Morphological analysis of bronchial arteries and variants with computed tomography angiography and its relevance in the treatment of massive hemoptysis.

Poster No.: C-0119
Congress: ECR 2017
Type: Scientific Exhibit
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Keywords: Anatomy, Thorax, Arteries / Aorta, CT, CT-Angiography, Image manipulation / Reconstruction, Education, Infection, Education and training
DOI: 10.1594/ecr2017/C-0119

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Aims and objectives

Massive hemoptysis is a life-threatening clinical event. Its main etiology is secondary to rupture of the bronchial arteries and rarely from other systemic arteries or the pulmonary artery. Chronic inflammatory lung diseases (e.g. tuberculosis) produce hypertrophy and fragility of the bronchial arteries, which can lead to rupture and bleeding.

The most effective nonsurgical treatment for massive hemoptysis is the embolization of bronchial arteries. Its location by imaging studies is the most important step to control bleeding. Knowledge of anatomical variants could reduce the time of diagnosis and intervention, patient radiation, and embolization material costs; It could also avoid complications such as spinal cord ischemia from non-visible anastomoses between the bronchial circulation and anterior spinal artery during surgeries of the posterior mediastinum.

The anatomical variants of the bronchial arteries have been reported in cadaveric studies, angiography, and computed tomography angiography (CTA), the latter considered the most suitable method. Cauldwell et al. (1948) were the first to describe patterns of branching of the bronchial arteries and their classification is currently the most widely used. Yener et al. (2015) studied the branching patterns by computed tomography and reported that the most frequent variation (24.03%) corresponded to a left bronchial artery originating directly from the thoracic aorta and the right bronchial artery originating from the intercostobronchial trunk (type II Cauldwell). Other studies have described the origin of the bronchial arteries, without reporting its full pattern, which limits the analysis of the results. Other variables have been evaluated by computed tomography, such as ostium of the bronchial arteries in the aorta, the vertebral levels origin, path through the posterior mediastinum and diameter. To our knowledge, there isn’t a study that evaluates all of these variables in the same population.

The objective of our study was to analyze the arterial origin, branching pattern, location ostium, vertebral level of origin, mediastinal trajectory and diameter of the bronchial arteries using CTA.
Methods and materials

We performed a retrospective, observational, cross-sectional descriptive study, in which 297 angiograms were evaluated by CTA from a Mexican population, carried out in the Radiology and Imaging Division of the Hospital Universitario "Dr. José Eleuterio González." Consecutive cases were selected between January 1st, 2013 and December 31st, 2015 from patients who were 18 years old or older, including those with suspected pulmonary, pleural, or heart pathologies. Studies from patients younger than 18 years were excluded. Pathologies that did not allow the proper evaluation of one or both bronchial arteries were eliminated (158 studies).

CTA studies were performed using a 64-slice CT (General Electric CT99 Light Speed VCT) Software 2978195VCT, with a 0.4s rotation of helical acquisition, 40mm detector coverage, Kv of 120 mAs and 400; slice thickness of 1.25mm, 0.984:1mm/rot Pitch, and a 40 to 50 cm FOV. All patients were injected with intravenous iodinated contrast medium (Ultravist 370, Bayer, Germany) at a dose of 1 to 2ml/kg with a 3.5ml/second injection rate. The data obtained were transferred and analyzed in a Work Station AW Volumen Share2 from General Electric using multi-planar reformatting (MPR) with maximum intensity projection (MIP), and volume rendering (VR). To perform the measurements, a range of window WW:400 and WL:40 was used in a standarized manner for all patients taking into account the internal diameter of each artery evaluated.

Imaging studies were evaluated by an experienced radiologist with prior training in the use of software and knowledge of the most commonly accepted anatomical classification (Cauldwell et al.).

The evaluation of the bronchial arteries was performed according to the following variables: origin, branching patterns, location ostium, vertebral level source, diameter, and mediastinal trajectory in reference to the esophagus and the main bronchi.

