MACROANATOMICAL INVESTIGATION OF THE AORTICORENAL GANGLION IN DOMESTIC PIG (*Sus scrofa domesticus*) IN PERINATAL PERIOD

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Abstract. The macroanatomical research of the aorticorenal ganglion (ARG) was conducted on 14 domestic pigs – 4 males and 10 females of 110 days of gestation. The pigs were obtained from one uterus. The examinations were carried out using the method of macroscopic preparation with a forehead magnifying glass and binocular (magnification 2.0–5.0x). The measurements of the ARG were performed with the aid of an electronic slide-caliper to an accuracy of 0.01 mm. The measurements of studied individuals were summarized with the use of arithmetical means, standard deviation (S.D.) and coefficient of variability (C.V.). According to our study, the ARG is characterized by variable location in relation to the suprarenal gland, the renal artery, the caudal vena cava and the abdominal aorta (syntopy), the thoracic and lumbar segments of the vertebral column (skeletotopy) (between Th_{14}-L_5) and also by a different shape (triangular and elongated). A double ARG was found in two females on the left side of the body, and a triple ARG also on the left in one female near the suprarenal gland and the renal artery. The ARG size and its location in relation to the caudal end of the suprarenal gland were statistically independent of body size, length, and sex.
Keywords: aorticorenal ganglion (ARG), domestic pig, perinatal period.

KIAULIŲ (*Sus scrofa domesticus*) AORTIKORENALINIO NERVINIO MAZGO MAKROANATOMINIS TYRIMAS PERINATALINIU LAIKOTARPIU

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Santrauka. Makroanatominis aortikorenalinio mazgo tyrimas atliktas su 14 naminių kiaulių vaisių: keturiais patinais ir dešimčia patelių. Visi tirti vaisiai išimti 110 vaikingumo dieną iš vienos gimdos. Mikroskopinis tyrimas atliktas naudojant laisvų rankų didinamąjį stiklą ir binokuliarinį mikroskopą (2,0–5,0x). Mazgai išmatuoti naudojant elektroninį slankųjį skriestuvą. Paklaidos dydis – 0,01 mm. Matavimų aritmetiniai vidurkiai, standartiniai nuokrypiai ir kintamumo koeficientai buvo susumuoti. Tyrimas parodė, kad aortikorenaliniai mazgai gali susiformuoti skirtingose krūtinės ląstos arba strėnų ploto vietose (tarp Th_{14}–L_5) ir būti įvairiai išsidėstę antinksčių, inkstų arterijų, tuščiųjų venų ir abdominalinės aortos atžvilgiu. Jiems būdinga trikampė arba pailga forma. Dvigubas mazgas nustatytas dviejų patelių kairiojoje kūno pusėje, trigubas – vienos patelės kairiojoje kūno pusėje netoli antinksčio ir inkstų arterijos. Mazgų dydis ir vieta antinksčio atžvilgiu statistiškai nepriklausė nuo kūno dydžio, ilgio ar lyties.
Raktažodžiai: aortikorenalinis nervinis mazgas, naminė kiaulė, perinatalinis laikotarpis.

Introduction. The aorticorenal ganglion (ARG) is the main component of the coeliac plexus (*plexus coeliacus*), which is entered by the lesser splanchnic nerve (*n. splanchnicus minor*) (Kuder, 2002), and belongs to the paired coeliac ganglion (*ganglion coeliacus*). It is situated between the cranial mesenteric artery (*a. mesenterica cranialis*) and the renal artery (*a. renalis*) (Dyce et al. 1996; Marciniak and Ziółkowski, 1992). The ARG in human is most frequently located above the renal artery, or between the renal artery and the abdominal aorta. In some cases on one side of the body there are two or three smaller ganglia instead of one single ARG; sometimes these ganglia form a whole with the coeliac ganglion (Bochenek and Reicher, 1989). The ARG is connected with the following nerves and communicating rami: the greater splanchnic nerve (*n. splanchnicus major*), the lesser splanchnic nerve, the lumbar splanchnic nerves (*nn. splanchnici lumbales*), the lumbar part of the sympathetic trunk (*pars lumbalis trunci sympathici*), the renal branches (*ramii renales*) and the renal plexus (*plexus renalis*) (Norvell, 1968; Pospieszny, 1977, 1986; Langenfeld, 1981). According to Evans (1993), in the dog the first lumbar splanchnic nerves distribute to one or more of the following aorticorenal, cranial mesenteric and gonadal ganglia. Dolezel et al. (1976) state that the fibres arising from the ARG provide adrenergic terminals found on the glomerular afferent and efferent arterioles and close to the macula densa cells of the kidney. These nerves also supply the vasa recta and the adjacent cortical veins (after Evans, 1993). Our study aiming at the morphological analysis of the ARG in domestic pigs in perinatal period (gestation day 110) presents the syntopy,

