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Original Research Article

Deep Circumflex Iliac Artery-vascularized Iliac Bone Graft for Femoral Head Osteonecrosis: Computed Tomography Anatomical Study

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Abstract

Background Deep circumflex iliac artery (DCIA)-vascularized iliac graft transposition is a method for treating femoral head osteonecrosis but with inconsistent efficacy. We aim to improve the method of this surgery by recommending the optimal location of the iliac pedicle to satisfy the vascular length for transposition and the blood supply of the vascularized iliac graft.

Methods The DCIA and its surrounding tissues were assessed on computed tomography angiography images for 100 sides (left and right) of 50 patients. The length of the vascular pedicle required for transposition and the length of the pedicle at different iliac spine positions were compared. The diameter and cross-sectional area of the DCIA and the distance between the DCIA and iliac spine were measured at different points to assess blood supply. We also compared differences in sex and left–right position.

Results The diameter and cross-sectional area of the DCIA gradually decreased after crossing the anterior superior iliac spine (ASIS), and it approached the iliac bone. However, when the DCIA was 4 cm behind the ASIS (54 sides, 54%), it coursed posteriorly and superiorly away from the iliac spine. The vascular length of the pedicle was insufficient to transpose the vascularized iliac graft to the desired position when it was within 1 cm of the ASIS. The vascular length requirement was satisfied, and the blood supply was sufficient when the pedicle was positioned at 2 or 3 cm.

Conclusion To obtain a satisfactory pedicle length and sufficient blood supply, the DCIA pedicle of the vascularized iliac graft should be placed 2 to 3 cm behind the ASIS. The dissection of DCIA has slight differences in sex and left–right position due to anatomical differences.

Keywords
- deep circumflex iliac artery
- vascularized iliac bone graft
- osteonecrosis of the femoral head
- bone reconstruction
- computed tomography anatomy

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The treatment of osteonecrosis of the femoral head (ONFH) in young adults has long been a difficult problem.[1] Regular hip-preservation surgery is rarely performed due to the maturity of total hip arthroplasty and the inconsistent effect of hip-preservation treatment.[2,3] However, the high activity levels of young people pose challenges to the longevity of artificial joints, requiring repeated surgeries.[4] Furthermore, the cost of such surgeries places a heavy financial burden on society.[5]

Hip-preservation therapies, such as deep circumflex iliac artery (DCIA)-vascularized iliac graft transposition and free vascularized fibular flaps, aim to avoid or delay hip arthroplasty.[6–8] DCIA-vascularized iliac graft transposition does not require vascular anastomosis and additional surgical sites, with a short operation time and an incision close to the bikini area.[8] It is typically performed before the Association Research Circulation Osseous classification III B stage, that is, when the femoral head has not collapsed or the collapse is less than 2 mm.[9,10] Taylor et al[11,12] first reported the anatomical characteristics of the DCIA-vascularized graft and its treatment of soft tissue and bone defects in 1979, with promising results. Subsequently, the graft became well-known and widely used.[13] In 1990, Solonen et al[14] reported using a DCIA-vascularized iliac graft to treat ONFH.

The efficacy of DCIA-vascularized iliac graft surgery for ONFH has varied in previous studies, which may be due to unique surgical details.[10,15,16] We found during the operation that after transposition of the DCIA-vascularized iliac graft, the length of the vascular pedicle was sometimes slightly shorter and the vascular tension was high. Similar problems arose when other researchers used DCIA-free grafts.[17] In addition, the vascular pedicle may twist and spasm, which is not conducive to postoperative blood supply reconstruction or early functional exercise of the affected limb.[18] All of these factors may have an impact on the surgical outcome. Therefore, surgical details must be pursued to achieve stable and effective surgical methods.

It is now possible to obtain clear vascular images thanks to the development of computed tomography (CT) imaging. Many scholars have reported CT-related anatomical studies and preoperative designs with reliable results;[19,20] therefore, we used a three-dimensional CT angiography volume rendering (VR) technique to observe the anatomical relationship between the DCIA and surrounding tissues in normal young adults, primarily to explore the vascular pedicle problem of the DCIA-vascularized iliac graft and to propose an anatomical basis to explore the surgical method.

Materials and Methods

The arterial phase data of 50 patients (100 sides; 25 males and 25 females) who underwent enhanced CT imaging of the whole abdomen for abdominal diseases, including liver tumors, were observed and measured. All measurement operations were performed independently by two researchers, and their average values were taken. If there was a significant difference in measurement, the team would discuss the reasons and measure again. We received permission from the ethics committee for this study, and informed consent was obtained from all patients.

