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Case Report

A Cadaveric Study on the Anomalous Origin of Renal and Gonadal Vasculature: An Observational Study

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Abstract

Background: Due to the increasing prevalence of kidney transplantation, a greater awareness of variations in the surrounding vasculature is of surgical importance. During embryological development, both the renal and gonadal arteries arise from the lateral mesonephric branches of the dorsal aorta. In adults, gonadal arteries are paired vessels that normally arise from the aorta at the level of the second lumbar vertebra. **Methods:** Routine cadaveric dissection completed by first-year medical and dental students incidentally revealed anatomical anomalies. **Results:** We describe two cadaveric findings in males that demonstrate unilateral and bilateral variations of testicular arteries originating from an aberrant renal artery in one case and an accessory renal artery in the second case. **Conclusion:** By increasing awareness of anomalous testicular arteries, we aim to encourage the standardization of preoperative vasculature exploration to minimize intraoperative risk to living male kidney donors and increase patients' understanding of the potential risks and complications prior to consenting to the procedure, providing more accurate information prior to surgery.

Key Words: Renal Transplantation; Congenital Abnormality; Medical Imaging; Dissection (Source: MeSH-NLM).

Introduction

The number of kidney transplants performed globally has increased each year. The number of transplants were: 17,611 in 2015, 19,061 in 2016, 21,028 in 2017, 22,393 in 2018, and 24,273 in 2019.[1,2] Over the past decade, 62% of countries have reported at least a 50% increase in the number of living kidney donor transplants.[3] The outcomes of recipients of deceased donors include a one-year survival rate of 95.4%, five-year survival of 79.7%, and an adjusted ten-year survival rate of 49.2%. In comparison, the outcome of recipients of living donors had a one-year survival rate of 98.8%, five-year survival of 88.0%, and an adjusted ten-year survival rate of 61.5%.[2] Given the greater potential for survival with living donors, it is important to create a standard screening and informed consent process to increase the safety of living donors, which may lead to more individuals feeling safe enough to sign up as living donors.[2]

Highlights:

- These cases highlight the clinical relevance of post-mortem finding of anomalous origins of the testicular artery in conjunction with aberrant renal vasculature.
- Acknowledging the existence of the aforementioned vascular anomalies becomes clinically relevant for male kidney donors, as ligation of renal vasculature during surgery poses a post-surgical risk to the testes in such cases.

In the embryo, three sets of lateral mesonephric arteries branch off the aorta: caudal, middle, and cranial. As the kidney ascends from its initial position in the pelvis to its more cranial position in the abdomen, its arterial supply also transitions from caudal to middle to cranial. Typically, the last branch of the middle group or the first branch of the caudal group becomes the main renal artery while the rest regress.[4] It is postulated that if one of the rest of the branches does not regress, they may persist as accessory renal arteries.[5] Of the caudal arteries, one will typically persist and differentiate into the gonadal artery. It is speculated that if one of the middle groups of lateral mesonephric arteries persists, it will give rise to a gonadal artery that originates from the main or accessory renal artery rather than the aorta.[6]

There are numerous possible embryological manifestations of gonadal and renal artery anatomy. There are many proposed classification systems for these manifestations,[6-8] most comprehensively by Kayalvizhi et al., who proposed a system that indicates four primary groups of variations: Group I arising from the abdominal aorta, Group II arising from the renal trunk, Group III arising from a suprarenal branch, and Group IV arising from any other vasculature. According to this system, further

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classification can be made on the basis of specific branch points in Groups I and II.[9]

Renal arteries normally arise from the abdominal aorta at the level of the second lumbar vertebra.[10] In both sexes, the gonadal arteries arise from the anterolateral surface of the abdominal aorta, typically below the level of origin of the renal artery but superior to the origin of the inferior mesenteric artery (L3).[10]

In both sexes, the gonadal artery travels along the superficial surface of the psoas major muscle in the retroperitoneum.[10] In males, the gonadal artery is known as the testicular artery, which enters the inguinal canal through the deep inguinal ring, where it proceeds down to the testes.[10] In addition to supplying oxygenated blood to the testes, the testicular artery is involved in countercurrent temperature exchange with the pampiniform plexus of veins. This venous plexus functions to maintain a slightly cooler temperature within a very narrow range to accommodate spermatogenesis. In females, the gonadal artery is referred to as the ovarian artery. It travels superficially to the psoas major muscle, down the suspensory ligament of the ovary, enters the mesovarium, and may form an anastomosis with the uterine artery in the broad ligament.[10]

