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The superior gluteal artery and the posterior division of the internal iliac artery: an analysis of their complete anatomy

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Background: *The superior gluteal artery (SGA) is the largest, terminating branch of the internal iliac artery (IIA). Knowledge about the anatomy of the SGA is extremely important when performing numerous reconstructive and endovascular procedures.*
Materials and methods: *The results of 75 consecutive patients who underwent pelvic computed tomography angiography (CTA) were analysed.*
Results: *A total of 145 SGAs were analysed. The origin variation of each SGA was deeply analysed. Type O1 occurred in 79 SGA (56.4%). Furthermore, analogously, branching pattern types were also established. Initially 19 branching variations were evaluated, of which types 1–7 constituted 76.5%. The median SGA length was set to be 54.88 mm (LQ = 49.63; HQ = 63.26). The median SGA origin diameter, in cases of SGA originating from PDIIA, was set to be 6.27 mm (LQ = = 5.56; HQ = 6.87).*
Conclusions: *The origin of the said artery showed a low grade of variability, and the most prevalent origin type of the SGA was similar to the one presented by the major anatomical textbooks, namely, the PDIIA. However, the branching pattern of the SGA was highly variable. To present the anatomy of the SGA in a clear and straight-forward way, novel classification systems of the origin and branching patterns were made. Furthermore, the morphometric properties of the branches of the PDIIA were analysed. It is hoped that the results of the present study may be useful for physicians performing numerous reconstructive and endovascular procedures.* (Folia Morphol 2024; 83, 3: 604–614)

Keywords: superior gluteal artery, plastic surgery, superior gluteal artery perforator flap, surgery, anatomy

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INTRODUCTION

The superior gluteal artery (SGA) is the largest, terminating branch of the internal iliac artery (IIA) [19, 23]. It is the last branch of the posterior division of the internal iliac artery (PDIIA), and it travels from the pelvis between the lumbosacral trunk and the first sacral nerve root. It emerges from the pelvis by passing through the greater sciatic foramen, positioned above the piriformis muscle, and promptly splits into superficial and deep branches that extend throughout the gluteal area. The superficial branch is said to penetrate the gluteus maximus, supplying it, and the overlying skin over the proximal attachment of the muscle. The deep branch courses between the gluteus minimus and gluteus medius muscles and supplies them, as well as the tensor fascia lata. Later, it divides into an upper and lower branch, which anastomose with other arteries around the anterior superior iliac spine and the hip joint [11].

The complex and variable nature of the arterial structure in the pelvic region poses challenges for surgical procedures in this area [4, 9, 13, 14, 17, 21, 24, 26, 27]. The anatomical aspects of the SGA have been discussed in the past. The spatial relationship between the said artery and lumbosacral plexus was discussed by Anetai et al. [1]. In the study, the SGA pathways and variations were presented as a classification system consisting of 4 groups. The SGA was found to pass between the nerve trunks of L4 and L5, L5 and S1, S1 and S2, and even between the obturator nerve and the lumbosacral trunk. However, it has been stated that the most frequent course of the SGA is between L5 and S1, with a prevalence ranging between 60 and 80% [1]. This relationship is particularly important in the process of S1 sacroiliac screw placement. Zhao et al. [25] reported that there is a high risk of accidental injury of the deep superior branches of the SGA when performing this procedure, and that great attention should be paid to make thorough preoperative plans. Although the course of the SGA and its spatial relationships with other structures have been discussed in the literature, the origin and branching of this vessel have not yet been analysed. Therefore, in the present study, novel classification systems for both the origin and branching pattern were made.

Knowledge about the anatomy of the SGA is extremely important when performing numerous reconstructive and endovascular procedures. Breast reconstruction after mastectomy plays a crucial role in enhancing the sexuality, body image, and overall quality of life of women who have undergone cancer treatment. The use of superior gluteal artery perforator flap (SGAP) in breast reconstructions has gained an increase in popularity among surgeons [10] because the said flap demonstrates a satisfactory level of safety and a low complication rate validating its significant role as an efficient option in breast reconstruction [10].

The PDIIA is said to give rise to the SGA, the iliolumbar artery, and the lateral sacral artery. The anatomy of these branches has been discussed in the past, due to their relevance in reconstructive and endovascular procedures. Nonetheless, there is a notable scarcity of information concerning the morphological characteristics of these arteries. Therefore, the authors of the present study aimed to provide new data regarding this topic.

The findings from this study are expected to offer valuable information for medical professionals, particularly surgeons, involved in various endovascular and reconstructive medical procedures. Extensive knowledge about the relevant anatomy may help to reduce the risk of potential complications associated with the said operations.

MATERIALS AND METHODS

Bioethics committee

The research protocol was submitted for evaluation and approved by the Bioethics Committee of Jagiellonian University, Cracow, Poland (1072.6120.254.2022). Further stages of the study were carried out in accordance with the approved guidelines.