skeletotopy, shape and statistical analysis as well as nerve connections. It was a continuation of the research by Pospieszny (1977, 1986), Pospieszny and Klećkowska (2002), Pospieszny et al. (2003) and Klećkowska et al. (2009). The subject of the above mentioned studies was the macroanatomical morphology of the ARG in pigs from week 10 of prenatal period (Pospieszny, 1986), sheep from months 3 to 5 of gestation (Pospieszny, 1977), Persian cats from day 58 of gestation (Pospieszny and Klećkowska, 2002), also in American Staffordshire terriers from day 62 of prenatal period (Pospieszny et al., 2003) and in 1-day-old infant sheep (Klećkowska–Nawrot et al., 2009). Ghoshal and Getty (1969) and Langenfeld (1981) studied the ARG in adult pigs (after Pospieszny, 1986). The morphology of the suprarenal gland, kidney and the ARG and its renal physiology can be found in the studies by Norvell (1968) and Langenfeld (1981).

The aim of this study was the ARG anatomical description in the pig during perinatal period. The study results will be useful for the comparative analysis of mentioned organ. Moreover the perinatal development of the ARG can be a valuable contribution to the nervous system anatomy and domestic mammal embryology.

Material and Methods. Animals. The study was conducted on 14 domestic pigs (4 males and 10 females) in perinatal period (gestation day 110), whose age was determined according to Marrable (1971) and boar books. The pigs were obtained from one uterus. The examined material came from The Institute of Animal Anatomy at the Department of Animal Physiology and Biostructure, Wrocław University of Environmental and Life Sciences. The study material was crossbred offspring of sows pbz (polska biała zwisłoucha) x wpb (wielka biała polska) and wbp x pbz crossed with Duroc and Hampshire boars or their crossbreds with Pietrain. All the procedures had the relevance clearance from the local ethical committee for the use of animal experiments. Material with features of maceration, mummification or decomposition was excluded from the study. All the collected material was fully evidenced including the age, sex, place of birth of all the pigs and the identification number and date of material collection. In all the pigs mean body length measured from the frontal eminence to the ischial tuberosity was calculated (Pospieszny, 1986). The fetuses were kept in 6% solution of formic formaldehyde. The examinations were carried out using the method of macroscopic preparation with a forehead magnifying glass and binocular (magnification 2.0-5.0x). In order to better visualize the ARG and its branches, 0.5-3% acetic acid solution and 60-70% absolute alcohol solution were used for the examinations. The methods used in the topographic anatomy were syntopy and skeletotopy. The terminology used in this study follows Nomina Anatomica Veterinaria (2005).

Statistical analysis. The measurements of the ARG were performed with the aid of an electronic slide-calliper to an accuracy of 0.01mm. The measurements of the studied individuals were summarized with the use of arithmetical means, standard deviation (SD) and coefficient of variability (CV). The significance of the differences in the ARG length and the distance between the ARG and the caudal end of the suprarenal glands between the sexes was tested with the use of the Mann-Whitney test, while the Wilcoxon test was used for testing the differences in the above mentioned variables between the sides of the body. Pearson's correlation coefficient was used to verify the relationships between the ARG and body length.

Results. Gross investigation. In the investigated individuals, the ganglion most frequently was situated on the left before the renal artery (2 males and 10 females); behind the renal artery (2 males and 1 female) and in 1 female it was located under the abdominal aorta. On the right side this ganglion was found before the renal vein in 4 females and 3 males. In 4 females and 1 male the ganglion was situated underneath the caudal vena cava behind the renal vein. In 2 females it was located on the wall of the renal vein. A double ARG was found in 2 females on the left side and a triple ARG – in 1 female, also on the left (Figs. 1–4).

The location of the ARG varied not only among the individuals but also between both sides of the body. On the left side of the body, the ganglion in 4 cases (3 females and 1 male) was located in L_2-L_3 segments. In 1 male and 3 females, it was located at the L_3 height; and in 1 male and 1 female it was in L_2 segment. In 1 male it was situated between L_1 – L_2. In 2 females, the ARG was located in Th_{14} – L_1 segments. In 1 female, a triple ganglion was situated at the L_3-L_4-L_5. On the right side of the body, the ganglion occurred most frequently, i.e. in 5 cases (4 females and 1 male) lying at the L_2 – L_3 height, in 3 cases (2 females and 1 male) lying in L_1- L_2 segments. In 1 female, it was at the L_3 – L_4 height. In 3 individuals (2 females and 1 male), it was located in L_1 segment, and in 1 female and 1 male it was at the Th_{14} – L_1 height (Table 1).