All scanned data were obtained using an IQon-Spectral CT system (Philips Healthcare, Best, Netherlands). The inclusion criteria for the study were as follows: (a) $<$60 years of age, (b) CT slice thickness of $\leq$1 mm, (c) Iopromide (76.89 g/100 mL) as the contrast agent injected in the median elbow vein, (d) visible length of the DCIA $\geq$ 80 mm, and (e) the results of the DCIA reconstruction were distinguishable from the surrounding tissues. Patients were excluded if they had (a) vascular diseases, such as thrombosis and artery stent implantation, or (b) hip and pelvic diseases, such as fractures and bone tumors. The arterial phase image, which was 40 seconds after the contrast agent injection, was reconstructed on a workstation (ISP10.1.5LR*2020). The mode was set to 40-keV virtual monoenergetic level, the opacity of 49, and the imaging mode of CTA. The software's working interface and measurement items are shown in ►**Fig. 1**.

We collected data including (a) the total visible length of the DCIA on a curved planar reformation, (b) the distance between the origin of the DCIA and the anterior superior iliac spine (ASIS) during VR, (c) the distance between the origin of the DCIA and the center of the femoral neck (the midpoint of the line between the midpoint of the lower line of the femoral neck head and the midpoint of the basal line) during VR, (d) the trail of the DCIA in the iliac segment, and (e) the quantitative relationship between the DCIA and the iliac bone (i.e., measuring the distance between the DCIA and the iliac crest and the inner table of the ilium at the ASIS, and 1, 2, 3, 4 cm behind the ASIS on VR images and CRP images). In addition, (f) the vessel diameter and cross-sectional area of the DCIA were recorded at the origin, ASIS, and 1, 2, 3, 4 cm behind the ASIS, respectively. Furthermore, (g) the relationship between the origin of the DCIA and the inguinal ligament (IL) was examined (above, behind, or below the IL). The IL was defined as the line between the ASIS and the pubic tuberosity, which was 6 mm wide. Finally, (h) during VR, we measured the distance between the origins of the DCIA and the inferior epigastric artery.

Previous autopsy data from other scholars were used to confirm the reliability of the data collected by this imaging method. The length difference between the DCIA vascular pedicle of the iliac graft and the required transposition was mainly investigated. The pedicle length required for transposition was determined by measuring the distance between the origin of the DCIA and the center of the femoral neck. The pedicle length was calculated from the origin of the DCIA to different locations on the iliac crest. The larger the diameter/cross-sectional area of the DCIA and the shorter the distance from the iliac spine, the better the blood supply of the vascularized bone graft was considered. As a result, the optimal pedicle position was obtained based on vascular pedicle length and blood supply. Then, we investigated sex-related and left–right differences in surgery based on the anatomical data. Additionally, a 3D model of the DCIA and ilium based on the collected data was generated by a computer for reference. The model was developed using SolidWorks 2021 (Dassault Systèmes, USA) and Mimics 21 (Materialise Corporation, Belgium).

