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Abstract: Limited reports have evaluated the utility of the popliteal vein (PV) specific to cannulation. The objective of this study was to characterize the diameter and length of the PV to evaluate this area as a potential cannulation site. The popliteal region in 23 formalin-embalmed, prosected donors was dissected, and the PV was exposed from the adductor hiatus (AH) superiorly to the small saphenous vein (SSV) inferiorly. The diameter of the popliteal vein was measured at the AH, SSV, and half of the distance from the AH to the SSV (MID) using a brass plumb bob. The length of the PV was measured to the AH, SSV, MID, and femoral condyles (FCs). Overall, the mean diameters and mean lengths for the combined population were calculated, as well as individual limbs (right, left) and anatomical sex. Univariate analysis used to evaluate differences in mean diameter and length measurements based on anatomical sex revealed significant differences ($p < 0.05$) for both diameter and length at all the landmarks evaluated. Multivariate analysis of PV diameter at the AH and SSV landmarks was statistically significant ($p < 0.05$) when laterally and anatomical comparing sex. These data provide full characterization of the PV in support of its utility in vascular access.

Keywords: popliteal vein; cannulation; laterality; sex-based differences

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1. Introduction

Central venous catheterization is a staple of emergency medicine, intensive care, and anesthesia. The complications from this procedure include hemothorax, pneumothorax, arterial cannulation, infection, thrombosis, and hematoma [1]. The preferred sites for cannulation are the internal jugular, subclavian, and femoral veins, each carrying their own approaches and potential complications. The use of central venous catheters is multipurposed; however, in the acutely ill patient, they serve as a reliable entry site for large amounts of fluid, blood products, and medications as they are better for long-term care when compared to peripheral IVs [2].

While not a primary site for cannulation, reports have noted using the popliteal vein for central venous access [3–5]. This typically occurs in situations where the patient is placed in a prone position such as emergency surgery or in the Intensive Care Unit when patients suffering from acute respiratory distress syndrome (ARDS) are flipped, which has been shown to improve V/Q function [6], improve PaO_2/FiO_2 ratio [7], and decrease mortality [7]. During the COVID-19 pandemic, the use of the prone position in patients with ARDS became a widely adapted therapeutic modality [6–13] and has been utilized with both intubated and non-intubated patients [11], leading to the development of new terminology: awake prone positioning (aPP) [11]. Retrospective cohort studies have demonstrated that the rate of utilizing the prone position has grown exponentially due to the pandemic, with rates of 70% or greater being reported [12,14,15], compared to rates of roughly 20% before the pandemic [16,17]. It has also been demonstrated that awake prone positioning was associated with reduced treatment failure and reduced need for intubation [13]. Limited reports have demonstrated the use of this approach for patients experiencing deep vein thrombosis [18], severe burns [19,20], or post-traumatic lung injury following blunt injury [21]. Although limited in number, successful cannulation of the PV in patients requiring prone positioning due to severe burns [22] and renal replacement therapy [23,24] have been reported.

Given the relevance and importance of establishing central venous access within the clinical management of various conditions, and the potential opportunity provided by the popliteal vein, it provokes an evaluation of the anatomical challenges, if any, that prevent the usage of this site for cannulation. Therefore, the objective of this study was to evaluate and characterize the anatomical variation in the popliteal vein, specifically as it relates to sex and laterality, with the end goal of determining its utility in catheterization.

2. Methods

2.1. Donor Population and Ethical Approval

Twenty-three prosected, formalin-embalmed donors from the Gift Body Program at Kansas City University (KCU) were evaluated in this study. Participation as a donor in the program is completely voluntary; donors with known blood-borne disease (i.e., Hepatitis) or excessively large body habitus are precluded from participation. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Institutional Biosafety Committee (1954741-1). Donors were embalmed with a proprietary blend of formalin-based embalming solution within 36 h of death. Fifteen males and eight females were included for a total of forty-six limbs. Medical history from the twenty-three donors was reviewed, and any significant history of surgical procedures in the region was noted. All limbs were evaluated physically to determine if there were any signs of surgical history in the area as this may not be included in the medical history provided. One donor had an absent popliteal vein unilaterally due to dissection error, and the limb was excluded from the study. After exclusion criteria were applied, 29 male limbs and 16 female limbs for a total of 45 limbs were included in the study.