Study group

A retrospective study was conducted to establish anatomical variations, their prevalence, and morphometrical data on SGA and its branches. The results of 75 consecutive patients who underwent pelvic computed tomography angiography (CTA) were analysed. The CTAs were performed in the Department of Radiology of the Jagiellonian University Medical College, Cracow, Poland, between 2017 and 2022. The result of each patient was analysed bilaterally. The results of each patient were analysed in the Department of Anatomy of the Jagiellonian University Medical College, Cracow, Poland, in August 2022. A total of 150 SGAs were initially evaluated. Exclusion criteria were set as follows: (1) pelvic or abdominal trauma affecting the course of the SGA and/or its initial branches, (2) significant artifacts that prevented accurate and precise imaging and/or measurement of the SGA and/ /or its initial branches, (3) low-quality and illegible images, and (4) significant lack of filling the whole arterial system with contrast. Defects, which met the exclusion criteria but included only one side of the CTA, without interference with the contralateral side, did not disqualify the whole CTA but only the affected side. Therefore, of the initial 150, a total of 5 SGAs were excluded due to significant artifacts to minimise possible bias. Finally, 145 SGA of 73 patients met the required criteria.

Acquisition of results

All pelvic CTA were performed on a 128-slice scanner CT (Philips Ingenuity CT, Philips Healthcare). The main CTA imaging parameters were as follows: collimation/ /increment: 0.625/0.3 mm; tube current: 120 mAs; field of view: 210 mm; matrix size: 512 × 512.

All the patients received intravenous administration of contrast material at a dose of 1 mL/kg (standard dose). A non-ionic contrast medium (CM) containing 350 mg of iodine per mL was used (Jowersol 741mg/mL, Optiray®, Guerbet, France). CT data acquisition was triggered using a real-time bolus-tracking technique (Philips Healthcare) with the region of interest (ROI) placed in the ascending aorta. The CM was intravenously injected using a power injector at a flow rate of 5 mL/s. This was immediately followed by the injection of 40 mL of saline solution at the same flow rate. Following injection of CM and saline, image acquisition was automatically started with a 2-s delay when the attenuation trigger value reached a threshold of 120 Hounsfield units (HU). Scanning was performed in the caudocranial direction.

The CTAs were analysed on a dedicated workstation at the Anatomical Department of Jagiellonian University Medical College, Cracow, Poland. To ensure the highest possible quality of the visualisations and measurements and minimise potential bias, Materialise Mimics Medical version 21.0 software (Materialise NV, Leuven, Belgium) software was used. Three-dimensional (3D) reconstructions of each scan were developed, employing settings adjusted to each scan. The volume rendering opacity oscillated from 25 to 80 HU for the lower limit and up to 3070 HU for the higher limit. The range was individually adjusted to each TT after a visual investigation.

Evaluation and measurements

At the beginning of each evaluation, the authors ensured that each SGA, its branches, and its close anatomical area were fully visualised. Subsequently, each branch of the SGA was identified by following its course. The origin of the SGA and a set of its branches was evaluated with their arrangement and were descriptively noted. Subsequently, a set of measurements was conducted on each SGA by 2 independent researchers, and a mean was established taking both results into account. All measurements were rounded to 2 decimal places. The following measurements were taken: (1) SGA length [mm], which, due to the scarcity of literature, the authors established should be measured to the point in which the first branch appeared; (2) SGA origin diameter (in cases of SGA originating from PDIIA) [mm]; (3) SGA origin surface area (in cases of SGA originating from PDIIA) [mm^2]; (4) SGA origin diameter (in cases of SGA originating from IIA) [mm]; (5) SGA origin surface area (in cases of SGA originating from IIA) [mm^2]; (6) distance from the origin of the PDIIA to the origin of the SGA [mm]; (7) distance from the origin of the IIA to the origin of the SGA [mm]; (8) SGA origin angle; (9) SGA diameter at the lateral sacral artery origin [mm]; (10) SGA surface area at the lateral sacral artery origin [mm^2]; (11) the lateral sacral artery origin diameter [mm]; (12) the lateral sacral artery origin surface area [mm^2]; (13) distance from the origin of the SGA to the lateral sacral origin [mm]; (14) lateral sacral artery origin angle; (15) IIA origin diameter [mm]; (16) IIA origin surface area [mm^2]; (17) PDIIA origin diameter [mm]; (18) PDIIA origin surface area [mm^2]. (19) ADIIA origin diameter [mm]. (20) ADIIA origin surface area [mm^2]. (21) Iliolumbar artery origin diameter [mm]; and (22) iliolumbar artery origin surface area [mm^2]. In addition, several SGA branches and a set of individual patient parameters such as age and sex were recorded. Furthermore, each SGA origin and branching pattern was descriptively noted to establish the variation types in further stages.