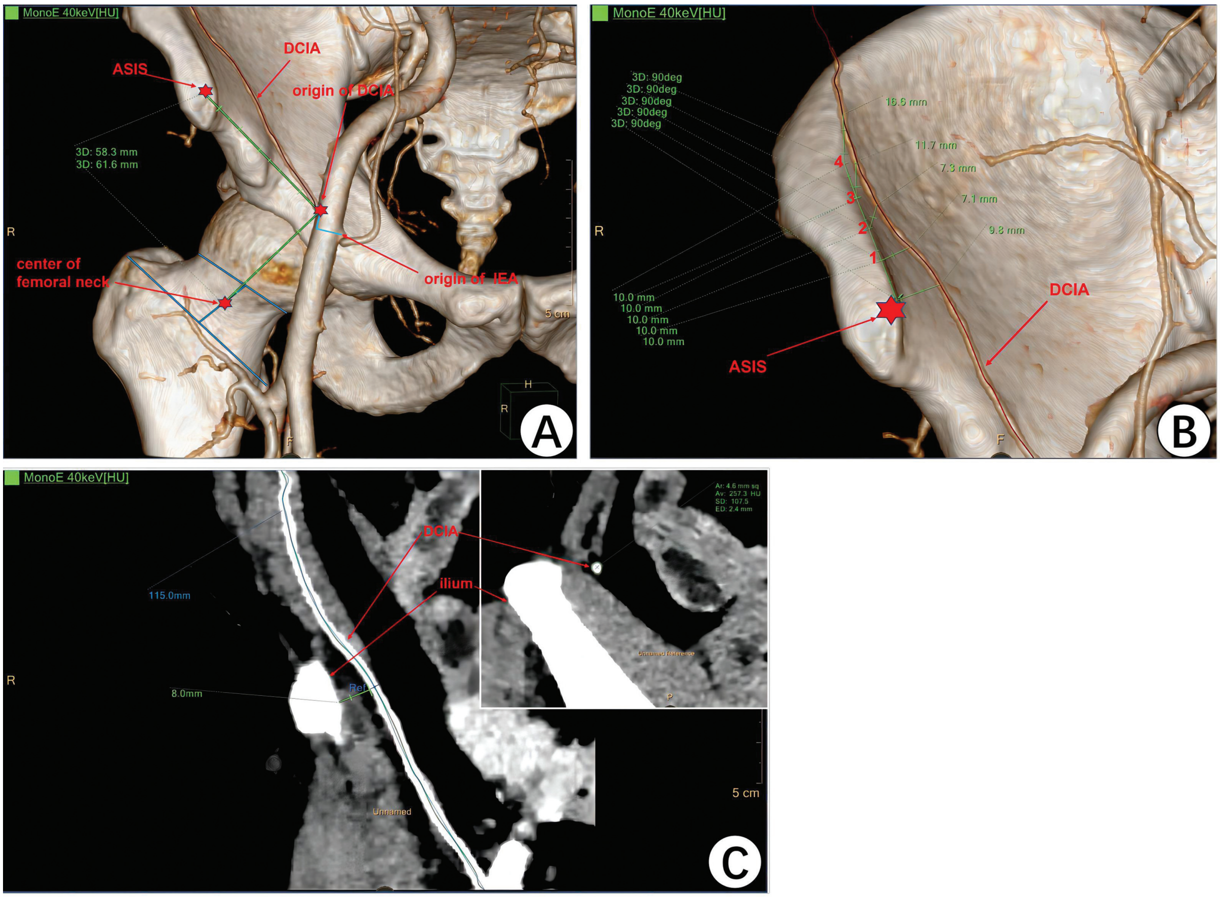

Fig. 1 Display of workstation interface. **(A, B)** were measured in 3D volume reconstruction, and **(C)** was measured under curved planar reformation. ASIS, anterior superior iliac spine; DCIA, deep circumflex iliac artery.

The SPSS version 26.0 statistical software (IBM Corporation, Armonk, NY) was used for analysis. Descriptive statistics were presented as mean ± standard deviation and maximum and minimum values for continuous variables and as number (n) and percentage (%) for categorical variables. To compare the length of the DCIA vascular pedicle of the iliac graft and the required transposition, the paired t-test was used. To compare the variable data of sex and left–right side groups, the independent sample t-test was used. The categorical variables were compared using Pearson's chi-square test. All statistical tests were two-sided; $p < 0.05$ was considered statistically significant.

Results

The origin, course, and anatomical relationship between DCIA and surrounding structures could be observed. All basic measurement results are shown in ►**Supplementary Table S1** (available in the online version only), and measurement data common to this study and other previous anatomical studies are summarized in ►**Supplementary Table S2** (available in the online version only). Five reliable anatomical studies investigating the DCIA were retrieved.[11,21–24] Our image anatomy data were similar to other anatomical studies and clinical observations.

The Satisfaction Rate of Vascular Pedicle Length

Whether the length of the vascular pedicle at different locations of the iliac crest satisfied the length required for transposition is shown in ►**Table 1**.

Relationship between Deep Circumflex Iliac Artery and Ilium

The visible length of the DCIA was 108.23 ± 18.92 mm, and all DCIAs initially coursed along the inner table of the ilium. However, 54 sides (54%) of the DCIA coursed posteriorly and superiorly away from the iliac spine 4 cm away from the ASIS at the iliac crest (►**Fig. 2**). A 3D model of the relationship between the DCIA and the ilium is shown in ►**Fig. 3**.

The distance between the DCIA and iliac crest decreased as the vessels progressed. The ASIS had the farthest distance (21.48 ± 5.29 mm), which became closer and more stable after 2 cm (13.88 ± 4.73 mm at 2 cm and 10.69 ± 4.54 mm at 3 cm behind ASIS). The diameter and cross-sectional area of the DCIA were significantly decreased at 3 to 4 cm behind the ASIS. The diameter and cross-sectional area changes of the DCIA are shown in ►**Fig. 4**. The changes in distance between the DCIA and the iliac spine and internal iliac plate are shown in ►**Fig. 5**.

Differences in Sex and Left–Right Sides

The results of sex and left–right side comparison for each measurement content are shown in ►**Supplementary Tables**

Table 1 Satisfaction rate of the vascular pedicle length

Location			ASIS	ASIS + 1 cm	ASIS + 2 cm	ASIS + 3 cm	ASIS + 4 cm
Satisfaction rate	All		30%	75%	96%	99%	100%
	Sex	M	16%	60%	92%	98%	100%
		F	44%	86%	100%	100%	100%
	Left and right	L	34%	80%	98%	98%	100%
		R	26%	68%%	94%	100%	100%
	Arterial origin	EIA	22.22%	80.83%	94.44%	98.61%	100%
		FA	50%	82.14%	100%	100%	100%

Abbreviations: ASIS, anterior superior iliac spine; DCIA, deep circumflex iliac artery; EIA, external iliac artery; FA, femoral artery.
The proportion of cases whose distances from the DCIA origin to ASIS, 1 cm behind ASIS, 2 cm behind ASIS, 3 cm behind ASIS, and 4 cm behind ASIS were greater than or equal to the distance from the DCIA origin to the center of the femoral neck, which was regarded as a rate of satisfaction.