2.2. Dissection and Measurement of the Popliteal Vein

With the donors in the prone position, the entirety of the popliteal vein from the adductor hiatus (AH, superior) to the branch point of the small saphenous vein (SSV, inferior) was dissected when viewed from the posterior aspect of the popliteal fossa. If the entirety of the popliteal vein was not visible within the superior/inferior parameters described above, further dissection occurred to gain appropriate visibility. Various landmarks of the region were then evaluated and visualized as these would be points from which measurement would be taken. If these landmarks were not explicitly visible in a consistent manner, further dissection occurred. The landmarks included were as follows: AH, SSV, half of the distance from AH to SSV (MID), and femoral condyles (FCs) (Figure 1).

The diameter of the popliteal vein was measured at the AH, MID, and SSV using a brass plumb bob (Figure 2A). Measurements of AH—SSV, MID-SSV, SSV-FCs, and AH—FCs were collected using a 150 mm electronic caliper (Mitutoyo, Takatsu-ku, Kawasaki, Japan). The methodology to include the use of the brass plumb bob was due to the understanding that the electronic caliper had the potential to alter the shape and measurements of the popliteal vein when clamped. The consistent expansion of the brass plumb bob was used to stretch each vessel to its max diameter (Figure 2B). The measurement was then taken directly distal to this point (Figure 2C). Taking the measurement using this protocol ensured that no manipulation of the vessel was caused by the caliper. All measurements and dissections were performed by the same investigator (AG) to reduce measurement error.

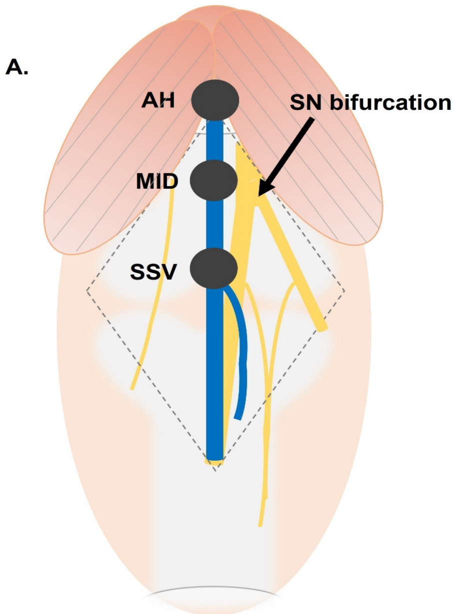

Figure 1. The popliteal vein regions and anatomical landmarks to evaluate prior to cannulation. (**A**) Graphic representation of the popliteal region and the anatomical landmarks utilized to characterize the popliteal vein (blue). (**B**) Graphic of anatomical landmarks adjacent to the sciatic nerve and its branches (yellow) and the bones of lower extremity (gray). AH, adductor hiatus; MID, half the distance between the AH and the small saphenous vein (SSV); FCs, femoral condyles.