Statistical analysis

Statistical analysis was performed with SATISTICA v13.1 (StatSoft Inc., Tulsa, OK, USA). The frequencies and percentages presented qualitative features. The Shapiro-Wilk test was used to assess the normal distribution. Quantitative characteristics were presented by medians and upper and lower quartiles (UQ, LQ), as well as means and standard deviation (SD), depending

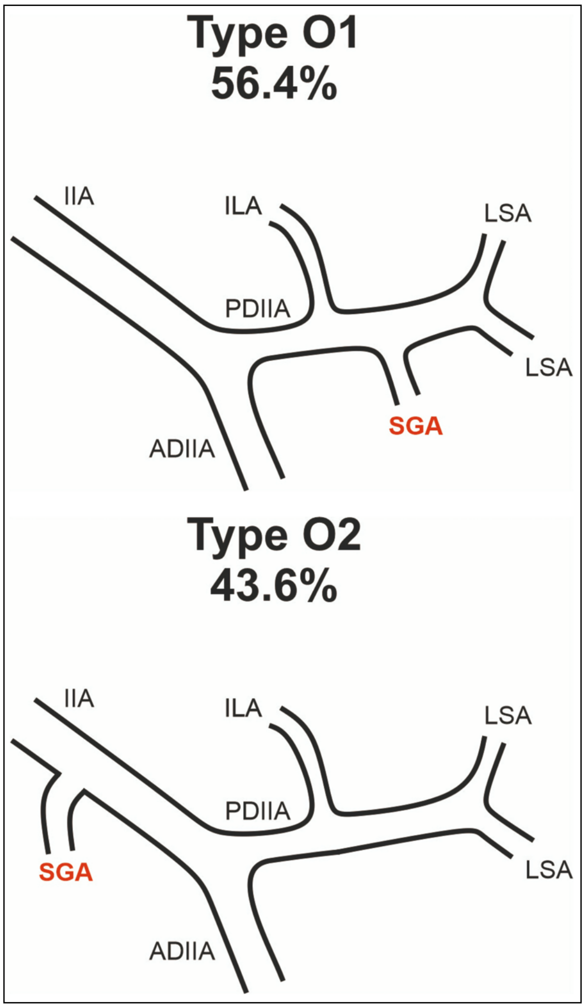

Figure 1. The origin types of the superior gluteal artery (SGA). ADIIA — anterior division of the internal iliac artery; IIA — internal iliac artery; ILA — iliolumbar artery; LSA — lateral sacral arteries; PDIIA — posterior division of the internal iliac artery.

on the verified normality of the data. Statistical significance was defined as $p < 0.05$. U Mann-Whitney and Wilcoxon signed-rank tests were used to establish potential differences between groups. Spearman's rank correlation coefficient was used to determine possible correlations between the parameters.

RESULTS

Qualitative results

All subsequent findings are reported in terms of the count of SGA instead of the count of patients. Out of the 145 SGAs examined, 78 belonged to women (55.7%) and 67 belonged to men (44.3%). A thorough examination was conducted to investigate the variations in the origins of each SGA. Two distinct origin variations were identified. To address the gap in the existing literature, a classification system for the SGA's origin was established, comprising 2 primary categories. These 2 primary categories were defined as follows: (1) Type O1 – SGA branches out from the PDIIA, and (2) Type O2 — SGA branches out directly from the IIA. Type O1 occurred in 79 SGAs (56.4%). The origin types are illustrated in Figure 1. Similarly, a classification system for branching patterns was established. Initially, 19 different branching variations were assessed, with types 1–7 accounting for 76.5% of the cases. To address the gaps in the existing literature, a classification method for SGA branching patterns was developed, comprising 7 primary types. Those main types were set as follows: (1) Type B1 — singular superficial, deep, and inferior branches consecutively branching out from the SGA. (2) Type B2 — 2 superficial and 2 deep branches consecutively branching out from the SGA. (3) Type B3 — 3 superficial and 3 deep branches consecutively branching out from the SGA. (4) Type B4 — 2 superficial and 3 deep branches consecutively branching out from the SGA. (5) Type B5 — 3 superficial and 2 deep branches consecutively branching out from the SGA. (6) Type B6 — one superficial and 2 deep branches consecutively branching out from the SGA. (7) Type B7 — 2 superficial and 4 deep branches consecutively branching out from the SGA. Initially, 12 other variants were also established. However, any type that did not occur in more than 5% of the cases was classified as "other" variant. The most common type was found to be B1, which occurred in 60 SGAs (42.9%). All the aforementioned statistics, as well as additional detailed data, are available in Table 1. Sample three-dimensional models of the studied SGAs can be found in Figures 2 and 3.

Measurements analysis

The median SGA length was set to be 54.88 mm (LQ = 49.63; HQ = 63.26). The median SGA origin diameter in cases of SGA originating from PDIIA was set to be 6.27 mm (LQ = 5.56; HQ = 6.87). The median SGA origin diameter in cases of SGA originating from IIA was set to be 6.22 mm (LQ = 5.42; HQ = = 7.28). The median number of SGA branches was found to be 3.00 (minimum = 2.00; maximum = = 13.00). The exhaustive results for each category are shown in Table 2.