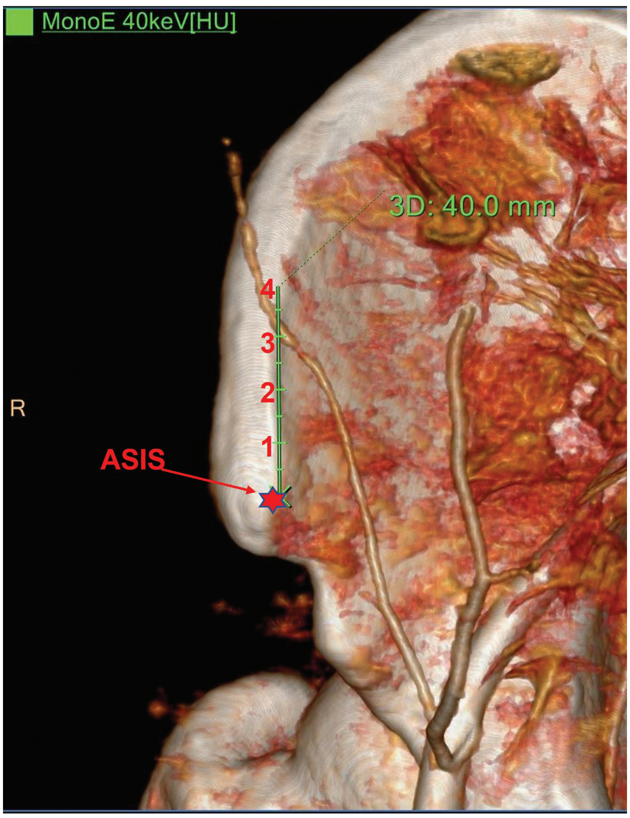

Fig. 2 Fifty-four sides (54%) of the DCIA coursed posteriorly and superiorly away from the iliac spine at 4 cm behind the ASIS. ASIS, anterior superior iliac spine; DCIA, deep circumflex iliac artery.

S3 and **S4** (available in the online version only). The visible length of the DCIA did not differ significantly between the sexes or between the left and right sides. Distance from DCIA origin to femoral neck in males (70.10 ± 7.21 mm) was longer than in females (64.35 ± 6.85 mm). Distance from DCIA origin to ASIS was longer on the left (65.92 ± 5.74 mm) than on the right (62.03 ± 7.04 mm). Distance from the origin to the inferior epigastric artery was longer in females (−4.93 ± 10.33 mm) than in males (−1.31 ± 7.25 mm) and on the left side (−5.15 ± 8.35 mm) than on the right side (−1.09 ± 9.41 mm). The distance from DCIA to the ilium's inner table significantly differed at ASIS and 1 and 2 cm behind ASIS between sexes (see ►**Supplementary Table S3** [available in the online version only]).

The origin of the DCIA was above the IL in 49 sides (49%), behind the IL in 23 sides (23%), and below the IL in 28 sides (28%). Because the external iliac artery becomes the femoral artery below the IL, 72 cases (72%) of DCIAs originated from the external iliac artery, and 28 cases (28%) of DCIAs originated from the femoral artery. In terms of sex, the location of origin of the DCIA differed significantly (►**Table 2**).

Discussion

We conducted this study to solve practical problems in surgery because increasing amounts of quantitative anatomical data obtained in imageology have been proven effective and applied in clinical practice.[19,20] The anatomical data obtained by this imaging method, such as the diameter of blood vessels, are similar to results gathered from cadavers (see ►**Supplementary Table S2** [available in the online version only]), indicating that the data of imageology anatomy can be discussed and studied.

In previous DCIA-vascularized iliac graft transposition procedures, the iliac graft was typically harvested arbitrarily, sometimes at the ASIS.[25] These surgical details may have contributed to the wide variation in results, with the survival rate of the femoral head ranging from 24 to 100%.[1,10,15,16,26] In this study, when the pedicle location of the iliac bone graft was selected at the ASIS, the average length of the pedicle was 64.00 ± 6.69 mm. In the study by Kheradmand et al,[27] the pedicle length of the free DCIA-vascularized iliac graft was 64.93 ± 7.26 mm. However, the average straight-line distance from the DCIA origin to the center of the femoral neck was 67.23 ± 7.57 mm. As a result, when the pedicle location was selected at the ASIS, the length of the vascular pedicle could not satisfy the required transposition. Furthermore, forced traction and transposition can lead to increased vascular tension, causing the vascular pedicle to twist and spasm, which is not conducive to postoperative blood supply reconstruction or early functional exercise of the affected limb.[18]