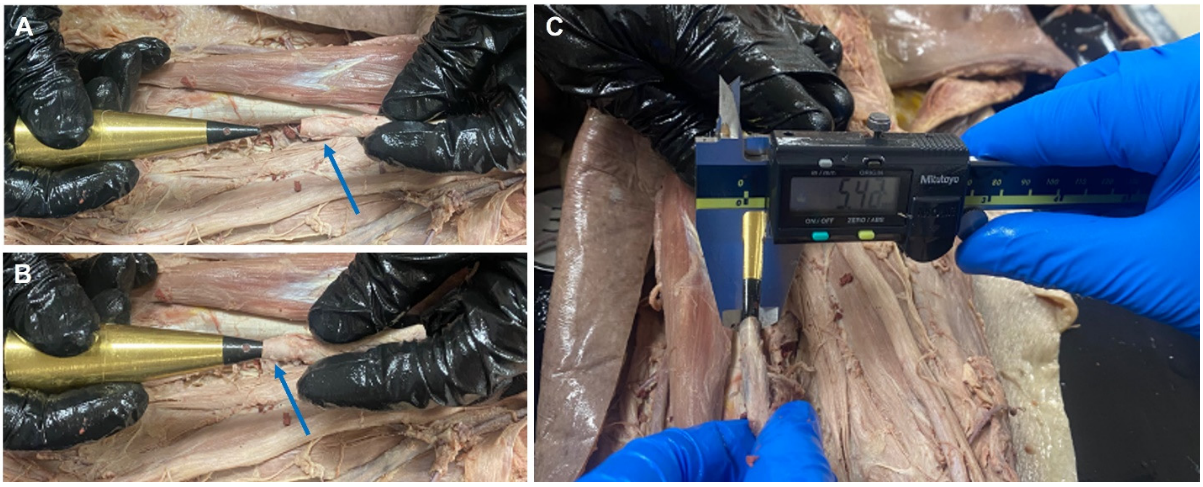

Figure 2. Characterizing the popliteal vein. (**A**) Demonstration of popliteal vein (blue arrow) diameter measurement using a brass plumb bob (left). (**B**) The end of the tip of plumb bob was inserted into the patent end of the popliteal vein (blue arrow) to restore circular shape of the vein. The diameter measurement was recorded (**C**).

2.3. Statistical Analysis

Recorded vessel diameters and lengths were used to determine descriptive statistics (mean, standard deviation, confidence interval) for each group. Statistical differences between groups were determined by Levene's statistical test for equality of variance, and Student's *t*-test or the Mann–Whitney U (MWU) test was utilized for univariate analysis (males vs. females; left limb vs. right limb). If multivariate analysis was conducted (male left vs. male right vs. female left vs. female right), statistical comparisons were made by ANOVA. A p value of <0.05 was used to determine significance across all tests. All analysis was conducted using Jamovi Open-source Software (The jamovi project (2024). jamovi

(Version 2.5) [Computer Software]), Sydney Australia, retrieved from https://www.jamovi.org (accessed 15 March 2024).

3. Results

3.1. Descriptive Statistics of the Popliteal Vein

The mean diameters of our entire sample population at the AH, MID, and SSV landmarks, as well as the mean length from the AH-SSV, AH-FCs, MID-SSV, and SSV-FCs are included in Table 1, respectively.

Table 1. Descriptive measurements of donor population.

Landmark	Measurement	Mean (SD) (95% CI)
AH	Diameter	7.69 (1.37) (7.27–8.11)
MID		7.69 (1.73) (7.17–8.21)
SSV		7.28 (1.76) (6.75–7.81)
AH-SSV	Length	115.20 (35.39) (104.59–125.86)
AH-FCs		145.99 (16.99) (140.83–151.15)
MID-SSV		57.61 (17.70) (52.30–62.93)
SSV-FC		32.41 (30.61) (23.21–41.60)

Combined N = 45 limbs, male N = 30 Limbs, female N = 15 Limbs; all measurements are in mm. AH, adductor hiatus; MID, 1/2 the distance between adductor hiatus (AH) and small saphenous vein (SSV); FCs, femoral condyles.

3.2. Laterality-Based Univariate Analysis

Diameter and length measurements were calculated for left and right limbs (Table 2). No statistical significance was found when comparing any diameter or length measurements between left and right limbs (Table 2).

Table 2. Laterality-based analysis of diameter and length measurements.

Landmark	Measurement	Left (SD) (95% CI)	Right (SD) (95% CI)	Test	*p* Value
AH	Diameter	7.56 (1.35) (6.96–8.16)	7.83 (1.40) (7.19–8.47)	Student's t	0.53
MID		7.59 (1.73) (6.82–8.35)	7.79 (1.76) (7.03–8.56)	Student's t	0.69
SSV		7.27 (1.82) (6.46–8.07)	7.30 (1.74) (6.55–8.05)	Student's t	0.95
AH-SSV	Length	120.84 (32.80) (106.30–135.38)	109.85 (37.64) (93.58–126.13)	Student's t	0.30
AH-FCs		146.56 (18.80) (138.22–154.89)	145.45 (15.88) (138.58–152.32)	Student's t	0.83
MID-SSV		60.42 (16.40) (53.15–67.69)	54.93 (18.82) (46.79–63.06)	Student's t	0.30
SSV-FCs		28.10 (21.40) (18.62–37.59)	36.52 (37.42) (20.34–52.70)	Mann–Whitney U	0.56

Combined N = 45 limbs, left N = 22 limbs, right N = 23 limbs; all measurements are in mm. *p* value of (<0.05) was used to determine significance; AH, adductor hiatus; MID, 1/2 the distance between adductor hiatus (AH) and small saphenous vein (SSV). FCs, femoral condyles. Levene's *p* value of (<0.05) was used to determine normality.

