**The prediction model of the aortic bifurcation**

**Abstract**

*Purpose:* Injury to the common iliac artery or aorta during a lumbopelvic surgical procedure is not so far from an uncommon complication with high morbidity and mortality rates.This study aims to investigate and make a prediction model of the aortic bifurcation, the left and right common iliac arteries for their lengths, diameters, and angles of branching.

*Methods:* The aorta and common iliac arteries of the cadavers with normal abdominal vessels were investigated and measured. Fifty cadavers, 27 males and 23 females, were enrolled.

*Results:* Mean age±SD was 69.6±12.1 years. For the length, diameter, and angle of the arteries, there was no significant difference between males and females (p-value>0.05). The respective mean±SD diameter of the aorta, left and right common iliac arteries were 1.72±0.19, 1.26±0.19 and 1.25±0.10 cm. The mean±SD length of the left and right common iliac arteries were 4.89±1.38 and 4.47±1.12 cm. The left common iliac artery was longer than the right one (p-value=0.001). The mean± SD angle of the left and right common iliac arteries were 28.40±7.37 and 30.29±15.51 degrees without a statistical difference (p-value>0.05). The diameter of the aorta, left, and right common iliac arteries were correlated well with Murray’s formula (Pearson’s coefficient 0.824).

*Conclusion:* The left common iliac artery was longer, more vertical, and closer to the lumbar spine than the right one. To avoid vascular complications associated with the surgical approach, surgeons should identify the lumbar spine in the midline and carefully dissect it to find out the left common iliac artery. The diameters of the aorta and the common iliac arteries best fit with Murray’s cubed expression formula, whereas the angle of aortic bifurcation best fit with two times Murray’s angular arterial branching model. Vascular surgeons can predetermine the diameter and angle of the aortic branching before actual surgical operation on these vessels.

**Keywords:** Aorta; Common iliac artery; Lumbopelvic; Vascular; Surgical procedure

**Manuscript Text**

**Introduction**

The anterior or anterolateral approach of the lumbopelvic region is one of the major routes of various surgical operations e.g., total disc arthroplasty, lumbosacral spine surgery, vascular surgery, pelvic organ surgery, and transabdominal endoscopic surgery. The key anatomy is usually the aorta and common iliac artery.1 The aorta bifurcates into common iliac arteries at the level of L4-L5, which approximately corresponds to the umbilicus level.2 The ureters cross over the lower end of common iliac arteries.2 Anterior approach to L4-L5 and above usually requires the mobilization of the aorta and inferior vena cava with ligation and sacrifice of the segmental vessels.3 For L4-5 and lower, the middle sacral artery must be ligated and sacrificed before the common iliac arteries are bilaterally retracted to expose the anterior surface of the lower lumbar spine.4

Arterial injury is one of the major complications associated with the anterior lumbopelvic approach. The left common iliac artery is found to be the most common arterial injury during anterior lumbar interbody fusion.5,6

The purpose of this study was to investigate the aortic bifurcation and its branches (the left and right common iliac arteries) for the length, diameter, and angle of branching of these arteries. The result of this study is useful for pre-operative surgical planning of vascular and lumbopelvic surgeries.

**Methods**

The study protocol was submitted to, and reviewed by the institute’s Ethics Committee for Human Research, and deemed exempt from the institutional review board oversight because the study met the criteria of the Exemption Determination Regulations (research involving the collection of study of bone, the body of persons who donate to the hospital and subjects cannot be identified directly or through identifiers linked to the subjects).

The aorta and common iliac arteries of the cadavers with normal abdominal vessels were investigated and the images of the aortic bifurcation and both common iliac arteries were captured. These photographs were evaluated and measured for the diameter, length, and angle of branching of these arteries using the ImageJ (version 1.45s National Institutes of Health, Bethesda, MA). The abnormal morphology and aneurysm of the abdominal vessels were excluded from the study.

*Outcome measurements*

The angle of aortic bifurcation was the angle between the medial border of the left and right common iliac arteries or the summation of the right and left angles (Fig. 1). As shown in Fig. 2, the length of the left and right common iliac arteries was measured. The diameter of the aorta was measured at the level just proximal to its bifurcation, and the diameters of the left and right common iliac arteries were measured at the level just distal to their branching. All lengths and diameters were recorded in a unit of a centimeter.