Sexual dimorphism

A distinct statistical analysis was conducted based on the gender of the patients. Statistically significant differences ($p < 0.05$) were observed between genders in 5 categories. These findings have been consolidated and are presented in Table 3.

Correlations

Potential associations between each category and patient's age and length of the SGA were demonstrated. Ten categories statistically significantly correlated with the patient's age, whereas 8 categories statistically significantly correlated with length of the SGA. The R values obtained in the correlation analysis between the groups can be found in Table 4. Those in which the p-value was less than 0.05 are highlighted in red.

Table 1. Qualitative results of the data analysis.

Category	n	Percentage
Patients' sex		
Female	78	55.7%
Male	67	44.3%
Origin types		
Type O1	79	56.4%
Type O2	61	43.6%
Branching types		
Type B1	60	42.9%
Type B2	17	12.1%
Type B3	8	5.7%
Type B4	6	4.3%
Type B5	6	4.3%
Type B6	5	3.6%
Type B7	5	3.6%
Other variants (< 5%)	33	23.6%

The two types of origin are established as follows: (1) Type O1 — SGA branches out from the posterior division of the internal iliac artery (PDIIA). (2) Type O2 — SGA branches out directly from the internal iliac artery (IIA). The 7 types of branching patterns of the SGA are established as follows: (1) Type B1 — singular superficial, deep and inferior branches are consecutively branching out from the SGA. (2) Type B2 — 2 superficial and 2 deep branches are consecutively branching out from the SGA. (3) Type B3 — 3 superficial and 3 deep branches are consecutively branching out from the SGA. (4) Type B4 — 2 superficial and 3 deep branches are consecutively branching out from the SGA. (5) Type B5 — 3 superficial and 2 deep branches are consecutively branching out from the SGA. (6) Type B6 — one superficial and 2 deep branches are consecutively branching out from the SGA. (7) Type B7 — 2 superficial and 4 deep branches are consecutively branching out from the SGA. Initially, 12 other variants were also established. However, any type that did not occur in more than 5% of the cases was classified as the other variant. SGA — superior gluteal artery.

Side differences

Following this, an examination was conducted to assess potential variations in the measured parameters, as well as the prevalence of origin types and their co-occurrence relative to the patient's lateral orientation. It was determined that there was a statistically significant difference in the length of the SGA on the right side ($p = 0.00$). For a comprehensive presentation of these findings, please refer to Table 5.

DISCUSSION

The present study is the first to analyse both the origin and the branching pattern of the SGA in just detail. Classification systems for both the origin and the branching pattern were made to clearly present the anatomy of the said vessel. The origin was not particularly variable, making up only 2 different types in our classification. The most common origin (Type O1 = 56.4%) was the SGA arising from the PDIIA, fitting the description provided by the major anatomical textbooks. The other type of origin (Type O2 = = 43.6%) represented the SGA to originate from the IIA before its bifurcation into the anterior and posterior trunks. Having adequate knowledge about the origin of the SGA is particularly important in endovascular procedures, such as embolisation. The embolisation of the SGA was presented by Arshad *et al.* [2] in a case report regarding a 32-year-old male with a rare SGA aneurysm. The aneurysm was diagnosed with the help of computed tomography, which is the mainstay

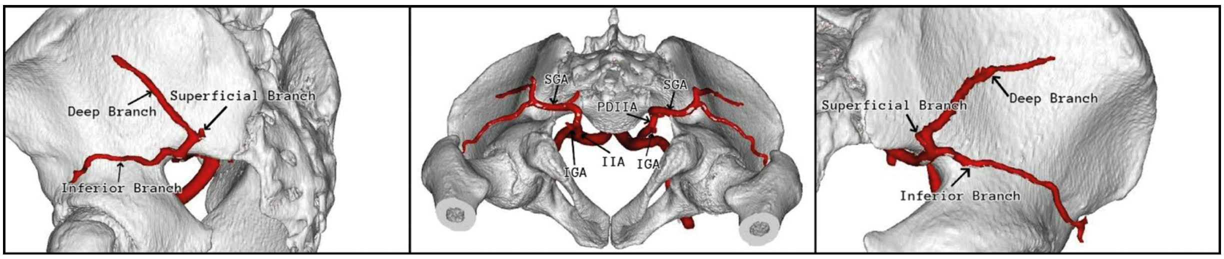

Figure 2. Three-dimensional model of the SGA. In the presented case, types O1 (SGA branches out from the PDIIA) and B1 (singular superficial, deep and inferior branches are consecutively branching out from the SGA) were established on the right SGA, whereas types O2 (SGA branches out directly from the IIA) and B1 (singular superficial, deep and inferior branches are consecutively branching out from the SGA) were established on the left SGA. IGA — inferior gluteal artery; IIA — internal iliac artery; PDIIA — posterior division of the internal iliac artery; SGA — superior gluteal artery.