3.3. Sex-Based Univariate Analysis

To determine any differences in the popliteal vein and anatomical sex, diameter and length measurements were compared between males and females (Table 3). The mean diameter at the AH, MID, and SSV was statistically larger in males than in females ($p < 0.05$) at all landmarks. For length measurements, values in female limbs were greater than those in male donors between all locations except SSV-FCs. In evaluating these differences statistically, only the AH-FCs approached significance, but they did not pass the threshold.

3.4. Multivariate Analysis of Anatomical Sex and Laterality

Diameter and length measurements were further compared between left and right limbs to evaluate differences across each limb and anatomical sex. Analysis of the differences in the diameter measurements is included in Table 4. When evaluating the diameter of the PV at the AH and SSV landmarks, the male left and right diameters were each larger than both the female left and right diameters, respectively ($p < 0.05$). In contrast, the

PV diameter at the MID landmark of the left male limb was statistically larger than the female left only, while the male right limb was statistically larger than both the female left and female right. No significance difference was noted when comparing any male–male or female–female diameters at the AH, MID, or SSV. Finally, no statistically significant differences for length measurements were identified.

Table 3. Sex-based analysis of diameter and length measurements.

Landmark	Measurement	Males (SD) (95% CI)	Females (SD) (95% CI)	Test	*p* Value
AH	Diameter	8.16 (1.33) (7.65–8.66)	6.73 (0.87) (6.23–7.23)	Student's t	<0.05
MID		8.28 (1.60) (7.67–8.88)	6.64 (1.46) (5.86–7.42)	Student's t	<0.05
SSV		7.94 (1.73) (7.29–8.60)	6.09 (1.07) (5.52–6.65)	MWU	<0.05
AH-SSV	Length	107.91 (40.84) (92.38–123.45)	128.48 (16.45) (119.71–137.24)	MWU	0.11
AH-FCs		142.33 (18.10) (135.45–149.22)	152.61 (13.47) (145.43–159.79)	Student's t	0.05
MID-SSV		53.96 (20.42) (46.19–61.72)	64.24 (8.22) (59.86–68.62)	MWU	0.11
SSV-FC		36.02 (36.79) (22.02–50.01)	25.86 (12.25) (19.33–32.39)	MWU	0.72

Combined N = 45 limbs, male N = 30 limbs, female N = 15 limbs; all measurements are in mm. *p* value of (<0.05) was used to determine significance; AH, adductor hiatus; MID, 1/2 the distance between adductor hiatus (AH) and small saphenous vein (SSV). FCs, femoral condyles. Levene's *p* value of (<0.05) was used to determine normality.

Table 4. Post hoc analysis of laterality vs. sex.

	ANOVA						
	Laterality vs. Sex		Mean Difference	SE	df	t	*p*
Diameter of PV at AH	Male Left	Male Right	−0.167	0.458	39.0	−0.364	0.718
		Female Left	1.403	0.546	39.0	2.571	0.014
		Female Right	1.258	0.601	39.0	2.094	0.043
	Male Right	Female Left	1.569	0.539	39.0	2.911	0.006
		Female Right	1.425	0.595	39.0	2.396	0.021
	Female Left	Female Right	−0.145	0.665	39.0	−0.217	0.829
Diameter at MID	Male Left	Male Right	−0.0520	0.588	41.0	−0.0885	0.930
		Female Left	1.8205	0.701	41.0	2.5957	0.012
		Female Right	1.4043	0.701	41.0	2.0022	0.052
	Male Right	Female Left	1.8726	0.693	41.0	2.7029	0.010
		Female Right	1.4563	0.693	41.0	2.1021	0.042
	Female Left	Female Right	−0.4163	0.791	41.0	−0.5261	0.602
Diameter of PV at SSV	Male Left	Male Right	0.104	0.581	41.0	0.178	0.859
		Female Left	2.009	0.693	41.0	2.899	0.006
		Female Right	1.808	0.693	41.0	2.609	0.013
	Male Right	Female Left	1.906	0.685	41.0	2.783	0.008
		Female Right	1.704	0.685	41.0	2.489	0.017
	Female Left	Female Right	−0.201	0.782	41.0	−0.257	0.798

p value of (<0.05) was used to determine significance. Note: Comparisons are based on estimated marginal means.