A common variation of renal vasculature is the presence of an "accessory renal artery," which has been estimated to be prevalent in up to 30% of the general population.[11] The accessory renal artery follows the path of the main renal artery to the renal hilum and arises from the aorta either below or above the main renal artery. A second known variation is an "aberrant renal artery," which differs from an accessory renal artery in that it crosses anteriorly to the inferior vena cava instead of posteriorly.[12]

Variations in renal vasculature are often accompanied by variations in gonadal artery origin. In this report, the following anomalies of gonadal artery vasculature and how they relate to variations in renal vasculature will be outlined: gonadal arteries arising from (1) a normal renal artery, (2) an aberrant renal artery, and (3) an accessory renal artery.

Methods

During cadaveric dissection by first-year medical and dental students at the Department of Anatomy and Cell Biology at New York Medical College, USA, 58 cadavers were dissected during the 2018-2020 academic years. All cadavers were well-embalmed and provided for academic dissection. Cadavers were chosen for inclusion based on availability sampling. In 2018, 21 female and 8 male cadavers were dissected. In 2019, 11 male and 18 female cadavers were dissected. Cadavers dissected prior to 2018 were excluded due to insufficient data collection. Cadavers with unidentifiable gonadal arteries due to improper dissection were also excluded. In routine academic dissection, the retroperitoneal structures of each cadaver were dissected following the instructions outlined in Grant's dissector.[13]

Figure 1. 2018 Male Cadaver; Left Gonadal Artery with Origin on Accessory Renal Artery, Right Gonadal Artery with Origin on Normal Renal Artery.

Legend: a. Superior mesenteric artery; b. Left adrenal vein; c. Left renal artery; d. Left kidney; e.* Left accessory renal artery; f. Left renal vein; g. Aorta; h. Left gonadal vein; i.* Left gonadal artery; j. Ureter; k. Right kidney; l. Right renal vein; m. Left renal vein; n. Right renal artery; o.* Right gonadal artery; p. Right gonadal vein; q. Inferior vena cava; r. Aorta.

The dissection occurred as follows: First, the posterior abdominal viscera were palpated, and the parietal peritoneum was removed. The renal fascia and the kidneys were opened, and the suprarenal glands were noted. Next, the testicular arteries were identified at the

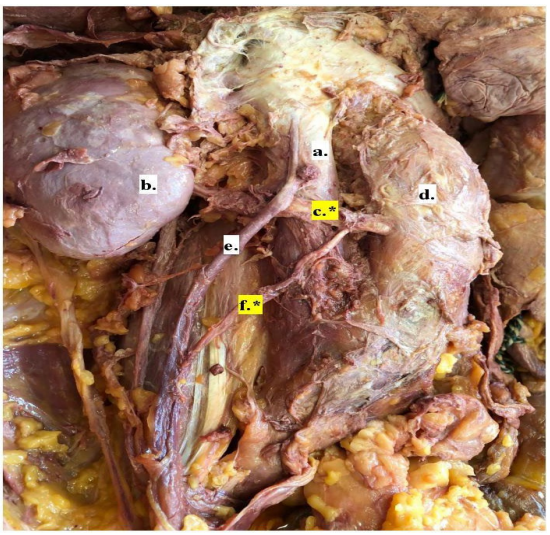
deep inguinal ring. The arteries were dissected cleanly, progressing superiorly along the retroperitoneal space to their origin on the abdominal aorta. Next, the renal veins were identified and followed to the inferior vena cava. Finally, the renal arteries were identified posteriorly to the renal veins and followed back to the abdominal aorta. Upon completion of the cadaveric dissection, variants of the renal and testicular arteries were noted and recorded.

Results

One male cadaver (2018) was incidentally identified to have bilateral variants with a left accessory renal artery (*Figure 1e*) from which the left testicular artery originated (*Figure 1i*), and a single right renal artery from which the right testicular artery originated (*Figure 1o*). A second male cadaver (2019) was also incidentally identified to have a unilateral variant on the right side where the testicular artery originated (*Figure 2f*) from an aberrant renal artery (*Figure 2c*). The renal vasculature of the second cadaver dissected in 2019 was not observed on the left side due to prior dissection of the entire kidney and associated vasculature.

