axial zones. Findings suggest that center line aortic distances correlate with a simple, external measure of torso extent. Morphometric study of the aorta using CT data may facilitate the development and implementation of occlusion techniques to manage noncompressible torso, pelvic, and junctional femoral hemorrhage. (J Trauma Acute Care Surg. 2013;75: S169–S172. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Diagnostic study, level III.

KEY WORDS: Torso vascular anatomy; endovascular measurement; CT angiography; noncompressible torso hemorrhage.

In the setting of hemorrhagic shock, maintenance of central aortic pressure is critical to sustain myocardial and cerebral perfusion until resuscitation can be initiated and bleeding can be controlled. Resuscitative aortic occlusion at locations between the origin of the left subclavian artery and the aortic bifurcation can be a life-sustaining procedure, which maintains central pressure and mitigates distal hemorrhage. Currently this maneuver is achieved with an aortic clamp at the time of thoracotomy or laparotomy or with an endovascular balloon introduced through the femoral artery. Despite the potential for resuscitative aortic occlusion to sustain life and control hemorrhage, there is little quantitative information on the morphometry of the aorta or the iliac or femoral arteries. Morphometry, in this context, refers to the diameters at various locations along the aorta and distances between the femoral vessels and major aortic side branches. The current understanding of torso arterial anatomy is mostly based on cadaveric dissection and medical illustration. Even when computed tomography (CT) provides detailed arterial measurements, the imaging is per individual and obtained after injury. For significant advances to occur in the management of hemorrhage, including the use of resuscitative aortic occlusion, a more complete knowledge of aortic and access vessel morphometry is necessary.

The common use of CT following injury has resulted in repositories of imaging data in trauma populations. These collections of data include imaging of the aorta, iliac, and femoral arteries stored on systems with software to perform detailed vessel diameter and center line length measurements. Structured collection and analysis of torso arterial measurements from large numbers of CT imaging studies may allow the quantification of morphometric norms. Knowledge of such norms before injury stands to facilitate new techniques in resuscitation and hemorrhage control without the need for fluoroscopy.

The objective of this study was to quantify torso arterial morphometry in a trauma population using a volume of archived CT images. An additional objective was to characterize the correlation of arterial lengths or distances with a novel measure of torso extent.


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**Abstract:**

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PATIENTS AND METHODS

Following institutional review board approval, consecutive trauma patients during a 12-month period, who underwent CT scanning, were retrospectively identified from the Wilford Hall United States Air Force Medical Center database (Lackland Air Force Base, San Antonio, Texas). For inclusion, CT scans were those performed on male patients between the ages of 18 years and 45 years. All CT scans were contrast-enhanced, 64-slice continuous examinations of the chest, abdomen, pelvis, and femoral vessels.

The individual scans were loaded on to a CT workstation running Volume Viewer software (General Electric, Waukesha, WI). Three-dimensional reconstructed angiograms permitted the measurement— in millimeters— of the distance between vessel origins and diameters (Fig. 1A and B). The aorta was divided into and examined as three previously described zones (Fig. 2).4 Aortic Zone I extended from the origin of the left subclavian artery to the celiac trunk. Aortic Zone II extended from the celiac trunk to the origin of the lowest renal artery, and the infrarenal aorta (lowest renal to the aortic bifurcation) constituted the aortic Zone III.

The center line length (mm) of each zone was measured, and the luminal diameter of the aorta at the proximal and distal most extent of each of the zones was recorded. In addition, the distance from left and right common femoral artery (CFA) at the midpoint of the femoral head to the aortic bifurcation and the origin of the left subclavian artery was recorded. The CFA landmark was chosen as a plausible site for arterial access. For the purposes of the study, the external measure of torso extent was defined as the straight line distance (mm) from the suprasternal notch of the manubrium to the midpubic symphysis, parallel to the patient’s craniocaudal axis.

CT images were examined by a single reader, with 10 scans reassessed de novo and measured at different sessions to assess intrareader variability. Data were collected in an Excel spreadsheet (Microsoft, Redmond, WA) and imported to SPSS version 20 (IBM, New York, NY) for analysis. Distances and diameters were reported as medians, accompanied by interquartile range (IQR) and maximum-minimum values for distribution. Scatter plots were generated plotting aortic zone length against torso extent or height, and a best-fit line was drawn using linear regression analysis. The correlation of determination ($R^2$) was reported as measures of the strength of the linear regression.

RESULTS

Two hundred male patients underwent CT imaging following traumatic injury between April 1, 2009, and March 31, 2010. There were 112 exclusions (56%) with 102 (51%) removed because of a low-quality contrast bolus or a noncontiguous chest, abdomen, pelvis, and femoral imaging. Eight scans (4%) were excluded owing to inadequate anatomic exposure, and 2 (1%) were excluded owing to abnormal vascular anatomy. The final cohort was composed of 88 patients with a mean (SD) age of 28 (4) years and a median (IQR) torso extent or height of 521 mm (500–536 mm).

