A simplified vision of hepatic arterial vascularization and the celiac superior mesenteric axes: a new classification based on 2034 patients

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Knowledge and precise descriptions of digestive vascular variants, including hepatic vascularization, are crucial when planning both radiological and surgical treatments. The anatomical variants reported in radiological reports require a good knowledge of 'standard' anatomy and of the different prevalent variants. An exact anatomical description is necessary, especially if an interventional treatment is being considered. This also applies to abdominal organs. Indeed, the type of vascularization can mean a different surgical technique is needed or even excluded (1). For example, a right hepatic artery coming from the superior mesenteric artery needs to be discovered before a surgeon conducts Whipple surgery (2), or an interventional radiologist will need to catheterize a superior mesenteric artery in cases of trans-arterial chemo-embolization (3).

The literature describes many studies, mostly involving hepatic vascularization (4, 5, and 6). Michel's classification, based on a retrospective study of 200 cadaveric dissections, is the most commonly used. The major aspect of this classification is that it highlights the difference between a replaced and an accessory artery. A replaced artery feeds a total lobe or the entire liver, and is different from the common hepatic artery. An accessory artery is a second hepatic arterial blood supply associated with classical hepatic vascularization (7). Hiatt then proposed a simplified version of Michel's classification (4). Several studies were consequently done on larger populations, using different methods. However, they underlined the insufficiency of these classifications (2, 8).

The use of angiography allowed the beginning of in vivo studies, with larger sample sizes. Nowadays, the technical difficulties that result in invasive imaging are outdated. Even if comparative studies between cadaveric dissections, angiography and CT scans are few, the reliability of the CT scan has been firmly established (5, 8, and 9). Moreover, technological progression and the emergence of multislice computed tomography (MSCT) have resulted in better visualization of small arteries, with higher accuracy and greater ease of use.

Koops et al. compared Michel's and Hiatt's classifications using 604 angiographic studies (2). Up to 1.7% of these examinations remained unclassified. De Cecco et al. studied the anatomical variants of the hepatic artery, in a retrospective study of 250 patients, using a 64-detector-row CT scanner and Michel's classification. Their study confirmed the efficiency of the new imaging techniques, but highlighted, once again, the difficulty in classifying all the variants found (9). Song et al. studied a big population, but with heterogeneous methods, and proved once again the major importance of a consensual nomenclature (10).
The aim of our study was to determine the prevalence of different anatomical variants. For this, we used a retrospective collection of 2034 multislice computed tomography (MSCT) examinations collected over 4 years.

Anatomical variants are not rare. Their actual classifications are complex and often do not describe all the types found; they are also inconvenient when assessing actual treatment implications. For these reasons, we propose a new simplified classification that can be used by all medical practitioners. This new descriptive classification can be used for radiological and surgical implications and has good reproducibility. We also looked for other celiac trunk-branch variants: i.e. left gastric artery, gastro-duodenal artery and splenic artery.
Methods and Materials

MATERIALS

We conducted a retrospective descriptive study that included 2034 MSCT examinations performed at our hospital between September 2007 and August 2011. The examinations were selected using strict technical criteria: MSCT using an arterial injection, which covered the entire abdomen, and was performed using a Scanner Sensation 16 (Siemens,Erlagen,Germany, 16x0.75mm collimation). The examinations were acquired within thin slices (2 mm).

For rare variants, reconstructions with MIP (maximum-intensity projection), MPR (multi-planar reconstructions) and VRT (volume-rendering technique) were performed. The selected studies were performed in different clinical situations, either from emergency cases (acute abdominal pain, clinical suspicion of aortic dissection…) or during the follow-up of neoplastic diseases.

Exclusion criteria included all situations where there was a local anatomical change:

- Supra-mesocolic abdominal surgery, which could change the anatomy and vascularization, such as Whipple's surgery.
- Vascular or neoplastic pathologies, which could modify local vascularization (compression of the celiac trunk by a median arcuate ligament, a big central mass…).
- Patients with hepatic transplantation.

