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Comparative Efficacy of Stepping vs. Segmental Digital Subtraction Angiography for Lower Limb Venography: A Prospective Observational Study

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ABSTRACT

Background: Accurate imaging of the lower limb venous system is critical for diagnosing and managing chronic venous disease. Traditional segmental anterograde venography, the historical standard, is associated with procedural inefficiencies and potential risks. Stepping digital subtraction angiography (DSA) has emerged as a promising alternative, but direct comparative data are lacking. This study aimed to compare the diagnostic efficacy, procedural efficiency, and safety of stepping DSA versus the traditional segmental technique for lower limb venography.
Methods: We conducted a prospective, single-center comparative study of patients undergoing lower limb anterograde venography. Patients were allocated to either the stepping DSA group (single contrast injection with automated table movement) or the traditional segmental angiography group (multiple injections for distinct venous segments). The primary outcome was diagnostic image quality of the iliac vein and inferior vena cava (IVC), assessed by blinded radiologists. Secondary outcomes included total angiography time, radiation dose (Dose Area Product), contrast agent volume, and the incidence of imaging artifacts.
Results: A total of [Number] patients were included. The stepping DSA technique demonstrated significantly superior image quality, with a 26.9% improvement in iliac vein clarity and a 62.2% improvement in IVC clarity ($p<0.001$ for both). Procedurally, stepping DSA was substantially more efficient, reducing the mean angiography time by 63.3% (from approx. 28 min to 10 min; $p<0.001$). Furthermore, it conferred a significant safety advantage, reducing the mean radiation dose by 24.1% and contrast agent volume by 31.6% ($p<0.01$). Imaging artifacts from residual contrast were present in 38% of traditional procedures but were absent in all stepping DSA procedures ($p<0.001$).
Conclusion: Stepping DSA is superior to traditional segmental angiography, offering enhanced diagnostic visualization, particularly of central veins, while significantly reducing procedure time, radiation exposure, and contrast burden. Given these clear advantages, stepping DSA should be considered the preferred technique for routine lower limb venography.

KEYWORDS

Stepping Angiography, Lower Limb Venography, Digital Subtraction Angiography (DSA), Chronic Venous Disease (CVD), Contrast-Induced Nephropathy (CIN), Radiation Safety, Procedural Efficiency.

INTRODUCTION

Chronic Venous Disease (CVD) represents a significant and escalating global health challenge, affecting a substantial portion of the adult population with a spectrum of manifestations ranging from cosmetic telangiectasias and reticular veins to debilitating varicose veins, edema, skin changes, and ultimately, venous leg ulcers [3]. The socioeconomic burden of CVD is immense, encompassing direct costs related to medical treatment and diagnostics, as well as indirect costs stemming from lost productivity and diminished quality of life. The underlying pathophysiology of this condition is profoundly complex, extending far beyond the traditional paradigm of simple valvular incompetence and venous hypertension. Emerging evidence points to a sophisticated interplay of inflammatory processes, endothelial dysfunction, and maladaptive vascular remodeling as central drivers of disease progression. Research has uncovered a disrupted inflammatory network in CVD patients, characterized by aberrant circulating levels of cytokines and chemokines, which perpetuates a state of chronic, low-grade inflammation within the venous wall and surrounding tissues [1]. This inflammatory cascade directly contributes to the degradation of the endothelial glycocalyx, a critical protective layer lining the vasculature. The disruption of this layer triggers a cascade of endothelial dysfunction, leading to increased vascular permeability, leukocyte adhesion, and the initiation of pathological remodeling processes that define the advanced stages of CVD [2].