4. Discussion

These data provide a much-needed characterization of the PV in support of its available and optional utility for vascular access. The consistency of the diameter measurements in both male and female patients, from superior to inferior along the popliteal vein, indicates that canulation can occur anywhere, if inadvertent damage to other structures is avoided.

Overall, the anatomical data described herein may be applied to various clinical settings and patient presentations requiring cannulation in prone positions.

4.1. Evaluating the PV for Cannulation

The diameter of the popliteal vein was a key element to explore and characterize so that this information could be compared to the known diameter of veins in the upper extremity where cannulation typically occurs [25–28]. Poiseuille's law of laminar flow states that the flow rate of fluid is directly proportional to the radius of the tube it is running through and indirectly proportional to the length of the tube [29–31]. Simplified, the larger the IV catheter, the quicker that fluids can be administered to a patient. Hence, larger bore IV catheters directly correlate to the rapidness one can fluid-resuscitate a patient. An observational study using ultrasound in 176 participants reported that the maximum diameters of the basilic, brachial, and cephalic veins measured were 7.30 mm, 7.10 mm, and 6.10 mm, respectively [28]. The datum reported herein denote a larger mean diameter for the PV at all sites measured (AH, 7.69 mm; MID, 7.69 mm; SSV, 7.28 mm), as compared to the sites typically used in the upper extremity. Collectively, these results suggest that flow rate into the popliteal vein would not limit resuscitation based on diameter alone. Additionally, when combined with recent reports utilizing popliteal cannulation [22–24], this datum provide additional evidence to support consideration for popliteal cannulation for patients if prone positioning is warranted by their condition.

Using these data, a stepwise plan for cannulation in the popliteal vein was devised should the need arise (Figure 3). Ultrasound is recommended to best visualize where the sciatic nerve bifurcates to avoid potential injury. Once the sciatic bifurcation is identified, this location is marked as the superior most boundary. Ultrasound is used to locate the small saphenous vein off the popliteal vein, and its location serves as the inferior landmark. Because the change in diameter of the popliteal vein from the SSV to adductor hiatus is insignificant (Table 2), cannulation can occur anywhere between the SSV and the area where the sciatic nerve is not interfering with the track of the needle. This area is generally covered by a superficial layer of skin and fascia with limited overlap of the hamstring muscles. Following this straightforward evaluation will allow for the best outcome and the avoidance of injury to surrounding structures.