According to the findings of this study, if the vascular pedicle was placed at 1 cm behind the ASIS, although the

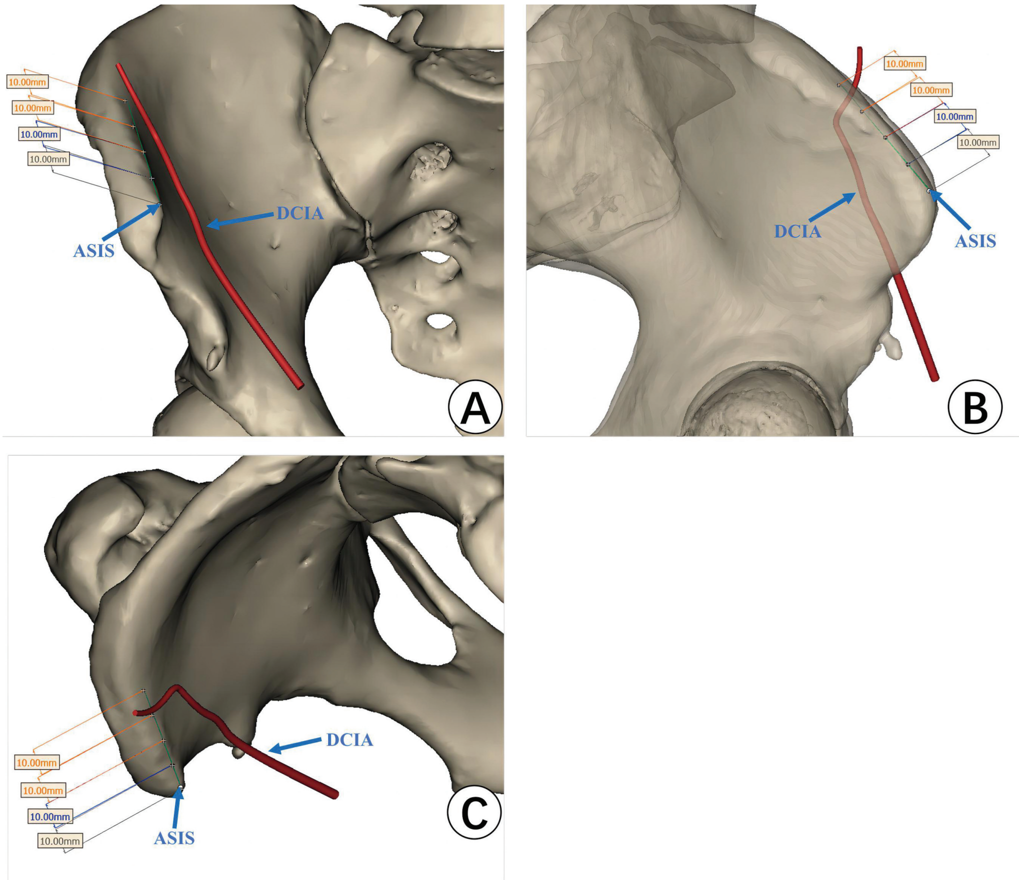

Fig. 3 Three-dimensional (3D) model of the relationship between the DCIA and the ilium drawn by software. The data were based on the mean value of the diameter of the DCIA and the quantitative relationship between the DCIA and the ilium. **(A)** Main view. **(B)** Side view. **(C)** Top view. ASIS, anterior superior iliac spine; DCIA, deep circumflex iliac artery.