The origin of the bronchial arteries (left and right) could be: independent, a common trunk or an intercostobronquial trunk. In turn, these arteries of origin could originate from the thoracic aorta, the aortic arch, the subclavian arteries, internal thoracic artery, or the thyrocervical trunk. Bronchial artery common trunk was considered when two or more bronchial arteries originated from the artery before contacting a main bronchus. The aortic arch was considered to end, and the thoracic aorta to begin, at the lower border of the T4 vertebra.

After establishing the origin of each of the bronchial arteries, their trajectory continued until contact with the corresponding main bronchus to determine their branching pattern. Patterns found were ordered according to their frequency and alphabetical letters (A-L) were designated for identification. Single frequency patterns were considered atypical
and were grouped in the L category and assigned Arabic numerals pattern (L1-L24). (Figure 1, supplementary files)

Ostium location for bronchial arteries originating from the thoracic aorta and aortic arch was determined using the methodology by Battal et al. as shown in Figure 2A and Figure 2B respectively.

The vertebral level origin was evaluated by drawing a horizontal line from the origin of each of the bronchial arteries to interconnect with the vertebrae (C7 - T7) (Figure 3). Arteries originating between T5 and T6 were considered orthotopic, and as ectopic those arising beyond these levels.

Position (left or right) of the bronchial arteries in relation to its medastinal trajectory was documented. The position (anterior or posterior) of the bronchial artery in relation to the main bronchus was determined by observing the point of first contact between the two structures.

The diameter of all bronchial arteries, common trunks, and intercostobronquial trunks involved were documented at the origin of the vessel, because it is the site where arterial embolization is performed. All measurements were reported in millimeters and were stored in a database for subsequent statistical analysis.

Subsequent to morphological and morphometric analysis, a statistical comparison between sides (left vs. right) and gender (men vs. women) for all variables was performed.

Statistical analysis

Statistical analysis was performed using the computer program SPSS version 20.0 for Windows XP. Measures of central tendency and dispersion tests were obtained by descriptive statistics for qualitative data. Nonparametric Kolmogorov-Smirnov to analyze the distribution of data were performed. Binomial tests of a sample was performed to determine whether there was a difference between the number of men and women, and the number of left and right bronchial arteries. Subsequently, Mann-Whitney U tests were performed to determine whether there was a difference between each of the qualitative variables regarding side (left vs. right) and gender. Likewise, t-student test for independent samples to assess statistical differences regarding diameter in relation to gender and side. A p of <0.05 was considered as significant.

Ethical considerations

This study was approved by the Ethics Committee and the Research Committee of the Universidad Autonoma de Nuevo Leon, Faculty of Medicine with the registration number AH14-005. No patient was radiated nor received contrast for the purposes of this study.
There were no financial or commercial gain in the realization of this study, so the authors declare no conflict of interest.
**Fig. 5:** Supplementary files. Single frequency patterns were considered atypical and were grouped in the L category and assigned Arabic numerals pattern (L1-L24)

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Fig. 2: Ostium location for bronchial arteries originating from the thoracic aorta and aortic arch was determined using the methodology by Battal et al. as shown in Figure 2A and Figure 2B respectively. In cross-section, when arteries originated from the thoracic aorta (Figure 2A). In a coronal section, when arteries arise from the aortic arch (Figure 2B).

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**Fig. 3:** In this figure, in a sagittal section, the evaluation method of the vertebral level of origin of the bronchial arteries is shown (dotted line). A branching pattern of a common of a bronchial arteries trunk (one right and one left), originating from the aortic arch is also shown. CTB = Common trunk of bronchial arteries, RBA = Right bronchial artery, LBA = Left bronchial artery.

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Results

We evaluated 139 angiograms by CTA (73 men, 66 women) from a population of Mexican patients. The mean age was 49.90 years ± 18.62 with a range between 18 and 90 years. Men had a mean age of 47.40 ± 19.05 years with a range between 19 and 90, while women had a mean of 52.67 ± 17.86 with a range between 18 and 85 years. Gender groups were distributed homogeneously (p = 0.215).