The ARG in the examined animals manifested two forms of shape on both sides of the body: triangular (4 females on the right side, and 1 male and 2 females on the left side) and elongated (oval) (4 males and 6 females on the right side and 3 males and 12 females, including 1 triple and 2 double ARGs on the left side).

We studied the following nerves and communicating rami connected with the ARG (Figs. 1–4):

1. The greater splanchnic nerve is formed by 2–3 nerve rootles which arise from the thoracic ganglia Th_{11} – Th_{14} (Th_{15}), giving off communicating rami. Initially it runs along the lateral plane of the spine, underneath the parietal pleura and communicates with the plexus aorticus in the thorax, the mediastinal organs and the pericardial pleura (*pleura pericardiaca*) by the rami. Next it passes through the aortic hiatus of the diaphragm to the abdominal cavity, where it forms a small ganglion of the splanchnic nerve. This nerve reaches the coeliac plexus and sends rami to the cranial mesenteric ganglion, the ARG and the suprarenal glands.

2. The lesser splanchnic nerve originates at spinal nerve levels Th_{15}– L_1 running between the sympathetic trunk and the greater splanchnic nerve. The lesser splanchnic nerve gives off the majority of communicating

rami to the coeliac plexus, the suprarenal ganglion and the ARG; some fibers, however, reach to the renal plexus along the renal artery.

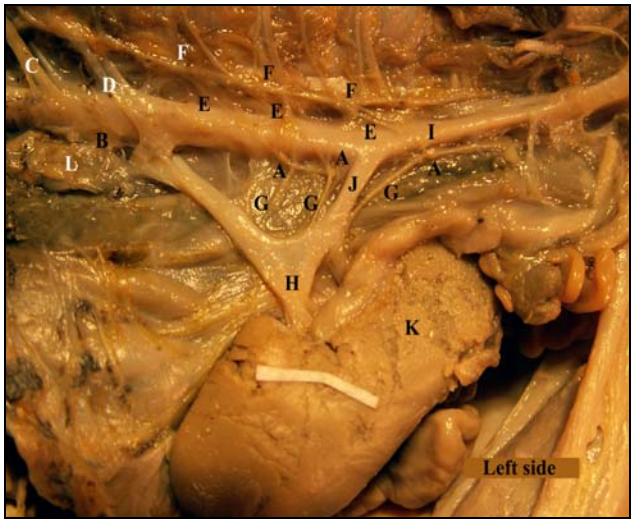

Fig 1. **The triple ARG. The left side. The female**

A – ARG, B – coeliac plexus, C - greater splanchnic nerve, D –lesser splanchnic nerve, E – lumbar splanchnic nerves, F – lumbar sympathetic ganglia, G – renal branches, H – renal plexus, I – abdominal aorta, , J – renal artery, K – kidney, Ł – suprarenal gland

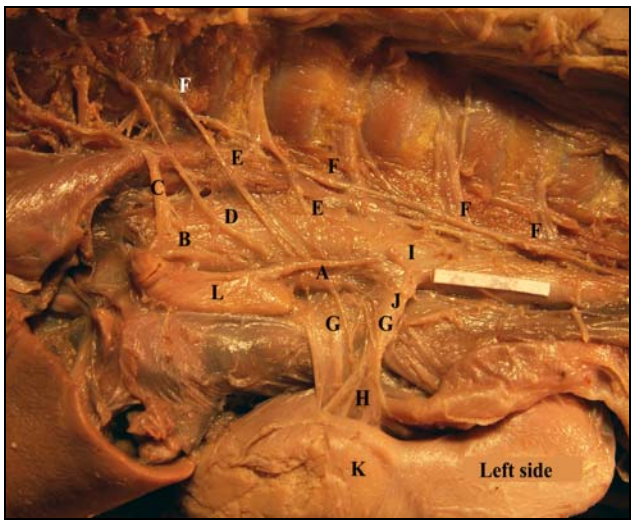

Fig. 2. **The ARG located under the abdominal aorta The left side. The male**

A – ARG, B – coeliac plexus, C - greater splanchnic nerve, D –lesser splanchnic nerve, E – lumbar splanchnic nerves, F – lumbar sympathetic ganglia, G – renal branches, H – renal plexus, I – abdominal aorta, , J – renal artery, K – kidney, Ł – suprarenal gland

3. The lumbar ganglia of the sympathetic trunk (L_1 – L_4) are spindle-shaped and lie medially to the major and minor psoas muscles. They give off lumbar splanchnic nerves (from 3 to 10 on both sides of the body) which join the renal plexus and are connected with the ARG.