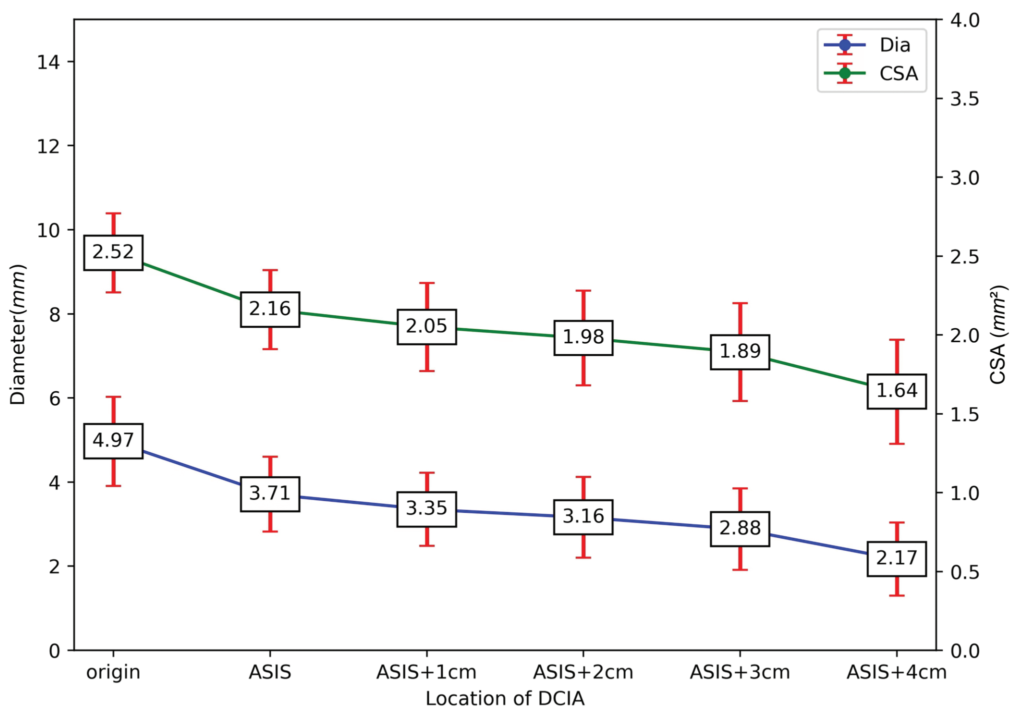

Fig. 4 Diameter and cross-sectional area changes of the DCIA. ASIS, anterior superior iliac spine; CSA, cross-sectional area; DCIA, deep circumflex iliac artery.

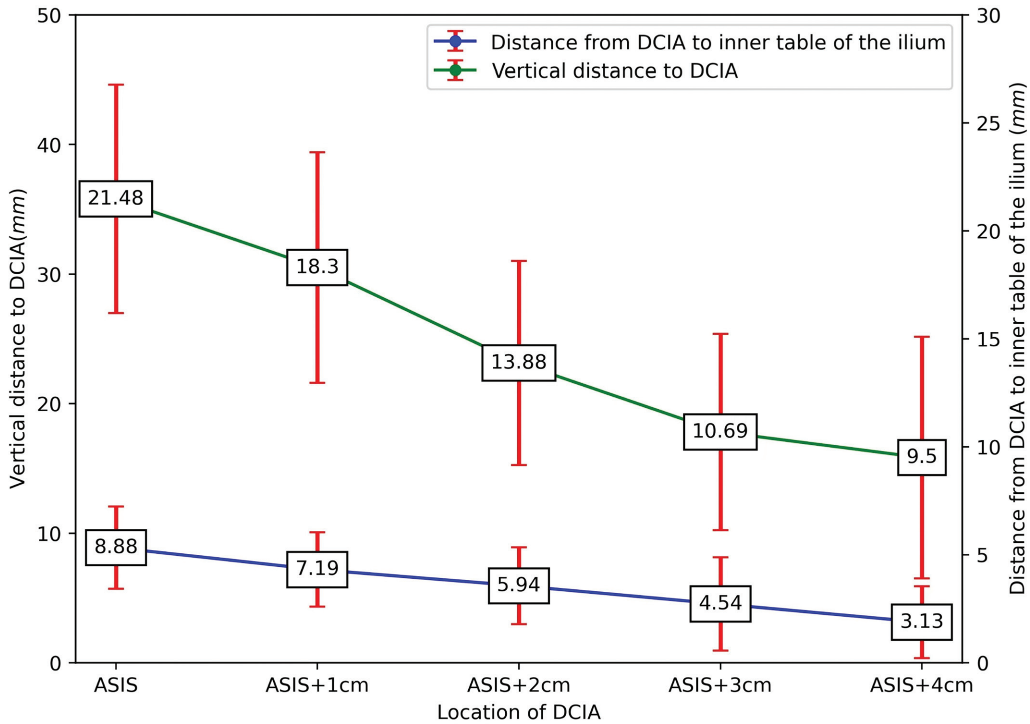

Fig. 5 Changes in the distance between the DCIA, the iliac spine, and the internal iliac table. ASIS, anterior superior iliac spine; DCIA, deep circumflex iliac artery.