METHODS

All 2034 studies were reported by a fifth-year radiological resident. All atypical variants were reviewed by an abdominal radiologist who was specialized in both diagnostic and interventional features.

All studies were first classified using Michels’ and Hiatt's classifications. Then our new classification (explained below) was applied to the all the cases.

Normal vascularization

The classical vascular supply is also known as 'normal' vascularization:

- Two arteries from the supra-mesocolic region: celiac trunk (CT) and superior mesenteric artery (SMA).
- The CT has three branches: the left gastric artery (LGA), the splenic artery (SA) and the common hepatic artery.

The common hepatic artery, coming from the CT, has a collateral branch called the gastro-duodenal artery (GDA) and a terminal branch to the liver, called proper hepatic artery (PHA).

Only the proper hepatic artery (PHA) ensures an arterial blood supply to the liver. The PHA is divided into left and right hepatic arteries, which are macroscopic terminal branches. This type of hepatic arterial-blood supply is called 'modal vascularization'.

**The new classification's nomenclature**

The use of consensual nomenclature, established especially for this classification, is required to apply this new classification.

- A right hepatic artery (RHA) is a vessel that feeds the right liver lobe in totality or to only a few segments. Most of time, this RHA comes from the SMA and has a retro-portal course.

- A left hepatic artery (LHA) is a vessel that feeds the liver lobe in totality or to only a few segments. Usually, the LHA comes from the LGA and crosses the fissure of the ligamentum venosum.

- A median hepatic artery (MHA) is a vessel that comes from the CT and arrives at the liver via the hepatic hilum. It can reach the whole liver, just one lobe, or only a few segments.

**Use of the new classification**

The new classification is divided into three consecutive steps. For each CT examination, three types of variations are searched for: variants in number, variants in origin and variants in course. These variants can be isolated or associated. The chronological methodology is explained below:

1. **Variants in number:**

First, all arteries arriving at the liver are searched for. The liver can be fed by only one artery, the MHA from the CT, for example. However, the liver is often fed by two, three or four arteries.

2. **Variants in origin:**
The hepatic arteries described above, such as the RHA, LHA and MHA, have classical origins, which are known by anatomists and surgeons and are described in the literature. Classically, the RHA comes from the SMA, the LHA from the LGA and the MHA from the CT. However, a right hepatic artery for the total liver or for a few segments can arise from the aorta or the CT. All variants of origin of RHA, LHA and MHA were recorded in our collection.

3. Variants in course:

As with the origin of variants, the variant arteries usually had a classical course. The RHA that came from the SMA almost always has a retro-portal course. The LHA that came from the LGA crossed the fissure of the ligamentum venosum and arrived at the liver hilum. These classical routes almost always occurred, even if these arteries only reached an entire lobe or a few segments.

4. Vascular anastomoses:

Following the diagnostic tree outlined above, almost all our examinations could be determined, although a few rare variants could not be correctly described because of their atypical anatomical features. In order to understand these variants, we used our descriptive classification, which allowed us to "name" them in a comprehensive way.

Study of other celiac trunk branches

The last step of this study was to report celiac trunk-branch variants: i.e. left gastric artery, gastro-duodenal artery and splenic artery.
Results

Global description of the population

Of the 2034 MSCT examinations, 62.97% had a classical arterial blood supply, called 'normal vascularization'. This vascular distribution was not found in 37.02% of cases because of hepatic vascularization or because of one of the other arteries (SMA, LGA, SA).

Comparisons with the literature

Our results, using both Michels' and Hiatt's classifications, are summarized in Table 1. Among the 2034 examinations, 65.24% (n=127) were unclassified by Michels' classification and 4.91% (n=100) by Hiatt's classification.