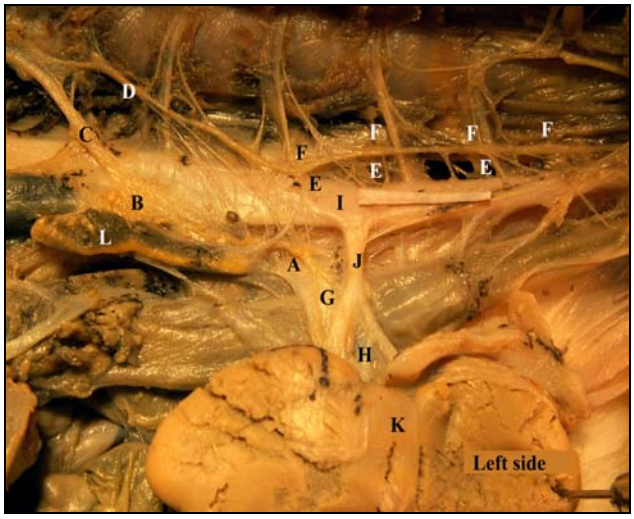

Fig. 3. **The ARG located before the renal artery. The left side. The female**

A – ARG, B – coeliac plexus, C - greater splanchnic nerve, D –lesser splanchnic nerve, E – lumbar splanchnic nerves, F – lumbar sympathetic ganglia, G – renal branches, H – renal plexus, I – abdominal aorta, , J – renal artery, K – kidney, Ł – suprarenal gland

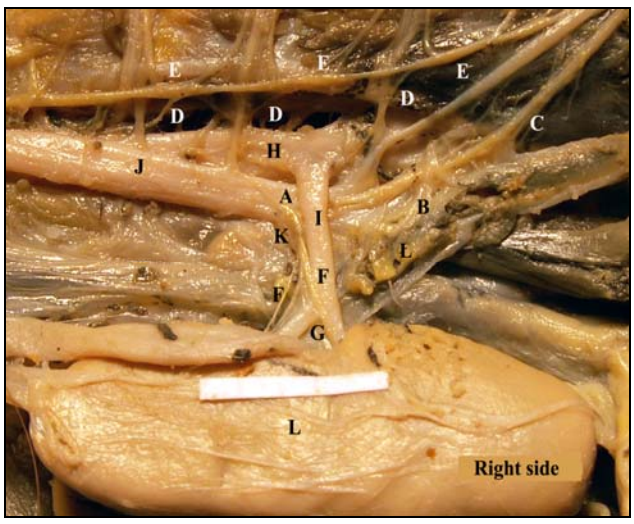

Fig 4. **The ARG located on the wall of the renal vena. The right side. The female**

A – ARG, B – coeliac plexus, C - greater splanchnic nerve, D –lumbar splanchnic nerves, E – lumbar sympathetic ganglia, F – renal branches, G – renal plexus, H – aorta, I - renal artery, J – caudal vena cava, K – renal vena, L – kidney, Ł – suprarenal gland

4. The lumbar splanchnic nerves arise from the four lumbar ganglia on both sides of the body and reach to the ARG. The first lumbar ganglion sends 1–7 branches terminating mainly in the ARG and 1–4 branches reach

the renal plexus. The three remaining lumbar ganglia give off 1–2 branches entering the ARG.

Table 1. **Skeletotopy of the ARG with respect thoracic and lumbar part of vertebral column**

Number	Sex	Left side	Right side
1	F	L_3, L_4, L_5 (T)	L_3-L_4
2	M	L_2	L_1-L_2
3	F	L_2-L_3	L_1-L_2
4	M	L_3	Th_{14}-L_1
5	F	L_2-L_3, L_3-L_4 (D)	L_1
6	F	L_3-L_4	Th_{14}-L_1
7	F	Th_{14}-L_1	L_2-L_3
8	F	Th_{14}-L_1	L_1-L_2
9	F	L_3	L_2-L_3
10	F	L_2, L_3 (D)	L_2-L_3
11	M	L_2-L_3	L_2-L_3
12	F	L_3	L_2-L_3
13	M	L_1-L_2	L_1
14	F	L_2-L_3	L_1

F – female, M – male, Th – thoracic part of vertebral column, L – lumbar part of vertebral column

5. The renal branches (from 1 to 4 branches on both sides of the body) arise from the caudal pole of the ARG and run to the renal hilus.