In summary, 2 out of the 19 males presented with variations of anomalies in renal or testicular vasculature. No renal or ovarian vasculature anomalies were observed in the 39 females in our cohort. Other demographic, clinical, and social characteristics of the cadaver population were not known.

Figure 2. 2019 Male Cadaver; Right Gonadal Artery with Origin on Aberrant Renal Artery.



Legend: a. Inferior vena cava b. Right kidney c.* Aberrant right renal artery d. Aorta e. Right gonadal vein f.* Right gonadal artery

Discussion

Classification of Variations in Testicular and Renal Arteries

Using the Kayalvizhi et al. classification system,[11] the variations observed in our cadaver study are classes IIB (from an accessory renal branch) and IIC (from an aberrant renal branch).

Prevalence

In our cohort, two male cadavers presented with variations of anomalies in renal or testicular vasculature, suggesting a prevalence of approximately 10.5% among males; and no anomalies existed in the female subgroup, suggesting an overall prevalence of 3.4%. This is considerably less than some of the reported estimates in the literature,[12] presumably due to the small sample size. The higher prevalence in males corresponds well with previous findings,[7] which report a higher prevalence on the left side (81.23%) compared to the right side in cases with unilateral anomalous arteries.[14] One study found that 25% of cases occurred bilaterally.[14]

Method of Identification and Significance

Understanding atypical anatomic presentations of the renal and gonadal vasculature is essential prior to renal and testicular surgery in order to mitigate the associated risks. We speculate that the surgical risks posed by the unfamiliar vasculature during nephrectomy, including longer operation times, increased blood loss, and greater risk of complications associated with unfamiliar vasculature,[15] are greater for male kidney donors because the testicular artery provides the most significant blood flow to the testes. Aside from their surgical significance, the variations in renal vasculature or origin of the gonadal vasculature do not present with any clinical manifestations and are often discovered during surgery or post-mortem.

Imaging

There is currently no standardized imaging in the United States for the preoperative screening of a kidney donor. However, magnetic resonance imaging (MRI) and computed tomography scan (CT) are commonly used to assess the anatomy of the kidney, vasculature, and urinary collecting system in living donors.[16] Although necessary for the preoperative workup, both MRI and CT are considered suboptimal for visualizing anomalous gonadal vasculature involving the kidney.[17] CT Angiography remains the gold standard for visualizing the gonadal and renal vessels, although it is not universally used.[18] Doppler ultrasound of the renal hilum is a quick and effective diagnostic procedure that could be alternatively implemented to screen for the presence of atypical renal vasculature prior to surgery for male kidney donors after a statistically significant proof of a higher risk to male donors has been established. This method is preferred over conventional sonography as it provides functional and vascular information, locating the presence and blood flow of vessels. It can also be a useful tool to assess the donor organ for fibrosis, masses, and chronic kidney disease.[19] Research suggests that the presence of a gonadal artery with anomalous origin is often associated with variants in renal vasculature.[15,20] The presence of atypical renal vasculature in the living donor might raise suspicion in the physician regarding variants in gonadal vasculature, and therefore, arteriography can be performed to further investigate the anatomy of the gonadal arteries. As the global rate of kidney transplantation has risen in past decades,[2] a standardization of screening methods to minimize risks for transplant candidates is increasingly important.

In addition to the lack of preoperative imaging, there is currently no standardized procedure for obtaining informed consent from the donor for nephrectomy, and research has shown that donors often make their decision based on moral beliefs and without full knowledge of the scope of potential complications.[21]