<table>
<thead>
<tr>
<th>Actual study</th>
<th>Michels' classification</th>
<th>Hiatt's classification</th>
<th>Actual study</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.24% (1327)</td>
<td>I</td>
<td>I</td>
<td>65.24% (1327)</td>
</tr>
<tr>
<td>6.34% (129)</td>
<td>II</td>
<td>II</td>
<td>12.93% (263)</td>
</tr>
<tr>
<td>6.58% (134)</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.16% (166)</td>
<td>III</td>
<td>III</td>
<td>8.89% (181)</td>
</tr>
<tr>
<td>0.73% (15)</td>
<td>VI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.55% (52)</td>
<td>IV</td>
<td>IV</td>
<td>3.93% (80)</td>
</tr>
<tr>
<td>1.37% (28)</td>
<td>VII</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>VIII</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.65% (54)</td>
<td>IX</td>
<td>V</td>
<td>2.65% (54)</td>
</tr>
<tr>
<td>0.04% (1)</td>
<td>X</td>
<td>VI</td>
<td>1.42% (29)</td>
</tr>
<tr>
<td>6.29% (128)</td>
<td>unclassified</td>
<td>unclassified</td>
<td>4.91% (100)</td>
</tr>
</tbody>
</table>

Table 1: Different variants found in our study, classified according to Michels' and Hiatt's classifications. Between brackets and in italic are the percentages of each variant.
The most frequent variants, according to the literature, were double vascularizations: i.e. types II, III, V and IV of Michels' classification (II and III of Hiatt's). Their frequencies were close to those previously described in the literature (9). The 'type X' of Michels' classification is very rare: it corresponds to a single hepatic artery coming from the LGA, which feeds the entire liver. It has been described only once since Michels' study (7, 9), and we found one case in our collection (Fig. 1 on page 13).

*The new classification*

By following the diagnostic methodology described above, we were able to describe all the variants found in our study, whereas Michels' classification only classified 93.71%. Table 2 shows the outline used for this classification, though this table is not exhaustive as we only specified variants found in our collection. For example, 'type VII' of Michels' classification; which corresponds to two LHAs and two RHAs feeding the liver, was not found in our collection, but has been already described, and could be described by our new classification (9).

<table>
<thead>
<tr>
<th>Number</th>
<th>Origin</th>
<th>CT</th>
<th>SMA</th>
<th>LGA</th>
<th>RHA+MHA</th>
<th>MHA+LHA</th>
<th>RHA+LHA</th>
<th>MHA+RHA+LHA</th>
<th>Aorta</th>
<th>TC</th>
<th>Aorta (+SLGCT)</th>
<th>CMCT</th>
<th>Complete agenesis of CT</th>
<th>MHA in the fissure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RHA</td>
<td>1327 (65.24%)</td>
<td>54 (2.65%)</td>
<td>1 (0.04%)</td>
<td>235 (11.55%)</td>
<td>263 (12.93%)</td>
<td>51 (2.50%)</td>
<td>28 (1.37%)</td>
<td>1 (0.04%)</td>
<td>53 (2.60%)</td>
<td>34 (1.67%)</td>
<td>3 (0.14%)</td>
<td>10 (0.49%)</td>
<td>2 (0.09%)</td>
</tr>
<tr>
<td>2</td>
<td>MHA</td>
<td>1 (0.04%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>LHA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2
<table>
<thead>
<tr>
<th>Course</th>
<th>Origin</th>
<th>Of ligamentum venosum</th>
<th>RHA: Pre-portal +/- trans-pancreatic</th>
<th>2 (0.09%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHA</td>
<td>Retro-portal</td>
<td></td>
<td></td>
<td>1 (0.04%)</td>
</tr>
</tbody>
</table>

**Table 2:** The new classification (cases of vascular anastomoses are shown in Table 3). The variants shown in this table are those found in our collection, though the list is not exhaustive.

One examination could show one or more variants (number +/- origin +/- course).

1. **Number variants:**

The liver can be fed by only one artery, the MHA from the CT, for example. But the liver is often fed by several arteries (Fig. 2 on page 13, Fig. 3 on page 14). In our study, there were 34.68% variants, where the most common was double vascularization involving MHA: MHA-RHA or MHA-LHA. The RHA-LHA double vascularization was found in 51 cases. We also found 28 cases of triple vascularization: MHA-LHA-RHA.