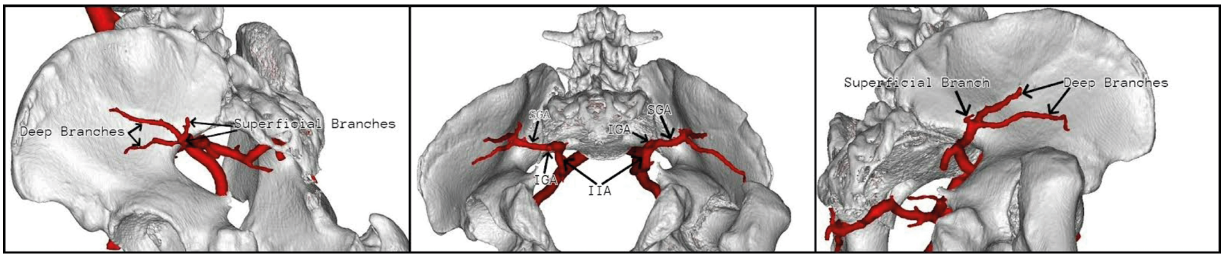

Figure 3. Three-dimensional model of the SGA. In the presented case, types O2 (SGA branches out directly from the internal iliac artery IIA) and B6 (one superficial and 2 deep branches are consecutively branching out from the SGA) were established on the right SGA, whereas types O2 (SGA branches out directly from the IIA) and B2 (2 superficial and 2 deep branches are consecutively branching out from the SGA) were established on the left SGA. IGA — inferior gluteal artery; IIA — internal iliac artery; SGA — superior gluteal artery.

Table 2. Results of the measurements.

Category	Median	LQ	HQ	Minimum	Maximum	Mean	SD
SGA length [mm]	54.88	49.63	63.26	29.04	87.16	55.77	10.66
SGA origin diameter (in cases of SGA originating from PDIIA) [mm]	6.27	5.56	6.87	4.33	133.61	7.94	14.54
SGA origin surface area (in cases of SGA originating from PDIIA) [mm^2]	26.43	20.27	32.15	7.04	62.73	27.15	10.67
SGA origin diameter (in cases of SGA originating from IIA) [mm]	6.22	5.42	7.28	3.78	54.74	7.09	6.32
SGA origin surface area (in cases of SGA originating from IIA) [mm^2]	26.76	20.55	32.52	8.37	76.32	27.87	11.50
Distance from the origin of the PDIIA to the origin of the SGA [mm]	16.46	9.11	38.12	2.11	83.06	24.49	20.01
Distance from the origin of the IIA to the origin of the SGA [mm]	27.28	11.72	51.82	2.50	76.71	32.79	22.99
SGA origin angle	120.13	79.25	135.87	8.31	173.85	106.82	39.59
Number of SGA branches	3.00	3.00	5.00	2.00	13.00	4.22	1.87
SGA diameter at lateral sacral artery origin [mm]	6.05	5.51	7.05	3.47	24.99	6.57	2.73
SGA surface area at lateral sacral artery origin [mm^2]	28.00	22.26	35.97	6.79	69.11	30.34	12.04
Lateral sacral artery origin diameter [mm]	2.99	2.66	3.58	1.51	5.78	3.16	0.83
Lateral sacral artery origin surface area [mm^2]	5.72	4.05	8.02	1.09	23.83	6.46	3.42
Distance from the origin of the SGA to the lateral sacral origin [mm]	13.18	4.20	21.24	0.00	57.10	15.00	12.55
Lateral sacral artery origin angle	118.40	100.66	135.02	31.04	161.34	117.49	23.97
IIA origin diameter [mm]	7.69	7.04	8.66	5.65	32.40	8.09	2.41
IIA origin surface area [mm^2]	40.13	33.66	50.90	18.50	99.22	43.55	14.86
PDIIA origin diameter [mm]	6.64	6.05	7.33	3.98	8.92	6.68	0.99
PDIIA origin surface area [mm^2]	29.05	22.73	33.71	10.41	49.00	29.21	8.70
ADIIA origin diameter [mm]	6.10	5.31	6.66	2.89	9.46	6.04	1.13
ADIIA origin surface area [mm^2]	25.61	20.17	29.48	6.20	49.98	25.48	8.58
Iliolumbar artery origin diameter [mm]	3.67	2.97	4.19	1.99	6.05	3.65	0.88
Iliolumbar artery origin surface area [mm^2]	8.64	5.95	11.55	2.55	20.96	9.13	4.09

ADIIA — anterior division of the internal iliac artery; HQ — higher quartile; IIA — internal iliac artery; LQ — lower quartile; PDIIA — posterior division of the internal iliac artery; SD — standard deviation; SGA — superior gluteal artery.

tool for diagnosing aneurysms in the gluteal region. The aneurysm was successfully coil embolised, and no post procedure complications were noted. In contrast to our observations regarding the origin of the SGA, the branching pattern was highly variable. The SGA is said to have 2 main branches; a superficial branch and a deep branch that further bifurcated into one upper and one lower branch. These branches are also referred to as perforators, specifically in the SGAP flap. Our classification of the branching of this artery consists of 8 types. The most prevalent branching pattern, represented as type B1 (42.9%), illustrated the SGA giving rise to singular superficial, deep, and inferior branches consecutively. Next, type B2 (12.1%)

Table 3. Results of the measurements concerning the sex.