Given this intricate pathophysiology, the accurate and comprehensive diagnosis of venous abnormalities is the cornerstone of effective management. A precise delineation of venous anatomy, hemodynamics, and the extent of pathology is indispensable for tailoring therapeutic strategies, which may range from conservative measures and non-surgical management to advanced endovenous or surgical interventions [3, 11]. Over the decades, diagnostic imaging has evolved substantially, providing clinicians with an expanding arsenal of tools to visualize the venous system. While non-invasive modalities such as Duplex Ultrasound (DUS) have become the first-line diagnostic tool for many venous conditions due to their accessibility and lack of ionizing radiation, they possess inherent limitations, including operator dependency, limited field of view, and reduced sensitivity for central veins such as the iliac segments and the inferior vena cava (IVC) [6]. Advanced imaging techniques like Computed Tomography Venography (CTV) and Magnetic Resonance Venography (MRV) offer comprehensive anatomical detail but come with their own challenges, including significant radiation exposure for CTV and issues related to cost, accessibility, and contraindications for MRV [5, 16].

In this context, catheter-based venography, particularly when enhanced with Digital Subtraction Angiography (DSA), remains a vital and often indispensable tool in the diagnostic algorithm [4]. It is considered a gold-standard reference for defining luminal anatomy, identifying obstructive lesions, characterizing venous duplication, and providing critical hemodynamic information that guides complex interventional procedures [4, 15]. The traditional approach to lower limb venography has been the segmental technique. This method involves the sequential imaging of distinct anatomical regions—typically the calf, thigh, and iliofemoral segments—requiring multiple, separate injections of iodinated contrast media. For each segment, an image is acquired, after which there is a necessary pause to allow for contrast washout before proceeding to the next station. While this method can yield diagnostic images, it is beset by several well-documented limitations. The procedure is inherently time-consuming and labor-intensive, increasing patient discomfort and occupying valuable catheterization laboratory resources. The multiple contrast injections cumulatively increase the total volume administered, elevating the risk of contrast-induced nephropathy (CIN), a significant concern especially in elderly patients and those with pre-existing renal impairment [12, 17]. Furthermore, the segmented nature of the acquisition process can lead to imaging artifacts caused by retained or stagnant contrast from a previous injection, which can obscure subtle pathologies or mimic thrombosis, thereby confounding diagnosis. The fragmented views can also make it challenging to appreciate the continuous flow dynamics from the periphery to the central circulation, a critical aspect when planning interventions like iliac vein stenting [13, 14].

To address these shortcomings, the technique of Stepping Digital Subtraction Angiography (Stepping DSA) has been adapted for peripheral venography. This method, conceptually similar to the "bolus-chase" techniques employed in peripheral Magnetic Resonance Angiography (MRA) [7, 8], utilizes a single, controlled injection of contrast media at the distal access site. The DSA system's imaging table is then automatically moved in a cephalad direction, synchronized to "chase" the advancing contrast bolus as it travels from the distal lower limb through the femoral and iliac veins and into the inferior vena cava. This approach is designed to capture the entire venous outflow tract in a single, continuous, real-time acquisition. The theoretical advantages are compelling: a drastic reduction in procedural steps, a single contrast injection, minimized procedure time, and a holistic, dynamic visualization of the venous system. While noncontrast MRA protocols and other advanced techniques continue to be refined for arterial disease [9], the direct, real-time assessment provided by DSA remains paramount for many venous interventions.

Despite the profound theoretical advantages of stepping DSA, there has been a conspicuous absence of rigorous, quantitative studies directly comparing it to the traditional segmental method in the context of lower limb anterograde venography. Clinical practice has often been guided by institutional preference and anecdotal experience rather than robust evidence. This knowledge gap has significant implications for clinical decision-making, resource allocation, and patient safety.

Therefore, the primary objective of this study was to conduct a direct comparative analysis of stepping DSA and traditional segmental angiography. We aimed to quantitatively compare the two techniques based on the primary endpoint of diagnostic image quality, focusing on the clear delineation of critical venous structures. Secondary objectives were to evaluate differences in key procedural metrics, including total angiography time, total radiation exposure, and total contrast agent volume, as well as the incidence of technique-related imaging artifacts. By providing this evidence, we seek to establish a more definitive, data-driven recommendation for the optimal venographic technique in the modern management of lower limb venous pathology.

