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Research article

Anatomical variations of the renal arteries: Cadaveric and radiologic study, review of the literature, and proposal of a new classification of clinical interest

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ABSTRACT

Purpose: To analyse the variations of the renal arteries in two samples, cadaveric and computerized tomographic (CT) images, as well as to propose a simple classification of such variations based on the obtained results and an extensive review of the literature on the topic.
Material and methods: Sixty human dissected kidneys and their vessels, and 583 abdominal CT were studied.
Results: A total of 86 arteries were described in the cadaveric sample, whereas 1223 were analysed in the radiological one. Five types (a–e) and patterns (I–V) have been stablished in the classification. Type a, aortic hilar artery, incidences were 79% in cadavers and 95% in CT; Type b, hilar upper polar artery, incidences were 10% in cadavers and 2% in CT; Type c, aortic upper polar artery, incidences were 5% in cadavers and 2% in CT; Type d, aortic lower polar artery, incidences were 3% in cadavers and 1% in CT; Type e, hilar lower polar artery, incidences were 2% in cadaver and less than 0.1% in CT. The pattern represents the number of arteries reaching one kidney. Patterns I–IV were found in cadavers (I: 78%; II: 19%; III and IV: 2%); in CT sample only patterns I (88%) and II (12%). Pattern V was added because it has been described in the reviewed literature.
Conclusions: Type a and pattern I are the most prevalent, both in the cadaveric and the CT samples. Also in the consulted literature. There are no differences in the types and pattern incidences by side or sex. A simple, comprehensive and useful classification is proposed.

1. Introduction

There is significant variation in the anatomy of the renal arteries. These anatomical variations are of clinical and scientific interest, not only because knowledge of them is necessary when performing renal surgery or transplantation (Gray, 1906; Gillaspie et al., 1916; Troppmann et al., 2001; Aydin et al., 2004; Mazzuchi et al., 2005; Shakeri et al., 2007; Arévalo Pérez et al., 2013), but also when undertaking newer techniques such as catheter-based renal denervation using radio frequency ablation therapies in patients with resistant hypertension (Nathan, 1958; Vink et al., 2002; Fleischmann, 2003; Aydin et al., 2004; Atherton et al., 2012). Moreover, it has been described that the course of the lower polar arteries originating from the aorta may compromise the route of the ureter, being a cause of hydronephrosis (Graves, 1956; Bordei et al., 2004).

Usually, two renal arteries, arising from the aorta at the level of the second lumbar vertebra, are described, with the right renal

Abbreviations: CT, computed tomography; MDCT, multiple detector computed tomography; MPR, multiplanar reformatted image; MIP, maximum intensity projection image; ha, single hilar renal artery; hup, hilar upper polar renal artery; aup, upper polar renal artery; alp, lower polar renal artery; hlp, hilar lower polar renal artery.

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Table 1
Chronologic table showing the results recorded from some of the main studies on the renal arteries. The data reported in the literature cited have been adapted to our proposed classification.

Author reference	Year	n	Sample	Type a %	Type b %	Type c %	Type d %	Type e %
Weinstein et al. (1940)	1940	656	Cadaver	414 63.1%	56 8.5%	32 4.9%	63 9.6%	63 9.6%
Merklin & Michels (1958)	1958	260	Cadaver	220 84.6%	23 8.8%	14 5.4%	1 0.4%	2 0.8%
Geyer & Poutasse (1962)	1962	866	Arteriography	844 97.5%	0 –	11 1.3%	11 1.3%	0 –
Sampaio & Passos (1992)	1992	406	Cadaver	319 78.6%	47 11.6%	19 4.7%	18 4.4%	3 0.7%
Khamanarong et al. (2004)	2004	637	Cadaver	579 90.9%	0 –	39 6.1%	19 3.0%	0 –
Kornafel et al. (2010)	2010	459	Computed Tomography	403 87.8%	0 –	20 4.4%	36 7.8%	0 –
Our sample	2016	86	Cadaver	68 79.0%	9 10.5%	4 4.7%	3 3.5%	2 2.3%
Our sample	2016	1309	Computed Tomography	1247 95.3%	23 1.8%	22 1.7%	16 1.2%	1 0.07%