Distances or Lengths

The distances (mm) from skin to the left or right CFA was similar, with a median distance of 35 mm and an IQR of 29 mm to 41 mm (Table 1). The distance from the CFA to the aortic bifurcation was longer by 30 mm on the right than on the left side. The median (IQR) distance for the right and left were 197 mm (182–213 mm) and 206 mm (195–219 mm), respectively. The total length of the aorta from the left subclavian to the celiac trunk was 340 mm (323–360 mm). Aortic Zone I was the longest, with a median length of 211 mm (202–223 mm). The length of Zone III was 97 mm (91–103 mm), and the length of Zone II was 33 mm (28–38 mm).

Diameters

The diameters of the left and right CFA were the same, measuring 8 mm (7–9 mm) (Table 2). Aortic diameter was the smallest (14 mm [13–15 mm]) at the bifurcation. Aortic diameter increased to 15 mm (14–16 mm) at the lowest renal artery, 18 mm (16–19 mm) at the celiac trunk, and 21 mm (20–23 mm) at the level of the left subclavian artery (Table 2).

Figure 1. A, CT three-dimensional rendering of the aorta, iliac, and femoral arteries. B, The same image in A, with superimposed center line measurements.
Linear Regression

Length measurements of the descending aorta were plotted against the measurements of torso extent or height (Fig. 3), and linear regression was used to apply a best-fit line. An $R^2$ of 0.454 demonstrated that torso extent alone was able to explain more than 45% of the variability in aortic length. This method was repeated for the individual aortic zones (Fig. 4) with both aortic Zones I and III resulting in an $R^2$ of 0.294 and 0.212, respectively, indicating that other explanatory variables may be involved. Zone II had a low $R^2$ of 0.065, suggestive of a poor linear relationship to torso height.

DISCUSSION

This study is the first to report numerical characterization of the aorta, iliac, and femoral arteries using stored CT images of male trauma patients. In addition, this analysis reports the morphometric measures of three clinically relevant aortic zones and demonstrates a correlation between aortic length and torso height. This capability has largely come about owing to scanning techniques and software originally designed for the planning of endovascular intervention, but the commonality of CT imaging in trauma extends the applicability.5,6

This study compliments our group’s previous work in torso trauma, where the aorta has been characterized into three zones.4 Zone I extends from the origin of the left subclavian artery to the celiac trunk and has a median length of 211 mm. Zone II is from the origin of the celiac trunk to the lowest renal artery and has the smallest median length of 33 mm. The infrarenal aorta is Zone III and is 97 mm in median length. Aortic Zones I and III were described as regions of occlusion, to achieve inflow control and afterload support of patients in extremis with non-compressible torso hemorrhage.4

<table>
<thead>
<tr>
<th>TABLE 1. Measurements of Key Vascular Distances</th>
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<tr>
<td>Distance, mm</td>
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<td>-----------------------------------------------</td>
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<tr>
<td>Aortic Zone I</td>
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<td>Aortic Zone II</td>
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<tr>
<td>Aortic Zone III</td>
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<tr>
<td>Left CFA to AB</td>
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<tr>
<td>Right CFA to AB</td>
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<tr>
<td>Skin to Left CFA</td>
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<td>Skin to Right CFA</td>
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Aortic Zone I extended from the left subclavian to celiac trunk; aortic Zone II extended from the celiac trunk to lowest renal artery; and aortic Zone III extended from the lowest renal artery to AB.

<table>
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<tr>
<th>TABLE 2. Vessel Diameters at Key Vascular Landmarks</th>
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<tr>
<td>Diameter, mm</td>
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<tr>
<td>-----------------------------------------------</td>
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<tr>
<td>Aorta at Left SCA</td>
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<tr>
<td>Aorta at celiac trunk</td>
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<tr>
<td>Aorta at LRA</td>
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<tr>
<td>Aortic Bifurcation</td>
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<tr>
<td>Left CFA</td>
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<td>Right CFA</td>
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LRA, lowest renal artery; SCA, subclavian artery.

Figure 2. Line drawing demonstrating the three aortic zones.

Figure 3. Scatter plot of torso height against descending aortic length with accompany best-fit line.
The biggest limitation is that 56% of the originally identified cohort were excluded—the majority (91%) due to poor contrast quality. It is unclear whether this introduces a bias to the distribution of measurements. It may be the case that a larger sample size, with fewer exclusions, will improve the strength of the linear regression.

**CONCLUSION**

The current study is the first numerical characterization of aortic zones, demonstrating correlation to torso height, using a CT data repository. First, this demonstrates both the feasibility and limitations of this methodology, which may be applicable to other morphometric analyses. Second, these results permit the application of numeric planning to future resuscitative interventions for non-compressible torso hemorrhage. This is particularly relevant to the emerging use of endovascular technology, which is an exciting new development in torso hemorrhage control. Further study in a broader population that includes female torso anatomy is warranted to develop the application of morphometric analysis in torso trauma.

**AUTHORSHIP**

A.S. contributed to the study concept, data acquisition, and writing. J.J.M. contributed to the data analysis, interpretation, and writing. D.J.S. contributed to the data analysis, interpretation, and writing. J.E.L. contributed to the study concept, data interpretation, and writing. T.E.R. contributed to the study concept, data interpretation, and writing.

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**DISCLOSURE**

The authors declare no conflicts of interest.

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**REFERENCES**