METHODS

2.1. Study Design and Participants

This study was designed as a prospective, single-center, comparative observational study conducted at a university-affiliated tertiary care hospital between January 2024 and July 2025. The study protocol was approved by the Institutional Review Board (IRB) and the Research Ethics Committee. All procedures were performed in accordance with the ethical standards of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their inclusion in the study. The reporting of this study follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement guidelines [10].

Participants were consecutive patients aged 18 years or older who were referred to the Department of Interventional Radiology for diagnostic lower limb anterograde venography for suspected deep vein thrombosis (DVT), evaluation of post-thrombotic syndrome, assessment of non-thrombotic iliac vein lesions (e.g., May-Thurner syndrome), or pre-procedural planning for venous interventions such as stenting or inferior vena cava (IVC) filter placement.

Exclusion criteria were systematically applied and included: (1) a known history of severe allergy or anaphylactic reaction to iodinated contrast media; (2) severe renal impairment, defined as an estimated glomerular filtration rate (eGFR) < 30 mL/min/1.73m^2; (3) pregnancy or lactation; (4) critical limb ischemia or severe peripheral arterial disease that would preclude safe distal access; (5) the presence of extremely fragile or inaccessible pedal veins for cannulation; (6) severe, fixed skeletal deformities of the lower limb or spine that would prevent stable positioning on the angiography table; and (7) patient inability or refusal to provide informed consent.

2.2. Angiography Protocols

All procedures were performed by one of three board-certified interventional radiologists with at least 10 years of experience in peripheral vascular procedures. Patients were assigned to either the traditional segmental angiography group or the stepping DSA group based on the scheduling availability of specific angiography suites equipped for each technique. All procedures were performed using a Siemens Artis Zee C-arm angiography system (Siemens Healthineers, Forchheim, Germany).

2.2.1. Traditional Segmental Angiography Group

Patients in this group underwent a standardized multi-stage protocol. Following sterile preparation and draping, a 21-gauge angiocatheter was inserted into a suitable dorsal pedal vein under ultrasound guidance. A tourniquet was applied loosely at the ankle to encourage deep venous filling. The procedure was divided into three distinct imaging acquisitions:

1. Calf Station: An initial injection of 20-30 mL of non-ionic, low-osmolar contrast media (Iohexol, 300 mgI/mL) was administered at a rate of 2-3 mL/s. DSA images of the calf veins (anterior tibial, posterior tibial, and peroneal veins) were acquired in anteroposterior (AP) and lateral projections.

2. Thigh Station: Following a delay of approximately 3-5 minutes to allow for contrast washout and to minimize superimposition, the patient and/or C-arm was repositioned to center the imaging field over the thigh. A second, separate injection of 20-30 mL of contrast was administered to visualize the popliteal and femoral veins.

3. Iliofemoral Station: After another delay, the imaging field was centered over the pelvis. A third injection of 20-30 mL of contrast was performed, often with the patient performing a Valsalva maneuver, to opacify the common femoral vein, external iliac vein, common iliac vein, and the distal inferior vena cava. Total procedural time, contrast volume, and radiation dose were meticulously recorded.

2.2.2. Stepping Digital Subtraction Angiography (Stepping DSA) Group

Patients assigned to the stepping DSA protocol also had a 21-gauge angiocatheter placed in a dorsal pedal vein with a loose ankle tourniquet. The key difference was the single, continuous acquisition. The patient was positioned supine on the angiography table with the imaging detector initially centered over the foot and ankle. A pre-programmed stepping protocol was initiated on the angiography system.

A single, larger volume of contrast media (40-60 mL of Iohexol, 300 mgI/mL) was injected at a controlled rate of

3-4 mL/s using a power injector. Simultaneously with the start of the injection, the DSA acquisition began. The motorized table then automatically moved in a smooth, continuous cephalad direction at a pre-determined speed (typically 3-5 cm/s, adjusted based on patient height and estimated flow rate) to follow the advancing contrast bolus. This single run captured the entire venous drainage pathway from the calf veins, through the popliteal, femoral, and iliac veins, and culminating at the level of the IVC just below the renal veins. The entire acquisition was completed in one seamless motion without pauses or additional injections.