A total of 315 bronchial arteries were identified, of which 209 (66.34%) were orthotopic, 95 (30.15%) left, and 114 (36.19%) right sided. We also found 106 (33.65%) ectopic bronchial arteries, of which 69 (21.90%) were left and 37 (11.74%) right.

We identified between 2 to 5 bronchial arteries per patient, with higher prevalence for the left side than the right, however this difference was not statistically significant (p = 0.499). Men also had a higher number of bronchial arteries than women but was not statistically significant (p = 0.650).

All bronchial arteries were evaluated according to their origin, branching patterns, ostium location, vertebral level of origin, lumen diameter, and mediastinal trajectory in reference to the esophagus and the main bronchus.

Artery origin

Bronchial arteries originated from the thoracic aorta (70.60%), aortic arch (23.49%), and other vessels (1.90%). In the aorta they emerged as independent branches (40.95%), branches from a common trunk (29.84%) (Figure 3), or branches of an intercostobronchial trunk (27.30%) (Figure 4). The origins of other vessels (1.90%) were: 2 left bronchial arteries from the left subclavian artery, one right of the right thyrocervical trunk, one right and one left from a common trunk of the left thyrocervical trunk, and one left from the left internal thoracic artery. There was no significant difference between arterial origins regarding the side (p = 0.293) or on gender (p = 0.354).

Branching pattern

We identified 35 different branching patterns. (See Figure 1 and supplementary files). Patterns "A" to "K" were presented with more than one frequency and patterns "L (1-24)" as single cases. The most common branching patterns were the "A", "B", "C", "D" and "E", respectively. (Figure 1). Twenty four atypical patterns (L [1-24]) were found. Patterns "A", "C", "D" and "E", occurred more frequently in women, while patterns "B" and "F" to "J" were more frequent in men, with pattern "K" equally presented in both genders. Men had a higher prevalence of atypical patterns with 14 cases and 10 cases in women. Branching patterns and the frequency are listed in Figure 1 and supplementary files.
**Ostium**

The location of the ostium depended on the artery origin. In the bronchial arteries originating from the thoracic aorta, the location of the ostium was found mainly in the anterior-medial portion (58.29%), followed by the medial portion (13.19%), and anterior-lateral portion (10.63%). Those arising from the aortic arch, the location of the ostium was found mainly in the superior-medial portion (60.81%), followed by inferior-medial (14.86%) and superior-lateral (13.51%). There was no significant difference in the location of the ostium between the left and right bronchial arteries (p = 0.398), and no significant difference between genders (p = 0.872).

**Vertebral level**

All bronchial arteries originated between C7 and T7 vertebral levels. Between T5 and T6 66.34% of bronchial arteries originated, 54.54% right sided and 45.45% left, 55.98% were men and 44.01% women. Above the vertebral level T5, 32.69 % originated, of which 34.95% were right and 65.04% left, 48.54% corresponded to men and 51.45% to women. Below T6, the remaining 0.95% originated, 33.33% were right and 66.66% were left, 66.66% were men and 33.33% women.

Men had higher incidence of orthotopic bronchial arteries (55.98%) but were similar to women in ectopic bronchial arteries (49.05% vs. 50.94%, respectively). A statistically significant difference in the distribution of vertebral origin level between genders (p = 0.006) was identified, however there is no difference for this parameter between arteries on both sides (p = 0.997).

**Mediastinal trajectory**

The left bronchial arteries passed in 96.95% of cases to the left of the esophagus and 3.04% to the right of the esophagus. The right bronchial arteries passed in 56.29% of cases the right of the esophagus and 43.70% to the left of the esophagus. A significant difference was established between both sides in the mediastinal trajectory regarding the esophagus (p <0.001), but there was no significant difference between genders (p = 0.943).

Both the left and the right bronchial arteries came in contact with the corresponding main bronchus predominantly on the posterior surface (70.15%). The mediastinal trajectory to the main bronchus was similar on both sides (p = 0.318) and in both genders (p = 0.527).

**Diameter**

In both genders, the luminal diameter of the bronchial arteries had a mean of 1.62 ± 0.29 mm with a range of 1.14 to 2.97 mm (the minimum and maximum values were both found in the left bronchial arteries). However, in most cases, the right bronchial arteries showed
larger diameters than the left (p <0.001). Significant difference was also evident between genders (p = 0.013), as men had larger diameters than women.

