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Research article

Fetal development of the mesonephric artery in humans with reference to replacement by the adrenal and renal arteries

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ABSTRACT

According to the classical ladder theory, the mesonephric arteries (MAs) have a segmental arrangement and persist after regression of the mesonephros, with some of these vessels becoming definitive renal arteries. To avoid interruption of blood flow, such a vascular switching would require an intermediate stage in which two or more segmental MAs are connected to a definitive renal artery. To examine developmental changes, especially changes in the segmental distribution of MAs, we studied serial paraffin sections of 26 human embryos (approximately 5–7 weeks). At 5–6 weeks, 1–2 pairs of MAs ran anterolaterally or laterally within each of the lower thoracic vertebral segments, while 2–5 pairs of MAs were present in each of the lumbar vertebral segments, but they were usually asymmetrical. The initial metanephros, extending along the aorta from the first lumbar to first sacral vertebra, had no arterial supply despite the presence of multiple MAs running immediately anterior to it. Depending on increased sizes of the adrenal and metanephros, the MAs were reduced in number and restricted in levels from the twelfth thoracic to the second lumbar vertebra. The elimination of MAs first became evident at a level of the major, inferior parts of the metanephros. Therefore, a hypothetical arterial ladder was lost before development of glomeruli in the metanephros. At 7 weeks, after complete elimination of MAs, a pair of symmetrical renal arteries appeared near the superior end of the metanephros. In conclusion, the MAs appear not to persist to become a definitive renal artery.

1. Introduction

Felix observed the mesonephric arteries (MAs) in an 18-mm human embryo and superimposed the results onto a contour drawing of the suprarenal gland, mesonephros, metanephros (definitive kidney) and gonad of a 19.4-mm embryo (Keibel and Mall, 1912). Using the superimposed diagram, he postulated the so-called "ladder theory", according to which all of the segmental MAs are thought to persist and change into (become re-used as) the definitive phrenic, adrenal, renal, accessory renal, gonadal, and accessory gonadal arteries. Thus, according to Felix, the definitive kidney or metanephros, which initially develops near the aortic bifurcation, "climbs" to its final position up a ladder of MAs during the so-called process of renal ascent. Even in recent reports, this ladder theory has been employed to explain variations of the renal arteries in adults (Adamakis et al., 2013; Narita et al., 2012). Somewhat similar to the ladder theory, Evans proposed his famous "network theory", which states that arteries and veins are selected from primitive capillary beds by blood flow (Evans, 1909). An initial vascular network around the rat metanephros (rather than the mesonephros) was recently demonstrated by Isogai et al. (2010) using their excellent injection method.

Both the network theory and the ladder theory seem to be based on the assumption that the dorsal aorta loses the ability to sprout new vessels at a very early stage. There have been several detailed studies of the ladder theory (Hochstetter, 1893; Isogai et al., 2010;

Abbreviations: AO, dorsal aorta; AD, adrenal; C, colon; CA, celiac artery; CBD, common bile duct; DP, dorsal pancreas; F, femur; FN, femoral nerve; G, gonad; GL, celiac ganglia; IL, ileum; IMA, inferior mesenteric artery; IN12, twelfth intercostal nerve; IVC, inferior vena cava; K, metanephros or definitive kidney; L, liver; LA, lumbar artery; LN1-3, first-third lumbar nerves; M, mesonephros; ON, obturator nerve; P, pubis; PCV, posterior cardinal vein; R, rectum; SCA, subcostal artery; SMA, superior mesenteric artery; SMV, superior mesenteric vein; SP, spleen; ST, stomach; SV, subcardinal vein; UA, umbilical artery; UGA, urogenital sinus; UR, ureter; VP, ventral pancreas; WD, Wolffian or mesonephric duct.

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Table 1
Development of the adrenal gland and metanephros disturbs the segmental arrangement of the mesonephric arteries at 5-6 weeks.

	Adrenal (elimination of MAs)	Metanephros (elimination of MAs)	Corresponding figures
SH-5 (6 mm)	+ (+)	+ (−)	
OY-4 (5 mm)	−	−	Fig. 1A–C
SH-6 (6 mm)	+ (−)	+ (−)	
GT (7 mm)	−	−	Figs. 1D, E and 5
SH-8 (8 mm)	+ (+)	+ (−)	
BOT (9 mm)	+ (−)	−	
SH-9 (9 mm)	+ (−)	+ (−)	
PU (10 mm)	+ (−)	+ (−)	
HO (11 mm)	+ (−)	+ (−)	Figs. 4D–F and 5
MAR-4 (12 mm)	−	−	Fig. 2C and D
GV-4 (12 mm)	+ (−)	+ (−)	
MAR (12 mm)	+ (+)	−	Fig. 2A and B
SH-15 (15 mm)	+ (+)	+ (−)	
CIV-2 (16 mm)	+ (+)	+ (+)	Fig. 6
S-12 (17 mm)	+ (+)	+ (+)	Fig. 3
CIV-1 (18 mm)	+ (+)	+ (−)	Figs. 4A–C and 6

Adrenal + Metanephros + the organ is present. Elimination of MAs + segmental arrangement of the mesonephric arteries (MAs) was lost at the level of the developing adrenal gland and/or metanephros.