6. The renal plexus is situated in the renal hilus around the renal artery. This plexus is formed by all the described nerves (the lesser splanchnic nerve, the lumbar splanchnic nerves and the renal rami from the ARG).

Relationships between ARG size and location versus sex and body length. The ARG length was not affected by the side of the body. The difference between the left and right sides was statistically insignificant (the Wilcoxon test, t=45, p=63). No significant differences between sexes were found for either side of the body (the Mann-Whitney test: U=11, p=0.20 and U=10, p=0.16, respectively). The ARG length was not correlated with the length of the body regardless of the body side: r=0.01, p=0.96 for the left side and r=0.17, p=0.55 for the right one. Similarly, the location of the ARG was related to neither the body sides nor sex. The differences in the distance from the caudal end of the suprarenal glands to the ARG between the sexes were statistically insignificant for both body sides (U=18, p=0.78 and U=12, p=0.26, respectively) and the differences in the distance from the caudal end of the suprarenal glands to the ARG between the sides of the body were statistically insignificant, too (the Wilcoxon test: T=38, p=0.36) (Tables 2 and 3).

Table 2. **Summary statistics for females** (N=10)

Statistics	Body length	Left side		Right side	
		ARG length	Distance	ARG length	Distance
Average	292.6	1.83	6.72	1.34	6.24
Median	295.5	1.03	6.54	1.18	4.44
SD	14.6	1.77	3.77	0.60	6.07
CV	5.0	96.56	56.12	44.35	97.24

SD – standard deviation, CV – coefficient of variability

Table 3. **Summary statistics for males** (N=4)

Statistics	Body length	Left side		Right side	
		ARG length	Distance	ARG length	Distance
Average	295.0	2.10	7.67	1.74	3.13
Median	295.0	2.10	7.67	1.74	3.13
SD	19.1	1.39	6.43	0.55	1.49
CV	6.5	66.10	83.84	31.85	47.55

SD – standard deviation, CV – coefficient of variability

Discussion. Our study was aimed at describing the ARG macromorphology in pig fetuses and comparing the results with our earlier research into the ARG in other domestic animals in the peri- and postnatal periods and the available literature on the subject. Being aware of the fact that it is not easy to obtain a material uniform in respect of genetics, age, breed and even the number of specimens, we hope that our results, reliable and cognitive, will prove useful in indicating differences in the ARG macromorphology within a given species.

The ARG is reported to be most frequently situated in animals near the site where the renal artery arises off the side of the abdominal aorta (Dyce et al. 1996; Evans, 1993; Nickel et al., 2004).

Our study has shown that ARG syntopy in pig fetuses is a trait varying not only within one species – sheep, dogs, cats (Pospieszny, 1977; Pospieszny and Klećkowska, 2002; Pospieszny et al., 2003; Klećkowska et al. 2009) but also in individuals (including the body side), as well as in individuals belonging to one litter. In his studies carried out on sheep fetuses from 3–5 months of pregnancy (175–425 mm of body length), Pospieszny

(1977) distinguished two types of ARG concerning the ganglion syntopy (as compared with the abdominal aorta and the renal artery). In type 1, the ganglion in the form of an independent accumulation of nerve cells was situated on the wall of the abdominal aorta, in the vicinity or at the level where the renal artery was branching off the abdominal aorta (anteriorly to the renal artery – variant A spindle-shaped, 3 to 6 mm long; on the wall of the abdominal aorta – variant B oval shape, 0.5 to 1.5 mm long, posteriorly to the renal artery – variant C spindle-shaped, 1 mm to 3 mm long). A typical feature of this ganglion (type 1) is the joining branch, surrounding the renal artery which branches off from the ganglion along with the branch connecting the L3 ganglion with the coeliac-mesenteric plexus and the lumbar ganglia L_1–L_3. Type 2 lacks the classical ganglion, instead there is the oval increased sympathetic ganglion L_2 which has the same connection with the environment as type 1 ganglion. The size of this ganglion varied from 4 mm to 6 mm in length. It was situated on the lateral wall of the abdominal aorta, and when the sympathethic ganglia L_1 and L_3 and other were localized at the level of the sympathethic trunk course, then the sympathetic ganglion L_2 showed in these cases a distinct movement downwards, thus it was placed on the wall of the abdominal aorta together with a better or less detached ARG. On the other hand, the study by Pospieszny (1986) on 10-week old pig fetuses obtained from three uteri showed that the ARG most frequently is situated close to the origin of the renal artery from the abdominal aorta. Our present study as well as the earlier ones carried out on Persian cat fetuses (Pospieszny i Klećkowska, 2002), American Staffordshire terrier fetuses (Pospieszny et al. 2003) and 1-day-old infant sheep (Klećkowska-Nawrot et al. 2009) confirm the occurrence of type 1 ganglion in ARG. However, we have not found out in our present study on pig fetuses the occurrence of the joining branch surrounding the renal artery as it was in Pospieszny (1977). Interestingly, in all our studies (the present and the former ones) we have observed a double or triple ARG ganglion.