**Bronchial artery common trunk**

Forty-six common trunks of bronchial arteries were identified in 46 patients, of which 28 originated from the thoracic aorta (60.86%), 17 from the aortic arch (36.95%), and one originated from a left thyrocervical trunk. Those originating from the thoracic aorta, the ostial location was primarily in the anterior-medial portion (56.52%), and those from the aortic arch the ostial location was primarily superior-medial (64.70%). In the thoracic aorta originated, 60.71% originated at the vertebral level T5, and in the aortic arch 76.47% at the vertebral level T4. The common trunk that originated from the left thyrocervical trunk has a vertebral level of C7-T1. The mean diameter was 1.82 ± 0.35 mm (range 1.19 to 2.69 mm).

The common trunks gave rise to 94 bronchial arteries, of which 43 were right (45.74%) and 51 left (54.25%). In 40 cases (86.95%), it was the origin for one left bronchial artery and one right bronchial artery. In 4 cases (8.69%) it branched one right and two left bronchial arteries, and in 2 cases (4.34%) two left bronchial arteries (see figure 1 and supplementary files). Its trajectory through the mediastinum, it passed to the left of the esophagus, although not all completed this path since some branched the corresponding bronchial arteries before passing along the esophagus. None of the common trunks came in direct in contact with a main bronchus.

**Intercostobronquial trunk**

A total of 83 intercostobronquial trunks were found in 82 patients, of which 77 (93.90%) originated in the thoracic aorta and 6 (7.22%) in the aortic arch. The ostium localization was found predominantly in the anterior-medial portion (54.54%) in the ones originating from the thoracic aorta, and in the inferior-medial portion (50%) for the ones originating in the aortic arch. The vertebral level were T5 (62.33%), and T4 (100%) respectively, with a mean luminal diameter of 1.99 ± 0.40 mm (range 1.32 to 3.21 mm).

The intercostobronquial trunks gave rise to a total of 86 bronchial arteries, of which 80 (93.02%) were right and 6 (6.97%) left (see Figure 1 and supplementary files). Most cases (96.38%) it gave rise to one right bronchial artery and one posterior intercostal artery; in two cases (2.40%) it divided into one left bronchial artery and one posterior intercostal artery; in one case (1.20%) it originated one left bronchial artery, one right bronchial artery, and posterior intercostal artery; and in one case (1.20%) it branched into one right bronchial artery, two left bronchial arteries, and posterior intercostal artery. Most trunks branched before passing next to the esophagus, therefor weren't included in the mediastinal trajectory analysis. None of the intercostobronquial trunk came in contact with a main bronchus.
DISCUSSION

Our study is the first to comprehensively assess the anatomy of the bronchial arteries, common trunks and intercostobronchial trunks using CTA in the same population. We are the first to report all branching patterns found and perform statistical analysis for all parameters according to gender and side. We showed that in our community there are anatomical variations in terms of numbers, arterial origin, branching pattern, vertebral level of origin, mediastinal trajectory and diameter. The knowledge of these is essential for embolization procedures in the treatment of massive hemoptysis.

There is a high frequency of ectopic origin, reported between 13 and 30%, which is why it is important to consider the location of a bleeding bronchial artery before and during the embolization procedure. In our study we found a frequency of 66.34% of orthotopic bronchial arteries and 33.65% of ectopic. The frequency with which bronchial arteries are affected by hemoptysis processes relates to the nature of their origin, reason why previous authors describe them; these tend to be branches of the thoracic aorta and aortic arch, emerging, in order of frequency as: independent branches of a common trunk, an intercostobronchial trunk, and other arteries other than the aorta, similar to what was found in our study.