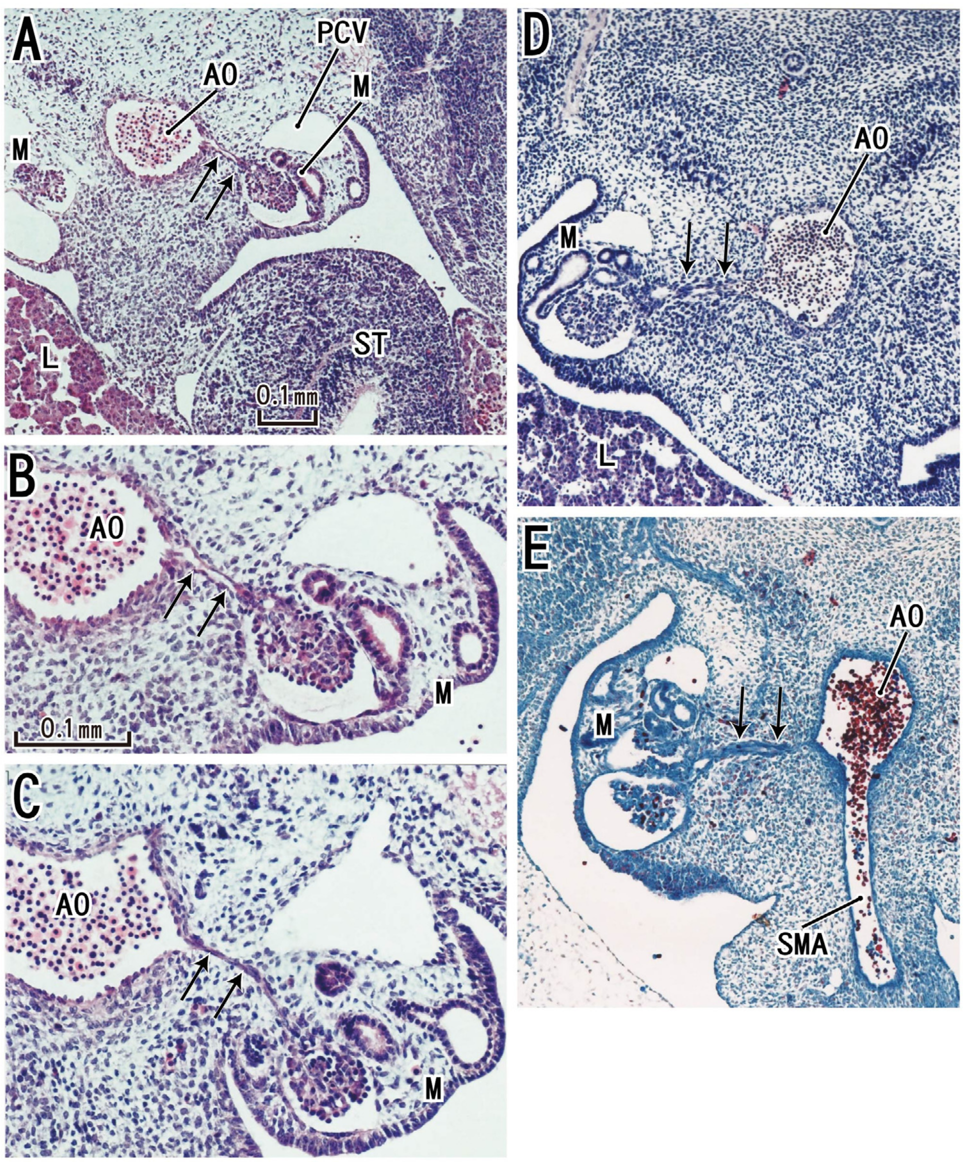

Fig. 1. A mesonephric artery connecting to a glomerulus at 5 weeks. Horizontal sections. HE staining (panels A–C) and azan staining (panels D and C). Panels A–C (or D and E) display a 6-mm embryo (7-mm embryo). Panel B shows a higher magnification view of the mesonephric artery (arrows) in panel A. Panel B–E have the same magnification (scale bar in panel B). Panels A, B, and D are sections at the level of the eleventh thoracic vertebra, while panels C and E are at the twelfth thoracic vertebra. The connection of the mesonephric artery with the glomerulus is clearly seen. All panels were prepared at the same magnification (bar in panel A).