A similar situation is in the case of high variability of ARG location in pig fetuses (most frequently on the L_2–L_3 segments) in respect to thoracic and lumbar sections of the spine (skeletotopy) not only among individuals but also on the right and left sides of the body. Although the study carried out on 1-day–old infant sheep revealed that the ARG was most often situated on L_1 segment of the spine (Klećkowska et al. 2009), in cat fetuses it was most often on the L_3–L_4 segments (Pospieszny and Klećkowska, 2002) and in dog fetuses on the L_1–L_2 segments (Pospieszny et al., 2003).

High variability is also manifest in the ganglion shape. Pospieszny (1986) in his studies on pig fetuses, week 10 of gestation, observed 3 types of ganglion shape (fusiform, triangular or irregular). Our research has shown the presence of two kinds of ganglion shapes (triangular and elongated), yet the elongated one is most frequent. Similarly, Pospieszny (1977) in sheep fetuses revealed 2 types of ganglion shapes (spindle and oval), and in cat fetuses - oval and elongated (Pospieszny and Klećkowska, 2002). Our former studies on 1-day-old infant sheep showed the presence of 4 ganglion shapes (elongated, round, triangular and oval) (Klećkowska-Nawrot at al., 2009).

As Langenfeld stated (1981), in the studies conducted on 11 pigs aged 6–16 months he had observed that the greater splanchnic nerve branched off from the sympathetic trunk ganglion at the Th_{12}–Th_{15} segments, whilst the lesser splanchnic nerve arose from the sympathetic trunk ganglion at the Th_{14}–L_1 segments. Splanchnic lumbar nerves originated as very thin visceral branches from the lumbar ganglia L_1–L_4. The ARGs were 1–2mm long and he found very few of them in his material (in 11 examined pigs he observed 3 on the right and 5 on the left). Besides, there also occurred double ganglia. Owing to the location of the ARG to the renal artery, he divided them into cranial ARG ganglia (anterior to the renal artery) and caudal (posterior to the renal artery). Our examination has confirmed (with slight differences) the way where the greater, lesser and lumbar splanchnic nerves originate in pig fetuses when compared with the study by Langenfeld (1981).

According to Mitchell (1950), in humans the ARG is usually located superiorly to the level of origin of the renal artery, in-between this artery and the abdominal aorta. After Norvell's study of 57 male adult human cadavers (1968), the ARG in man is usually located near the junction of each renal artery with the abdominal aorta. The ARG is irregular in shape and it may occur individually, in double or triple in the shape of small ganglia. In man this ganglion is approximately 10.0 mm long and 5.0 mm wide. He has also observed the presence of double ganglia (9 cases) and in a few cases the ARG were found partly fused with the coeliac ganglion. In humans, the ARG communicates with the greater and lesser splanchnic nerves, the first lumbar splanchnic nerve, renal plexus, coeliac plexus, superior mesenteric plexus, suprarenal glands and probably the ovarian and deferential plexus.

Conclusions. Our study showed that the ARG is characterized by a varying location in relation to the suprarenal gland, renal artery, caudal vena cava and the abdominal aorta (syntopy), the thoracic and lumbar segment of the vertebral column (skeletotopy) (between Th_{14}–L_5) as well as two shapes (triangular and elongated). We have also observed a double and triple ganglion in females on their left body side. The ARG communicates with the greater splanchnic nerve, lesser splanchnic nerve, lumbar splanchnic nerves, renal branches and the renal plexus. The ARG size and location in relation to the caudal suprarenal end was statistically independent of body size, length, and sex.

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