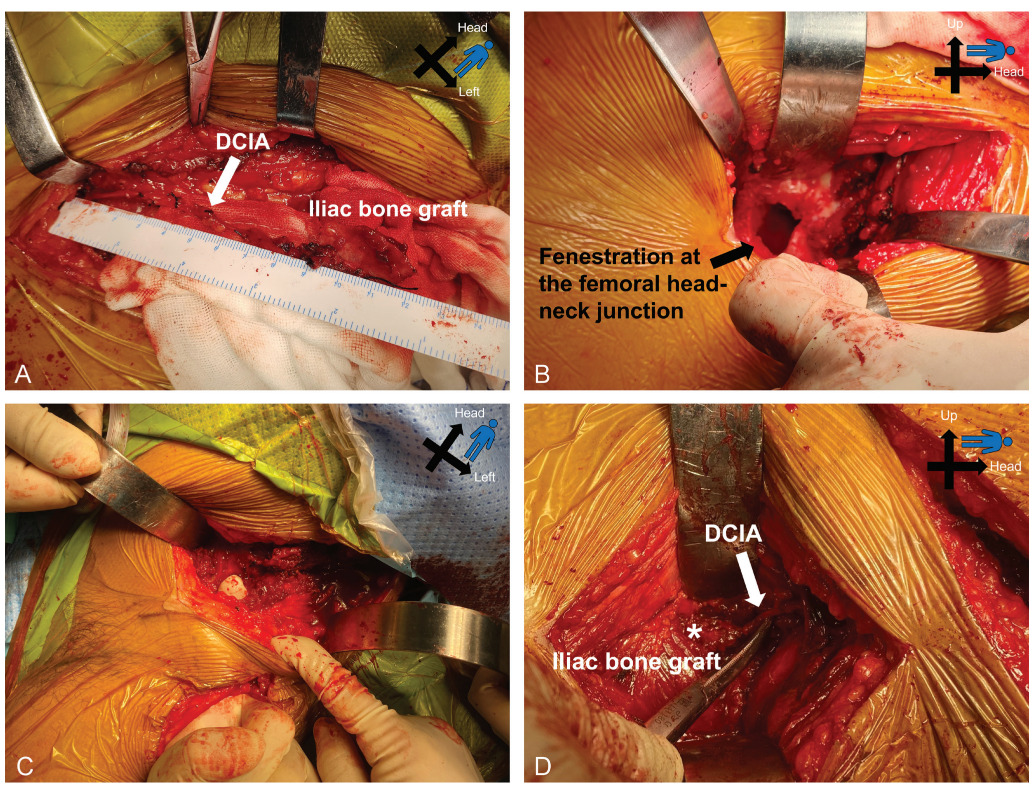

Fig. 6 A 29-year-old male patient, taking Medrol (methylprednisolone tablets) for 16 months because of the neuromyelitis optica, was diagnosed as ONFH (ARCOII). He was too young to be considered for a total hip arthroplasty and he also resisted it. Therefore, a DCIA-vascularized iliac bone graft transposition surgery was performed. **(A)** The pedicle of the DCIA-vascularized iliac bone graft was located 2.5 cm behind the ASIS along the iliac crest, so a long vascular pedicle measuring 90 mm was harvested. **(B)** Fenestration at the femoral head–neck junction. The necrotic bone was completely scraped, and space for transposition was reserved. **(C)** Establishment of the tunnel for vascular pedicle. The tunnel should have a sufficient width to allow easy passage of the index finger. **(D)** The tension of vascular pedicle was relaxed after transposition. The DCIA was lifted by a hemostatic forceps to show the relaxation. ARCO, Association Research Circulation Osseous; ASIS, anterior superior iliac spine; DCIA, deep circumflex iliac artery; ONFH, osteonecrosis of the femoral head.

Table 2 Comparison of deep circumflex iliac artery origins according to sex

	Male, *n* (%)	Female, *n* (%)	χ^2 (*p*)
External iliac artery	31 (62)	41 (82)	4.960 (0.026)
Femoral artery	19 (38)	9 (18)	–

average length of the vascular pedicle was 74.00 ± 6.69 mm, only 75% of the vascular pedicle length was larger than or equal to the required length (►**Table 1**). In addition, the distance measured in this study from the origin of the DCIA to the center of the femoral neck was a straight-line distance, whereas the actual surgical conversion channel may have vascular bending; when coupled with vascular spasm and other factors, the actual length of the vascular pedicle is required to increase, so using 1 cm on the ASIS as the location of the pedicle is not satisfactory. The length of the vascular pedicle was 84.00 ± 6.69 or 94.00 ± 6.69 mm when the pedicle was placed 2 or 3 cm behind the ASIS, and 96 or 99% of the vascular pedicle length satisfied the requirements.

In terms of blood supply, the diameters of the DCIA at 2 or 3 cm behind the ASIS were 1.98 ± 0.30 or 1.89 ± 0.31 mm, and the cross-sectional areas of the DCIA were 3.16 ± 0.96 or 2.88 ± 0.97 mm^2. There was no clinical difference in DCIA diameter/cross-sectional area 2 to 3 cm behind ASIS compared with 1 cm behind ASIS (►**Fig. 4**). The vertical distances between the DCIA and the iliac spine were 13.88 ± 4.73 or 9.50 ± 0.60 mm when the vascular pedicle was 2 or 3 cm behind the ASIS compared with 18.30 ± 5.34 mm at 1 cm behind the ASIS, where the blood vessel is closer to the iliac bone and its blood supply can be better guaranteed. These findings suggest that the DCIA vessels are not thinner and are closer to the iliac spine at 2 to 3 cm behind the ASIS, providing better blood supply to the iliac graft. Fifty-four sides (54%) of the DCIA had coursed posteriorly and superiorly away from the iliac spine at 4 cm behind the ASIS (►**Fig. 2**). Although a longer pedicle can be obtained here, the blood supply of the DCIA in the iliac graft will not be constant.