*Statistical methods*

All continuous variables were first assessed for their normality and the continuous data with normal distribution were compared between the groups using the t-test. All non-normal distribution data and categorical data were compared between the groups using the Wilcoxon signed-rank test. The significance level was 0.05. The 95% confidence interval was calculated. The correlation between the diameter of the artery in this region and Murray’s diameter model,7,8 or between the diameter of the artery and the HK diameter model 9 were analyzed using the Pearson correlation coefficient.

**Results**

Of the 50 cadavers, 27 were males and 23 were females and their mean age±SD was 69.6±12.1 years. The mean±SD diameter of the aorta at the level just proximal to its bifurcation was 1.72±0.19 cm. There were no statistically significant gender differences in the length and diameter of the common iliac artery (independent t-test, p>0.05) (Table 1). In the overall metric data given in Table 2, only the length of the left and right common iliac arteries showed a statistically significant difference (paired t-test, p=0.001).

The mean ± SD total angle between the left and right common iliac arteries was 58.69±11.81 degrees. Based on Murray’s formula ($D\_{a}^{3}= D\_{r}^{3}+D\_{l}^{3}$ (where $D\_{a, } D\_{r} $and $D\_{l}$ are the diameters of the aorta, right, and left common iliac arteries, respectively)),7 the Pearson correlation coefficient between $D\_{a}^{3} $and $D\_{r}^{3}+D\_{l}^{3} $was 0.824 (p-value=0.006). For the HK prediction model ($D\_{a}^{\frac{7}{3}}= D\_{r}^{\frac{7}{3}}+D\_{l}^{\frac{7}{3}}$), the Pearson correlation coefficient between $D\_{a}^{\frac{7}{3}}$ and $D\_{r}^{\frac{7}{3}}+D\_{l}^{\frac{7}{3}}$ was 0.807 (p-value=0.009).

**Discussion**

*The anatomy of the aorta and common iliac arteries*

The common iliac artery is an important structure during lumbopelvic surgeries. The common iliac artery should be identified for further dissection of the ovary which is located at the distal part of the left and right common iliac arteries.10

The left common iliac artery was, as shown in this study, longer and more vertical than the right. In line with Baker et al 's report, 15.6% of vascular injuries during the anterior approach to the lumbar spine are mainly inferior vena cava and common iliac vein.11 Therefore, to approach the anterior surface of the lower lumbar spine, we recommend the left side approach and retract the left common iliac artery before finding out, dissecting, and retracting the right common iliac artery.

For the L5-S1 disc surgery, we recommend identifying the aortic bifurcation and ligating the middle sacral artery.12 The normal saline solution should be injected into the presacral fascia and bluntly dissect the fascia to protect the superior hypogastric plexus and preserve sexual function.13

*Predetermination of aortic bifurcation*

We hypothesized that the prediction model of aortic bifurcation should conform with the principle of minimum work. However, there was no proposed prediction model for aortic bifurcation before. There are only the models for coronary artery branching by Murray and Huo et al.7,9

Murray derived and suggested the cubed diameter expression as $D\_{a}^{3}= D\_{r}^{3}+D\_{l}^{3}$.7,9,14 In the current study, the third power of the diameter of the aorta was very approximated to the third power of the diameter of the left common iliac artery plus the third power diameter of the right common iliac artery (Pearson correlation coefficient 0.824, p-value=0.006). The diameter of both common iliac arteries can predict the aorta diameter and vice versa.

 Murray, in other words, also calculated and proposed the angle of arterial branching as $\cos(\left(total angle of bifurcation\right)=\frac{(D\_{l}^{3}+D\_{r}^{3})^{\frac{4}{3}}-D\_{l}^{4}-D\_{r}^{4}}{2D\_{l}^{2}D\_{r}^{2}})$. He discussed that the numerous and important branching may not agree with his simple theory e.g., the bifurcation of the pulmonary artery makes too wide an angle.8 Rossitti and Lӧfgren concluded that the angles of arterial branching varied widely.15 In the present study, we found that every case had $2×\frac{(D\_{l}^{3}+D\_{r}^{3})^{\frac{4}{3}}-D\_{l}^{4}-D\_{r}^{4}}{2D\_{l}^{2}D\_{r}^{2}} $equal to 0.52, which is very close to cos (58.69) or the mean of the angle between the left and right common iliac arteries (mean±SD=58.69±11.81 degrees). Therefore, the prediction for the angle of aortic bifurcation was $\cos(\left(total angle of bifurcation\right)=2×\frac{(D\_{l}^{3}+D\_{r}^{3})^{\frac{4}{3}}-D\_{l}^{4}-D\_{r}^{4}}{D\_{l}^{2}D\_{r}^{2}})$. The diameter of both common iliac arteries can predict the aortic bifurcation angle and vice versa.