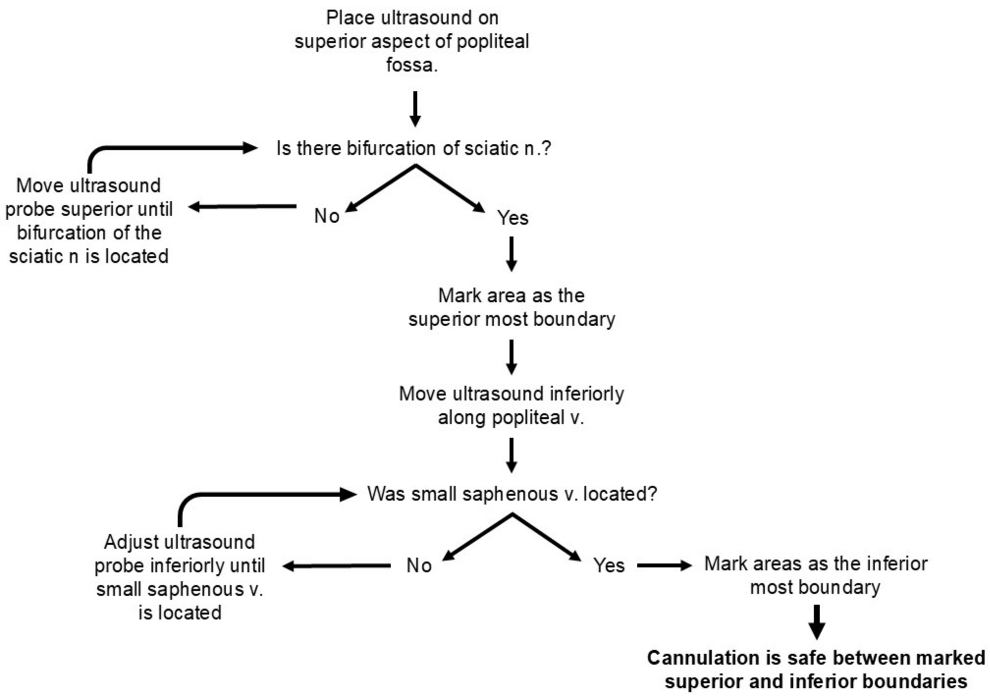

Figure 3. Flowchart for evaluating popliteal vein cannulation.

4.2. Clinical Application of Popliteal Vein Cannulation

The COVID-19 pandemic illustrated the need for novel ideas and techniques to be developed as new diseases and/or emergency responses arise. The need for central venous access in prone patients during the pandemic was high [32], but this prone positioning introduced challenges for the correct placement of catheters. Further, in patients suffering from major trauma, obtaining and maintaining patent vascular access is vital to ensuring proper management. The Advanced Trauma Life Support (ATLS) protocol dictates that two large bore peripheral IVs can be obtained as early as possible and that vascular access is maintained for the continued resuscitation and management of the patient [33]. However, in severe cases of traumatic injury (particularly large area burns [22], explosive injury, amputations) or disease [23,24], obtaining peripheral IVs and/or central lines may not be a viable option, and popliteal cannulation may be warranted. Our characterization of sex-based and laterality differences in the popliteal vein provides the important anatomical context necessary for clinicians to apply this information across a wide range of medical interventions, despite the historically atypical approach of popliteal cannulation.

4.3. Contraindications of Popliteal Vein Cannulation

A key consideration for placement in the popliteal vein would be the development of thrombosis. With indwelling central venous catheters, this may occur as a venous or mural thrombosis or a clot within the catheter itself [34,35]. These events for central lines may be as high as 18% [36], with symptomatic development occurring in 5% [37]. Studies have noted that lower-extremity (femoral) cannulation sites with central lines can have a higher risk of thrombosis compared to the subclavian approach [38]. It may stand to reason that the popliteal site will carry with it a similar risk, but additional data would need to be obtained. Current guidelines on thrombosis prophylaxis vary depending on the underlying disease process of the patient, with general agreement that prophylaxis is not needed for the central line itself but should rather be based off the diagnostic need for the underlying condition (i.e., malignancy, etc.) [39].

The insertion of any type of cannula introduces the risk of infection. Central venous catheters carry a heightened awareness of this risk due to the locality of the catheter tip near the heart and the increased risk of bacteremia and septicemia developing [40]. Depending on the site used, the risk of central-venous-catheter-bloodstream-related infections (CVCBRIs) can range from 5.3 to 8.75 per 1000 catheter days, resulting in a mortality as high as 25% [41,42]; however, this varies by facility and region of placement. While limited data exist for femoral vein catheters indicating that they held a higher risk of infection, the data appear to not be well founded [43]. Currently, no datum have been found on the relative risk of using the popliteal vein for CVC, supporting further investigation, such as through a randomized control trial.

4.4. Study Limitations

Select considerations should be noted in future evaluations of the PV as a cannulation site. Primarily, the measurements in this study were collected from embalmed donors. Additionally, the donor population was Caucasian with a mean age of 71.95 years, which limits the diversity of the sample, particularly when projecting generalizations from this research clinically across a wider variety of patients. Future studies using fresh donors, ultrasound, and/or medical imaging to measure the diameter of the popliteal vein would add to our understanding of PV cannulation.

5. Conclusions

While the popliteal vein will not become a primary area of central venous cannulation as compared to the upper extremity, these data, particularly the diameter measurements of the PV at various anatomical landmarks, support evaluation of its use as a site of entry when treating patients with specific conditions/presentations [22–24,44]. Given the increased availability of ultrasounds at the bedside or in the field, obtaining access via the popliteal vein would be an easily achieved feat by any physician trained in the central line procedure and could serve as a lifesaving modality when the time arises.

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Informed Consent Statement: All subjects gave their informed consent for inclusion before they participated in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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