In patients with massive hemoptysis requiring urgent arterial embolization, the lack of familiarity with the most common variants of bronchial arteries may be an important factor in the success or failure of the intervention procedure. The branching patterns of bronchial arteries were initially described by Cauldwell et al. in 1948 and, since then, they have been used as reference for bronchial artery embolization in cases of massive hemoptysis and for anatomical studies. Our study found that the most common branching pattern corresponds to the type A (type II Cauldwell), which coincides with the most frequently reported by previous authors. It is followed by type B and C patterns, similar to that reported in previous studies, however, neither of these were described by Cauldwell et al. In addition, pattern "I" of our study (type I Cauldwell, [Figure 1]), presented in the most widely used anatomy books, does not represent the totality of existing anatomical patterns nor its actual frequency according to recent literature. The study of bronchial artery branching patterns in other populations is necessary to determine their prevalence.

The embolization of bronchial arteries during massive hemoptysis is performed 2-3 mm from the ostium in order to avoid complications such as spinal ischemia from non-visible anastomosis between bronchial circulation and the anterior spinal artery. Previous authors have reported a predominant anterior-medial location of the ositum in the thoracic aorta, and superior-medial in the aortic arch, similar to our findings. Previous studies evaluated the arterial diameter at a proximal point to the origin, because when it is above 2mm, it is considered an indicator of a pathological bronchial artery.

In some cases massive hemoptysis may be treated surgically which is why it location in the posterior mediastinum is important. Previous studies have described the trajectory of the left bronchial arteries is to the left of the esophagus and the right bronchial arteries
to the right of the esophagus, both predominantly coming in contact with their respective main bronchus on the posterior surface, similar to our results.

Some studies report a higher number of right bronchial arteries compared to the left, however our results indicate a higher amount of left bronchial, as reported by Cauldwell et al., although this difference was not statistically significant. We believe this discrepancy may be because these studies reported cases of patients with a single bronchial artery, which, most often, is right-sided, causing small luminal diameter of left bronchial arteries, resulting in a possible underestimation of these. In our study we found 5 cases with only right arteries and 2 with only left arteries, which were excluded from the sample. We believe it is important to research the alleged "only bronchial artery" because it has been described that the bronchial arteries are vital for the proper functioning of the airway and lungs, and damage by erroneous embolization could lead to problems like ischemia and necrosis of mucosa, chronic lung problems, among others.

A limitation of our study was the omission of the bronchial arterial length because it was not possible to observe the full length of the vessel in a single projection and reformatting was needed for full view.
**Fig. 1:** In this figure some branching patterns of bronchial arteries are shown. At the bottom are three pieces of information: on the left the letter indicates the corresponding pattern found in our study, the center shows frequencies with which each pattern was presented (total, male and female), to the right is shown the comparison of the patterns found in our study with the classification of Cauldwell et al. (a line means that the pattern found in our study was not reported by Cauldwell et al.). Figure 1A shows the pattern I of our study, Type 1 of Cauldwell, corresponding to that found in medical books describing the “typical” anatomy of bronchial arteries. Figures 1B to 1F show the most frequent branching patterns found in our study (patterns A to E, respectively) M = Male, F = Female.
**Fig. 4:** This contains a right bronchial artery caused a trunk intercostobronquial shown in a coronal section. IBT = intercostal-bronchial trunk, RBA = Right bronchial artery, LBA = Left bronchial artery.

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**Fig. 3:** In this figure, in a sagittal section, the evaluation method of the vertebral level of origin of the bronchial arteries is shown (dotted line). A branching pattern of a common of a bronchial arteries trunk (one right and one left), originating from the aortic arch is also shown. CTB = Common trunk of bronchial arteries, RBA = Right bronchial artery, LBA = Left bronchial artery.

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Fig. 5: Supplementary files. Single frequency patterns were considered atypical and were grouped in the L category and assigned Arabic numerals pattern (L1-L24)

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Conclusion

The anatomy of the bronchial arteries is similar in both genders, except vertebral level origin and diameter, and similar in relation to side (left vs. right) except the mediastinal trajectory reference to the esophagus and lumen diameter. The data presented in this study demonstrated that the branching patterns of bronchial arteries and their frequencies reported in the literature do not coincide with results from a Mexican population. Further studies using higher resolution imaging techniques are needed to study the morphology of the bronchial arteries.
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