Category	Sex	Median	LQ	HQ	Minimum	Maximum	Mean	SD	P-value
SGA length [mm]	Female	55.00	50.27	64.00	33.59	87.16	56.29	10.25	0.55
	Male	54.32	49.10	61.35	29.04	76.13	54.72	11.61	
SGA origin diameter (in cases of SGA originating from PDIIA) [mm]	Female	6.20	5.62	6.75	4.33	8.95	6.26	0.99	0.66
	Male	6.28	5.51	6.95	4.47	133.61	9.66	20.68	
SGA origin surface area (in cases of SGA originating from PDIIA) [mm²]	Female	25.70	18.27	33.47	8.87	62.73	27.38	11.70	1.00
	Male	26.57	20.88	31.96	7.04	62.32	26.91	9.65	
SGA origin diameter (in cases of SGA originating from IIA) [mm]	Female	6.03	5.33	6.86	3.78	8.28	6.12	1.01	0.11
	Male	6.44	5.63	7.54	4.07	54.74	8.70	10.14	
SGA origin surface area (in cases of SGA originating from IIA) [mm²]	Female	26.20	21.01	30.77	10.98	53.63	26.97	8.89	0.68
	Male	27.64	19.16	34.54	8.37	76.32	29.37	14.96	
Distance from the origin of the PDIIA to the origin of the SGA [mm]	Female	12.67	8.60	37.58	2.50	81.81	22.13	19.54	0.10
	Male	21.24	10.78	38.12	2.11	83.06	27.00	20.39	
Distance from the origin of the IIA to the origin of the SGA [mm]	Female	34.78	8.73	48.78	2.50	76.71	31.77	23.47	0.37
	Male	25.00	15.08	58.04	3.16	75.21	34.45	22.56	
SGA origin angle	Female	113.42	65.76	135.51	8.31	158.78	100.77	42.44	0.12
	Male	126.95	106.18	136.28	34.20	173.85	115.83	33.42	
Number of SGA branches	Female	4.00	3.00	6.00	2.00	13.00	4.54	2.05	0.03
	Male	3.00	3.00	4.00	2.00	11.00	3.80	1.53	
SGA diameter at lateral sacral artery origin [mm]	Female	5.90	5.37	6.50	3.47	8.61	6.00	1.12	0.01
	Male	7.05	6.02	7.63	4.81	24.99	7.75	4.32	
SGA surface area at lateral sacral artery origin [mm²]	Female	26.65	19.75	33.10	6.79	57.88	28.16	11.79	0.02
	Male	34.25	27.89	41.26	17.72	69.11	35.08	11.50	
Lateral sacral artery origin diameter [mm]	Female	2.93	2.64	3.45	1.82	5.60	3.08	0.73	0.28
	Male	3.04	2.68	3.72	1.51	5.78	3.27	0.95	
Lateral sacral artery origin surface area [mm²]	Female	5.66	4.17	7.42	1.48	23.83	6.28	3.47	0.40
	Male	6.30	4.04	8.36	1.09	14.61	6.69	3.37	
Distance from the origin of the SGA to the lateral sacral origin [mm]	Female	12.76	5.95	23.44	0.00	57.10	15.32	13.10	0.86
	Male	14.26	3.46	20.46	0.00	40.77	14.31	11.57	
Lateral sacral artery origin angle	Female	120.02	103.57	134.91	79.73	160.50	119.29	20.34	0.68
	Male	117.12	93.41	136.07	31.04	161.34	114.77	28.73	
IIA origin diameter [mm]	Female	7.56	6.91	8.49	5.65	11.24	7.72	1.11	0.05
	Male	7.94	7.30	8.81	6.17	32.40	8.57	3.37	
IIA origin surface area [mm²]	Female	40.13	34.80	47.70	18.50	98.38	42.35	14.12	0.49
	Male	40.26	32.68	53.48	24.94	99.22	45.11	15.75	
PDIIA origin diameter [mm]	Female	6.44	5.85	6.77	3.98	7.92	6.28	0.88	0.00
	Male	7.10	6.36	7.69	4.68	8.92	7.04	0.95	
PDIIA origin surface area [mm²]	Female	26.10	21.32	30.53	10.41	48.39	26.58	8.94	0.01
	Male	31.71	27.42	37.77	12.31	49.00	31.55	7.88	
ADIIA origin diameter [mm]	Female	6.05	5.45	6.42	2.89	7.60	5.90	0.94	0.23
	Male	6.27	5.31	7.03	3.22	9.46	6.23	1.32	
ADIIA origin surface area [mm²]	Female	26.13	20.90	29.05	6.20	40.85	24.88	7.54	0.82
	Male	24.04	19.34	32.19	7.29	49.98	26.29	9.86	
Iliolumbar artery origin diameter [mm]	Female	3.73	2.91	4.24	1.99	6.05	3.64	0.94	0.90
	Male	3.59	3.13	4.17	2.26	5.17	3.65	0.80	
Iliolumbar artery origin surface area [mm²]	Female	8.81	5.91	11.37	2.55	20.96	9.11	4.09	1.00
	Male	8.43	6.09	11.65	3.14	18.47	9.17	4.14	

ADIIA — anterior division of the internal iliac artery; HQ — higher quartile; IIA — internal iliac artery; LQ — lower quartile; PDIIA — posterior division of the internal iliac artery; SD — standard deviation; SGA — superior gluteal artery.