2. **Origin variants:**

Classically, the RHA comes from the SMA; however, it can arise from the aorta or, more frequently, from an early bifurcation of the CT, but with a classical retro-portal course.

Also, the MHA can come directly from the aorta, with a splenic-left gastric common trunk (SLGCT) in 1.67% of cases. The MHA can also arise isolated from the aorta, such as from the SA or LGA. A celiaco-mesenteric common trunk (CMCT) was, exceptionally, the origin of the MHA in 0.14% of our cases (Fig. 4 on page 15).

3. **Course variants:**

As with the origin variants, variant arteries usually had a classical course. The RHA had a pre-portal or trans-pancreatic course in two of our cases (Fig. 5 on page 16). The left branch of the MHA, coming from the CT, had an ascending course in the ligamentum venosum fissure, to give rise to the right gastric artery (RGA), and mimicked the LHA in its course (Fig. 6 on page 17). In one case, the MHA had a retro-portal course (Fig. 7 on page 18).
Fig. 8 on page 19 summarizes the procedure employed to achieve this nominative classification.

4.- Vascular anastomoses:

Four cases (0.19%) were not correctly described by our technique because they had rare anatomical features. They most likely correspond to persistent embryological anastomoses, and are summarized in Table 3. They included a Bühler’s arc (case n°1, Fig. 9 on page 20), a right-median hilar anastomosis (case n°2, Fig. 10 on page 21), a right-median extra-hilar anastomosis (case n°3, Fig. 11 on page 22) and a left-right intra-hepatic anastomosis (case n°4, Fig. 12 on page 22).

<table>
<thead>
<tr>
<th>Case n°</th>
<th>LGA</th>
<th>SA</th>
<th>CT</th>
<th>MHA</th>
<th>RHA</th>
<th>LHA</th>
<th>Particularities</th>
<th>Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>n°1</td>
<td>CT</td>
<td>CT</td>
<td>Present</td>
<td>Left lobe</td>
<td>Absent From the LGA</td>
<td>Bühler arch</td>
<td>Fig. 9 on page 20</td>
<td></td>
</tr>
<tr>
<td>n°2</td>
<td>CT</td>
<td>CT</td>
<td>Present</td>
<td>Total liver</td>
<td>From the SMA</td>
<td>Absent MHA-RHA hilar anastomosis</td>
<td>Fig. 10 on page 21</td>
<td></td>
</tr>
<tr>
<td>n°3</td>
<td>CT</td>
<td>CT</td>
<td>Present</td>
<td>Total liver</td>
<td>From the SMA</td>
<td>Absent MHA-RHA extra hilar anastomosis</td>
<td>Fig. 11 on page 22</td>
<td></td>
</tr>
<tr>
<td>n°4</td>
<td>CT</td>
<td>CT</td>
<td>Present</td>
<td>Absent Right lobe</td>
<td>Left lobe</td>
<td>RHA-LHA intra hepatic anastomosis</td>
<td>Fig. 12 on page 22</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3:** Summary of the variants presenting persistent embryological anastomoses. Case-by-case, the origin of the each artery from the celiac and mesenteric axes, and their particulars are specified.

*The gastro-duodenal artery*
The GDA, a collateral branch of the common hepatic artery, insures an arterial supply to the stomach, the duodenum and the cephalic part of the pancreas. The course of this artery is along the superior and right-side of the head of the pancreas, and then along the anterior area. Each time the hepatic arterial blood supply was double with a median hepatic artery (MHA-RHA or MHA-LHA), or was simple with a RHA coming from the SMA to the whole liver, the GDA came from the common hepatic artery, whatever is its origin. Moreover, when the arterial blood supply was double left-right (n=51), the GDA arose from a terminal branch of the CT in 39.2% of cases (Fig. 2 on page 13).