artery being longer and often located more superiorly than the renal artery on the left (Merklin and Michels, 1958). A single renal artery is present on each side in about 70% of individuals but variations are common, and variations have been described in the number and origin of the renal arteries and their terminal division as they enter the kidney (Graves, 1956; Lippert and Pabst, 1985; Bergman et al., 1988). The most frequent variations are additional arteries arising directly from the abdominal aorta, or more rarely from the celiac trunk or superior mesenteric artery (Lippert and Pabst, 1985). These accessory renal arteries normally originate from the aorta, either above or below the principal renal artery, with variations in number being described as ranging between 2 and 7, and have been classified as hilar, upper polar and lower polar (Hollinshead, 1966; Lippert and Pabst, 1985; Bergman et al., 1988). Numerous studies have been published, using a range of methods in which these variations have been classified in more detail and their incidences estimated. Studies have been based either on cadaveric samples (Macalister, 1883; Rupert, 1915; Weinstein et al., 1940; Merklin and Michels, 1958; Sampaio and Passos, 1992; Satyapal et al., 2001; Khamanarong et al., 2004; Saldarriaga et al., 2008), aortography images (Boijsen, 1959; Geyer and Poutasse, 1962; Kinkaid and Davis, 1966; Özkan et al., 2006), Doppler techniques (Degani et al., 2010), or images derived from computed tomography CT studies (Fleischmann, 2003; Kornafel et al., 2010; Bouali et al., 2012). There are significant discrepancies in the findings between these studies and differences in their classificatory schemes and in the literature consulted. There are no studies that have combined both cadaveric and radiological samples (Table 1).

Therefore, the aim of this study is to revisit the variations of the renal arteries in our own cadaveric and CT samples and, based upon an extensive review of the main literature, to correlate our results with those already published to propose a simple classification of such variations based on types and patterns that take every case reported into account (Table 1).

2. Material and methods

Our research is based on the study of two different samples: cadaveric and a series of CT images (Table 1).

2.1. Cadaveric sample

A total of 30 donated adult human embalmed cadavers (Valderrama-Canales et al., 2015) from the Corpses Donation Centre of the Complutense University of Madrid were used for this study, allowing for the study of 60 kidneys and 86 arteries. The data were obtained from dissections performed by undergraduate medical students and thereafter completed by three of the authors (Cases, García-Zoghby, and Manzorro). None of the cadavers included in the study had any known history of kidney surgery, renal atrophy, renal malformations, or abnormal kidney migration; also, all the corpses had two kidneys. After dissection of the peritoneal contents, the kidneys and great vessels were removed *en bloc* from each cadaver, labelled with a code, and preserved in boxes until further dissection was undertaken. Unfortunately, the information about sex and age of the tissue was accidentally lost.

2.2. Radiological sample

This study complies with current ethical considerations and was approved by the institutional review board of the Hospital and all participants signed an informed consent form. In compliance with the Declaration of Helsinki, especially in reference to Article 23, to preserve the privacy of patients personal data were never known outside the purview of the doctors who treated them. Using the Picture Archiving and Communication System, we retrospectively reviewed the archives of the Clínico San Carlos Hospital Radiology Department for patients who had undergone abdominal multiple detector computed tomography (MDCT) angiography examination over a period of 15 months (January 2012–April 2013). All of the patients had undergone CT angiography for the abdominal aorta and its branches using a 64 slice General Electric Optima and a 64 slice Phillips Brilliance 190p. The scan included the renal arteries and covered the area at least from the level of the diaphragm to the iliac bifurcation. The scanning parameters were as follows: 120 kVp; 150–500 mAs; 0.6 gantry rotation time; 0.625 mm slice thickness; 40 × 0.6 mm collimation; pitch 0.984. In all the patients, 100 mL of iodinated contrast (Lobitridol 300 mgI/mL, Xenetix) was injected into the brachial vein with an automated injector at a flow rate of 4 mL/s. Arterial phases were obtained using bolus tracking systems at the level of the descending aorta.

Initially, we selected 609 CTs with intravenous contrast (410 males, 198 females). Several CTs were excluded for various reasons (post-surgical images, low quality, or duplications). Finally a total of 583 CTs were analysed (393 were from males, and 190 from females; 1166 arteries), aged between 42 and 88 years. All MDCT angiograms were evaluated and interactively processed on dedicated workstations (ADW 4.5, GE Medical Systems to build multi-planar reformatted (MPR) and maximum intensity projections (MIP) using IMPAX software. CT images in axial view required a three-dimensional reconstruction using MIP and MPR. The authors were trained in the use of IMPAX software, and also in applying MPR and MIP projections, and the interpretation CT sample was revised by the authors under supervision by a radiol-