Table 4. Correlations between the measured parameters of the superior gluteal artery (SGA) and patient's age and the length of the SGA. Red highlight indicates parameters that correlate statistically significantly ($p < 0.05$).

Category	Patient's age	SGA Length [mm]
SGA length [mm]	0.06	1.00
SGA origin diameter (in cases of SGA originating from PDIIA) [mm]	0.22	0.25
SGA origin surface area (in cases of SGA originating from PDIIA) [mm^2]	0.26	0.25
SGA origin diameter (in cases of SGA originating from IIA) [mm]	0.33	–0.06
SGA origin surface area (in cases of SGA originating from IIA) [mm^2]	0.23	–0.01
Distance from the origin of the PDIIA to the origin of the SGA [mm]	–0.14	–0.31
Distance from the origin of the IIA to the origin of the SGA [mm]	–0.15	–0.75
SGA origin angle	–0.21	–0.06
Number of SGA branches	0.03	0.24
SGA diameter at lateral sacral artery origin [mm]	0.40	0.38
SGA surface area at lateral sacral artery origin [mm^2]	0.39	0.35
Lateral sacral artery origin diameter [mm]	–0.11	–0.13
Lateral sacral artery origin surface area [mm^2]	–0.03	–0.15
Distance from the origin of the SGA to the lateral sacral origin [mm]	–0.13	0.30
Lateral sacral artery origin angle	–0.10	0.13
IIA origin diameter [mm]	0.39	0.19
IIA origin surface area [mm^2]	0.38	0.18
PDIIA origin diameter [mm]	0.22	0.25
PDIIA origin surface area [mm^2]	0.26	0.26
ADIIA origin diameter [mm]	0.15	0.42
ADIIA origin surface area [mm^2]	0.19	0.44
Iliolumbar artery origin diameter [mm]	–0.37	0.21
Iliolumbar artery origin surface area [mm^2]	–0.36	0.18

Highlighted in red are those in which the p-value was less than 0.05. R — Spearman's rank correlation coefficient. ADIIA — anterior division of the internal iliac artery; IIA — internal iliac artery; PDIIA — posterior division of the internal iliac artery.

describes the SGA as giving rise to 2 superficial and 2 deep branches. The other types had a relatively low frequency of < 6.0%. Interestingly, our classification system shows that the SGA, in many instances, has numerous branches, of considerable size, which makes them visible on CTA. The knowledge about the branches, or perforators of the SGA, is particularly important in plastic and reconstructive procedures, especially in breast reconstructions. The SGAP flap is a good alternative for breast reconstructions, especially when the abdomen is unsuitable as a donor site [10]. The anatomy of the SGAP and the inferior gluteal artery perforator flap was thoroughly analysed in a cadaveric study conducted by Georgantopoulou et al. [5]. In their study they stated that the mean number of perforators in both flaps was similar ($n = 7$). Our analysis shows that the SGA has between 3 to 5 branches, which is slightly lower than what was mentioned in the aforementioned study. A possible explanation may be that the perforators analysed in the study conducted by Georgantopoulou et al. [5] were of smaller calibre and therefore would not be visible on CTA.

The SGAP has some advantages over the flaps that originate from the abdomen. In terms of aesthetic results, the adipose tissue in the gluteal region is more rigid than the abdominal fat, which may ultimately lead to firmer and more projected breasts [6]. Furthermore, in a systematic review and meta-analysis concerning the safety and efficacy of the SGAP flap in autologous breast reconstruction, it was stated that the patients are satisfied with the scars being hidden by normal underwear, and that the lack of "mirror visibility" of the scar diminishes the patients' awareness of it [10, 22].

Anatomical knowledge regarding the SGA and its close area should always be taken care of when performing augmentation gluteoplasty with a dermal fat

Table 5. Comparison between patient's side.