In conclusion, the most appropriate DCIA pedicle location for transposition of the vascularized iliac graft should be 2 to 3 cm behind the ASIS, and the osteotomy should be centered on this vascular pedicle to obtain a satisfactory length of the vascular pedicle, sufficient blood supply, and operable osteotomy size (►**Figs. 6** and **7**).

There was no statistically significant difference in the visible length of DCIA between sexes or the left and right sides; however, the differences in the following cases may have clinical significance.

In female/left side/femoral artery origin of DCIA, it is easier to obtain a longer vascular pedicle to satisfy transposition requirements (►**Table 1**). It could be explained by the longer distance from DCIA origin to ASIS (the basic vascular pedicle length) in females and the shorter distance from DCIA origin to the femoral neck (the length of the vascular pedicle required for transposition) in the left side (see ►**Supplementary Table S3** [available in the online version only]).

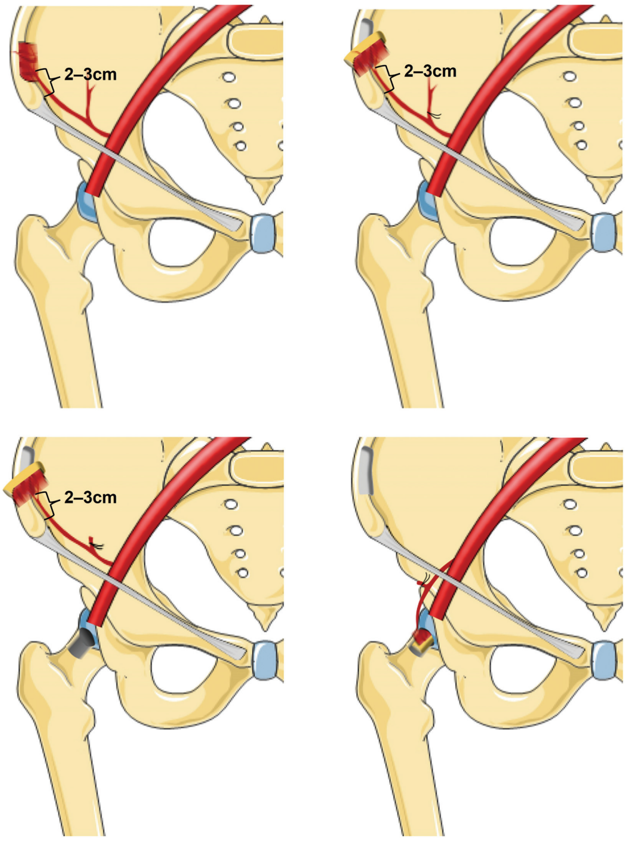

Fig. 7 Diagram of the operative process. Transposition to the femoral head with the vascular pedicle located 2 to 3 cm behind the ASIS along the iliac crest. ASIS, anterior superior iliac spine.

In males, the DCIA originated from the external iliac artery in 31 sides (62%) and the femoral artery in 19 sides (28%), whereas in females, it originated from the external iliac artery in 41 sides (82%) and the femoral artery in 9 sides (18%). There were statistically significant differences according to sex but no statistically significant difference between the left and right sides. This sex difference in DCIA origin has important implications for finding the root of DCIA in operation. To obtain a longer pedicle length, it is generally necessary to perform adequate vascular separation. Therefore, it is more likely to approach below the IL when separating male blood vessels in a retrograde manner. Particular care should be taken to avoid damaging the vessel roots.

The origin of the DCIA was more distant from the inferior epigastric artery in females (−4.93 ± 10.33 mm) than in males (−1.31 ± 7.25 mm), and on the left side (−5.15 ± 8.35 mm) than on the right side (−1.09 ± 9.41 mm), which suggests that the origin of the DCIA on the right and in males is closer to the inferior epigastric artery, which must be protected during the operation.

Other data with statistical differences, such as the distance from DCIA to the inner table of the ilium, were statistically different; however, the surgical process was unaffected by these small millimeter differences.

Conclusion

This study provides detailed refinements of DCIA-vascularized iliac graft transposition surgery based on CT anatomical data. The vascular pedicle of the vascularized iliac graft should be 2 to 3 cm behind the ASIS to obtain a satisfactory vascular pedicle length, sufficient blood supply, and operable osteotomy size. It is easier to obtain a longer vascular pedicle to satisfy the required transposition in the female/left side/femoral artery origin of DCIA. Due to anatomical differences, there should be slight differences in sex and left–right position during DCIA dissection.

Availability of Data and Materials

All data generated or analyzed during this study are included in this published article and its supplementary information files.

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None.

Conflict of Interest

None declared.

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