*The left gastric artery*

**Table 4** shows the frequencies of origins of variants of the LGA. In 92.87% of cases, the LGA arose from the CT. However, this artery can come directly from the aorta, from a common trunk with the SA, or from a celiaco-mesenteric common trunk (CMCT). Among the three cases of CMCT found in our study, only one case was a complete single common trunk arising from the aorta, and supplying all the supra mesocolic arteries (Fig. 4 on page 15). The splenic-left gastric common trunk (SLGCT) occurred when hepatic vascularization was on the right (RHA form of the SMA supplying the whole liver), which was seen in 54 cases in our study. However, this SLGCT was also seen in a modal type of vascularization (n=19) and with other variants (n=15). Exceptionally, the LGA can arise from the SMA (Fig. 13 on page 23).

<table>
<thead>
<tr>
<th>LGA origin</th>
<th>Number (frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>1889 (92.87%)</td>
</tr>
<tr>
<td>Aorta</td>
<td>55 (2.7%)</td>
</tr>
<tr>
<td>SMA</td>
<td>1 (0.04%)</td>
</tr>
<tr>
<td>Splenic-left gastric common trunk (SLGCT)</td>
<td>88 (4.32%)</td>
</tr>
<tr>
<td>Celiaco-mesenteric common trunk CMCT</td>
<td>1 (0.04%)</td>
</tr>
</tbody>
</table>

**Table 4**: Summary of LGA anatomical variants found in our collection.

*The splenic artery*
The SA has an almost constant origin and course, but it can arise from the aorta (n=13), alone or associated with complete CT agenesis. Exceptionally, the SA arises from the SMA, which was seen in one case from our study (Fig. 14 on page 24).
Fig. 1: Coronal maximum-intensity projection reconstruction (a) and volume-rendering technique (b) reconstruction, showing a LHA coming from the LGA (white arrows) and feeding the entire liver. Only one case was found in our collection.

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Fig. 2: Coronal volume-rendering technique reconstruction illustrating a double hepatic vascularization right-left, accompanied by a GDA coming from the CT (white arrow). This variant of the GDA was seen in 39% of the double right-left hepatic vascularizations.

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Fig. 3: Coronal maximum-intensity projection reconstruction showing a triple hepatic vascularization. Three arteries feed the liver: RHA, MHA and LHA. The GDA arises from the MHA (white arrow).

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**Fig. 4:** Sagittal volume-rendering technique reconstruction showing an origin variant with a complete celiaco-mesenteric common trunk (CMCT). The small vessel arising from the aorta above the CMCT (white arrow) is a diaphragmatic artery.

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Fig. 5: Coronal maximum-intensity projection reconstruction showing a variant in course. Coming from the SMA, the RHA (white arrow) runs across the pancreas and feeds the entire liver.

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**Fig. 6:** Coronal maximum-intensity projection reconstruction illustrating a variant in course. The left branch of the MHA (white arrow) is within the fissure of ligamentum venosum, where the right gastric artery can be seen (arrowhead).

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Fig. 7: Coronal (a) and axial (b) maximum-intensity projection reconstruction showing a variant in course. The MHA (white arrows) has a descending path, behind the portal vein (white stars).

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Fig. 8: The new classification and its different steps. Abbreviations: NO: normal origin, NC: normal course. a. The used nomenclature the new classification. LHA: left hepatic artery. MHA: median hepatic artery. RHA: right hepatic artery. b. Right hepatic artery variants in origin and in course found in our collection. The RHA can arise directly from the CT (O1), or from the aorta (O2). Also, it can have a pre-portal course (C2), associated to a trans-pancreatic course (C3). c. Left hepatic artery variant in origin. A branch coming from the MHA, before the hepatic hilum, has the same course that the classical LHA by crossing the ligamentum venosum fissure. d. Median hepatic artery variants in origin and in course found in our collection. MHA can arise from the aorta, associated to a common splenic-left gastric common trunk (1.), or if the CT is absent (3.). Also, it can arise from a coeliaco-mesenteric common trunk (2.). The MHA can have a retro-portal course (C1).
Fig. 9: Sagittal volume-rendering technique reconstruction (a) and coronal maximum-intensity projection (b) reconstruction, illustrating a Bühler’s arch. A vertical anterior arterial vessel (white arrows) links the CT to the SMA.