Surgical Risks

Variations in renal and gonadal vasculature are associated with intraoperative and postoperative risks to living donors. In living donors, if a variation in gonadal vasculature is unknown prior to surgery, it may result in the ligation of the donor's gonadal artery at the surgeon's discretion in the process of obtaining the donor kidney. In a male, the testicular artery provides the most significant blood flow to the corresponding. We speculate that ligation of this artery could contribute to the possible risk of complications to the testes following the procedure, including loss of the temperature regulation system of the testes. The ovaries have a dual blood supply supported by the ovarian and uterine arteries, lowering their potential risk of cutting complete supply to the female gonads. Post-operative outcomes of testicular ligation are not well-reported, so the risks of ligation remain unclear. However, current available research suggests that the incidence of adverse outcomes to the testes following testicular artery ligation is low.[13,14,21,22] Vascular variations such as these are of significance with the implementation of laparoscopic procedures, as unfamiliar anatomy in the surgical field is a common contributing factor to intraoperative complications.[23] In laparoscopic donor nephrectomy, multiple arteries were associated with longer operation times and increased blood loss during surgery.[20] In surgeries other than donor nephrectomy, certain variants of anomalous gonadal vasculature are absolute contraindications for surgical treatment; for example, a gonadal artery originating from the inferior polar renal artery can be a major contraindication for percutaneous treatment of the syndrome of the pyelo-ureteral junction.[14] Without preoperative awareness of the existence of certain variants in the vasculature and the risks associated with them, the donor is left to consent without full knowledge of the scope of potential intraoperative and postoperative complications.

Previously, to reduce the risk of unintentional ligations, surgeons would perform a "time-out" where all key structures would be identified. While implementing this strategy decreases the incidence of gonadal artery ligation, adding a pre-procedure US-Doppler could cut down on operation time, hence enhancing overall institutional efficiency, and over time have a beneficial impact financially due to reduced time per procedure in the operating room.

Limitations

Our estimates for the prevalence of atypical gonadal and renal vasculature are limited by availability sampling and the incidental nature of their discovery. In this observational study, all provided cadavers were screened according to our inclusion and exclusion criteria, as previously mentioned. Our cases were discovered by medical students who are in the process of familiarizing themselves with the procedures of cadaveric dissection and with typical anatomy. This is a potential source of selection bias, as candidates for inclusion may have been damaged in the process. Nonetheless, no cadavers met exclusion criteria and all were dissected under the direct supervision of physicians. The prevalence results of this sample cannot be generalized to the general population due to the small size and potential of misrepresentation in the sample compared to the general population. We accounted for the limited number of cadavers studied at the school by including data from multiple years to increase our sample size. Furthermore, due to limited access to cadaver demographic information, no conclusions can be made on how these results can be applied to specific demographic populations. Given the frequent clinical insignificance of these anomalies for the general population, much of our knowledge of these variants and their respective prevalence comes from post-mortem findings. We acknowledge that our results have limited external validity because of the aforementioned limitations, but are clinically valuable to raise awareness of the necessity of renal and gonadal vasculature screening.

Summary – Accelerating Translation

Title: A Cadaveric Study on the Anomalous Origin of Renal and Gonadal Vasculature: An Observational Study.

Main problem to solve: Due to the increasing prevalence of kidney transplantation, a greater awareness of variations in the surrounding vessels is important to surgeons and patients. During development, the renal and gonadal arteries arise from branches of the same vessels. In adults, gonadal arteries are paired vessels that normally arise from the aorta. Variations in vessels can be detected prior to surgery with imaging, although currently, there is no agreed-upon standard of pre-surgical screening.

Aim of study: To illustrate variations in vessels that supply the kidneys and the gonads; to explore the benefits of different imaging modalities.

Methodology: Routine cadaveric dissection completed by first-year medical students and dental students incidentally revealed anatomical variations.

Results: We describe two cadaveric findings in male cases which demonstrate unilateral and bilateral variations of testicular arteries originating from an aberrant renal artery in one case and an accessory renal artery in the other.

Conclusions: By increasing awareness of variations in testicular arteries, we hope to encourage the standardization of preoperative vasculature exploration to minimize intra-operative risk to living male kidney donors and increase patients' understanding of potential risks and complications prior to consenting to the procedure, providing more accurate information prior to surgery.

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Conflict of Interest Statement & Funding

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Compliance with ethical standards:

This study has authorization for the use of cadaveric images for educational publications. This study does not contain any identifiable patient data which would require informed consent. This study was in accordance with the Human Anatomy Act of the laws of the United States of America.

Author Contributions

Conceptualization: DQ; Supervision: DP; Writing – Original Draft Preparation: PF, DM, LB, JN, DQ; Writing – Review & Editing: PF, DM.

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