Occurrence of SGA origin type with respect to the patient's side		
Category	**Left side**	**Right side**
Type 1 (PDIIA)	39 (55.71%)	40 (57.14%)
Type 2 (IIA)	31 (44.29%)	30 (42.86%)

Co-occurrence of SGA origin types			
Co-occurrence		**Origin type on the right side**	
		Type 2 (IIA)	Type 1 (PDIIA)
Origin Type on the left side	Type 1 (PDIIA)	11 (15.71%)	28 (40.00%)
	Type 2 (IIA)	19 (27.14%)	12 (17.14%)

Comparison of selected parameters with respect to the patient's side									
Category	**Side**	**Median**	**LQ**	**HQ**	**Minimum**	**Maximum**	**Mean**	**SD**	**P-value**
SGA length [mm]	Left	51.56	44.75	57.87	29.04	87.16	51.87	11.47	0.00
	Right	60.31	53.05	64.35	42.59	76.50	59.67	8.23	
SGA origin diameter (in cases of SGA originating from PDIIA) [mm]	Left	51.56	44.75	57.87	29.04	87.16	51.87	11.47	0.83
	Right	6.51	5.64	7.20	4.33	133.61	9.72	20.67	
SGA origin surface area (in cases of SGA originating from PDIIA) [mm^2]	Left	24.23	18.01	32.05	13.90	62.32	26.26	10.48	0.97
	Right	28.23	21.81	33.99	7.04	62.73	28.05	10.92	
SGA origin diameter (in cases of SGA originating from IIA) [mm]	Left	6.13	5.55	6.89	3.78	54.74	7.76	8.78	0.31
	Right	6.31	5.26	7.32	4.81	10.70	6.41	1.35	
SGA origin surface area (in cases of SGA originating from IIA) [mm^2]	Left	25.63	20.55	30.59	8.37	53.63	26.55	9.67	0.40
	Right	27.78	20.54	32.84	12.41	76.32	29.24	13.15	
Number of SGA branches	Left	3.00	3.00	5.00	2.00	11.00	4.14	1.65	0.54
	Right	3.00	3.00	5.00	2.00	13.00	4.29	2.07	

ADIIA — anterior division of the internal iliac artery; HQ — higher quartile; IIA — internal iliac artery; LQ — lower quartile; PDIIA — posterior division of the internal iliac artery; SD — standard deviation; SGA — superior gluteal artery.

flap [7, 16]. The key to performing gluteal augmentation safely and minimising risk and complications is to truly know the anatomy of the gluteal area [7].

In the present study, the morphometric properties of all the branches of the PDIIA were analysed. The branches of the PDIIA: the SGA, the iliolumbar artery, and the lateral sacral artery, are all subject to considerable variety. The origin variability of the iliolumbar artery was analysed by Al Talalwah et al. [18] in a cadaveric study consisting of 171 cadavers. In the study, they found the origin of the said artery to be mostly from the PDIIA; however, other origins, such as from the SGA or the common iliac artery, were also noted. Kiray et al. [8] presented different conclusions regarding the origin of the iliolumbar artery, stating that it most frequently originated from the IIA, before its bifurcation into its anterior and posterior division. The morphometric properties of the iliolumbar artery were analysed by Teli et al. [20]. The authors of the said study stated that the mean diameter of the said artery, at its origin, was 3.5 ± 0.5 mm. Our study shows similar results, with a mean origin of 3.65 ± ± 0.88 mm. Knowledge about the anatomy and the morphometric properties of the iliolumbar artery are particularly important when performing the iliac crest free flap in maxillofacial reconstruction, because the pedicle of said flap may be the iliolumbar artery [15]. Knowledge about the morphometric properties of the lateral sacral artery, such as its diameter, may be of great importance when performing intravascular procedures. Although rare, cases of aneurysms of the lateral sacral artery have been presented in the literature [3, 12]. Having appropriate knowledge about the diameter of the said artery may be useful when choosing an appropriately sized catheter for embolisation procedures. Our study shows that the mean diameter of the lateral sacral artery is 3.16 mm.

The current study has some limitations. While the size of the study group in this paper is the most extensive among imaging studies focusing on the SGA, there remains a need for larger population-based research to accurately determine the prevalence of its variations. Moreover, reliance on radiological imaging alone restricts the assessment to haemodynamically efficient arteries, which introduces a significant potential source of bias when examining anatomical variations of the SGA and other arterial structures. It is essential that future investigations delve into the anastomoses with neighbouring vascular structures due to their potential clinical relevance in endovascular and orthopaedic procedures.

CONCLUSIONS

The current study conducted a comprehensive examination of the entire anatomical structure of the SGA. The origin of the said artery showed a low grade of variability, and the most prevalent origin type of the SGA was similar to the one presented by the major anatomical textbooks, namely, the PDIIA. However, the branching pattern of the SGA was highly variable. To present the anatomy of the SGA in a clear and straightforward way, novel classification systems of the origin and branching patterns were made. Additionally, an investigation into the morphological characteristics of the PDIIA branches was carried out. It is hoped that the findings from this study can provide valuable insights for medical practitioners engaged in various reconstructive and endovascular procedures.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Ethics statement

The research protocol was submitted for evaluation and approved by the Bioethics Committee of Jagiellonian University, Cracow, Poland (1072.6120.254.2022). Further stages of the study were carried out in accordance with the approved guidelines.

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Conflict of interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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