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Fig. 10: Axial maximum-intensity projection (a) and coronal volume-rendering technique (b) reconstructions illustrating a median-right hilar anastomosis. The RHA (white arrows)
coming from the SMA gets anastomosed with the right branch of the MHA (black arrows), inside the hepatic hilum (arrowheads).

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Fig. 11: Axial oblique maximum-intensity projection reconstruction (a) and coronal volume-rendering technique (b) reconstruction, showing a median-right extra hilar anastomosis. A small RHA (white arrow) is anastomosed with the right branch of the MHA outside of the hepatic hilum.

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Fig. 12: Coronal maximum-intensity projection reconstruction showing a left-right anastomosis. The LHA crosses the fissure of ligamentum venosum, and get linked to the RHA at the hepatic hilum (with arrow).

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**Fig. 13:** Coronal maximum-intensity projection reconstruction showing an ectopic birth of the LGA from the SMA (white arrow).

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Fig. 14: Coronal maximum-intensity projection (a) and volume-rendering technique (b) reconstructions showing an ectopic birth of the SA coming from the SMA (white arrows).

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Conclusion

Planning surgical and interventional procedures requires expert knowledge of arterial vascularization. If it exists, a perfect description of every possible arterial variant is needed. In-depth knowledge of arterial vascularization can reduce per-operative bleeding and increase the success of partial liver transplantation (1, 2, and 11).

Vascular embryogenesis starts within the third week of amenorrhea. Branches coming from the dorsal aspect of the under-diaphragmatic aorta show a "metameric distribution", also called Mackay's arches (12, 13, 14 and 15). The ventral arches (or visceral arches) can have multiple anastomoses. The disappearance of some of these anastomoses is the consequence of merging or obliterating processes (16). Finally, only two main axes persist: the celiac axis and the superior mesenteric axis (13, 16). Any change in this process could result in the existence of arterial variations. Even though these embryological theories have been proved by dissection, the factors that influence the frequency of different variants and the existence of rare variants were not well established (13, 14, and 16).

Rare variants are listed in the literature at frequencies of 0.02 to 4.11% (2, 10). They are probably caused by the persistence of one or more embryological anastomoses involving MacKay's arches (15).

In our collection, case n° 4 of vascular anastomosis was of particular interest: besides its scarcity, it does not have a good embryological explanation. Indeed, although celiac-mesenteric embryological anastomoses are documented, the existence of an embryological anastomosis between left gastric arterial vascularization and the superior mesenteric is not obvious (16, 10). However, if anastomoses between the celiac and superior mesenteric axes occur, then anastomoses between the different arteries of the CT (in particular the LGA) and the superior mesenteric axis can also exist. This is even more plausible if we know the existence of an ectopic LGA coming from the SMA: such a case of this was found in our collection (Fig. 13 on page 28). For these reasons, a purely descriptive nomenclature was chosen in our classification, which enabled us to "name" the variants regardless of their embryological meaning.

Despite the retrospective nature of this study, our new classification has numerous advantages. It allows simple assessment of arterial abdominal anatomy, it is easy to use and can be understood by all medical practitioners. It also combines the three variants of arterial blood supply: number, origin and course. Using this classification, we were able to describe all the variants found, using simple vocabulary that is especially useful for surgeons and interventional radiologists.
Anatomical variants of other arteries (GDA, LGA, and SA) are less frequent and have been reported in the literature (17, 18 and 19). The existence of these variants is another reason to support the existence of embryological vascular anastomoses between the different axes, and confirms embryological theories. The real interest of these variants is in surgery, especially within the pancreatic area. Also, the increased indications for arterial chemo-embolization confirm the value of having good knowledge of these variants (11). Their diseases (such as pseudo-aneurisms) are rare, but challenging, which highlights once again the importance of correct and accurate reports (20).
Fig. 13: Coronal maximum-intensity projection reconstruction showing an ectopic birth of the LGA from the SMA (white arrow).

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References


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