 The clinical application of this formula is based on the principle of minimum work applied to the angle of arterial branching.8 The surgeon can predetermine the size and angle of the aorta and common iliac arteries for surgical design to repair, re-anastomose or graft these major vessels. In difficult circumstances (e.g., the aortic bifurcation dissection), the aortic bifurcation lesion is removed and re-anastomosed using the arterial graft with an angle of 58.96 degrees (almost 60 degrees).

 Recently, Huo et al reported the HK prediction model for coronary arterial branching as $D\_{a}^{\frac{7}{3}}= D\_{r}^{\frac{7}{3}}+D\_{l}^{\frac{7}{3}}$.9 However, our data showed a correlation between $D\_{a}^{\frac{7}{3}} $and $D\_{r}^{\frac{7}{3}}+D\_{l}^{\frac{7}{3}}$ (Pearson correlation coefficient =0.809, p-value=0.009), which is less than the correlation between $D\_{a}^{3}$ and $D\_{r}^{3}+D\_{l}^{3}$ (Pearson correlation coefficient 0.824, p-value=0.006). So, the prediction model of aortic bifurcation is more highly correlated with Murray’s model than with the HK model. For the prediction angle model, the mean±SD of each $\frac{\left(\left.1+(\frac{D\_{s}}{D\_{l}})^{\frac{7}{3}}\right)\right.^{\frac{12}{7}}-\left.\left(1+(\frac{D\_{s}}{D\_{l}})^{4}\right.\right)}{2\left(\frac{D\_{s}}{D\_{l}}\right)^{2}}$ was 0.64±0.001 which represented the cos (50.2), whereas, the mean±SD of the angle between the left and right common iliac arteries was 58.96±11.81 degrees ($D\_{s }$= diameter of the smaller common iliac artery; $D\_{l }$=diameter of the larger common iliac artery). There was no statistical correlation between cos(total angle of bifurcation) and $\frac{\left(\left.1+(\frac{D\_{s}}{D\_{l}})^{\frac{7}{3}}\right)\right.^{\frac{12}{7}}-\left.\left(1+(\frac{D\_{s}}{D\_{l}})^{4}\right.\right)}{2\left(\frac{D\_{s}}{D\_{l}}\right)^{2}}$ (Pearson correlation coefficient -0.257, p-value=0.51). However, due to cadaveric study, these mathematical models cannot predict the elasticity of the vessels under pressurized as in viable vessels.

In conclusion, the left common iliac artery was longer, more vertical, and closer to the lumbar spine than the right common iliac artery. To avoid vascular complications associated with the surgical approach, surgeons should identify the lumbar spine in the midline and carefully dissect it to find out the left common iliac artery. The diameter of the aorta and its common iliac arteries best fit with Murray’s cubed expression formula ($D\_{a}^{3}= D\_{r}^{3}+D\_{l}^{3}$), whereas, the angle of aortic bifurcation is the best fit with 2 times Murray’s angular arterial branching model$ (\cos(\left(total angle of bifurcation\right)=2×\frac{\left(D\_{l}^{3}+D\_{r}^{3}\right)^{\frac{4}{3}}-D\_{l}^{4}-D\_{r}^{4}}{D\_{l}^{2}D\_{r}^{2}}))$. Vascular surgeons can predetermine the diameter and angle of the aortic branching before the operation involved with these vessels.

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x

**Figure Legend**

**Fig. 1.** Measurement of aortic bifurcation angle (the total bifurcation angle is the summation of the left and right angles.)

**Fig. 2.** Measurement of the length of the left and right common iliac arteries (A, B and C are the points of bifurcation of these arteries.)