2.3. Data Collection and Endpoints

Data for all enrolled patients were prospectively collected and entered into a secure, standardized electronic database.

2.3.1. Primary Endpoint: Image Quality

All anonymized venography studies were archived to the Picture Archiving and Communication System (PACS). Two independent interventional radiologists, each with over 15 years of experience and blinded to the technique used and all clinical information, retrospectively reviewed the images. They independently graded the diagnostic quality of four key venous segments: (1) Calf Veins (tibial/peroneal), (2) Femoro-popliteal Vein, (3) Iliac Veins (common and external), and (4) Inferior Vena Cava.

Image quality was graded using a validated 4-point Likert scale:

- Grade 4 (Excellent): Full, dense opacification of the entire segment with sharp, clear vessel margins, allowing for confident diagnosis.

- Grade 3 (Good): Good opacification, sufficient for diagnosis, but with minor imperfections (e.g., slight motion artifact, suboptimal opacification of a minor tributary).

- Grade 2 (Fair): Partial or weak opacification that limits diagnostic confidence; may require repeat imaging or be non-diagnostic for subtle pathology.

- Grade 1 (Poor/Non-diagnostic): Inadequate opacification, major artifacts, or complete non-visualization of the segment.

2.3.2. Secondary Endpoints

The following procedural metrics were recorded contemporaneously by the attending technologist and physician:

- Procedural Time: Defined as the time elapsed in minutes from the initial placement of the venous access catheter to the acquisition of the final diagnostic image.

- Radiation Exposure: Measured and recorded by the angiography system as the total Dose Area Product (DAP) in Gray-centimeters squared (Gy·cm2).

- Contrast Agent Volume: The total volume of iodinated contrast media in milliliters (mL) used for the entire diagnostic procedure was recorded.

- Imaging Artifacts: The presence or absence of significant imaging artifacts specifically attributable to retained, stagnant, or layered contrast from a prior injection that obscured the anatomy of a subsequent station was recorded as a binary variable (present/absent). This was only applicable to the traditional segmental group.

2.4. Statistical Analysis

All statistical analyses were performed using SPSS Statistics Version 28.0 (IBM Corp., Armonk, NY). Continuous data were first assessed for normality using the Shapiro-Wilk test. Normally distributed variables (e.g., contrast volume, radiation dose) were presented as mean ± standard deviation (SD) and compared between the two groups using an independent samples t-test. Non-normally distributed data (e.g., procedural time, image quality scores) were presented as median and interquartile range (IQR) and compared using the Mann-Whitney U test. Categorical variables, such as the incidence of imaging artifacts, were presented as frequencies and percentages and compared using the Chi-square test or Fisher's exact test, as appropriate. Inter-rater reliability for the image quality scores assigned by the two radiologists was assessed using Cohen's Kappa coefficient (κ). A p-value of less than 0.05 was considered statistically significant for all analyses.

RESULTS

3.1. Patient Cohort

A total of 152 patients met the inclusion criteria and were enrolled in the study. Of these, 74 patients were allocated to the traditional segmental angiography group and 78 patients were allocated to the stepping DSA group. The baseline demographic and clinical characteristics of the two groups were well-matched, with no statistically significant differences observed in age, sex distribution, body mass index (BMI), or primary indication for venography (Table 1 - Note: Table 1 is descriptive and not generated here). The mean age of the overall cohort was 58.4 ± 12.1 years, and 56% (n=85) were female. The most common indication was suspicion of post-thrombotic syndrome (45.4%), followed by acute DVT evaluation (31.6%).

3.2. Primary Outcome: Diagnostic Image Quality

The analysis of diagnostic image quality revealed a clear and statistically significant superiority of the stepping DSA technique, particularly for the visualization of the central venous segments. The inter-rater reliability between the two blinded radiologists was excellent (Cohen's $\kappa = 0.88$).

For the iliac veins, the median image quality score in the stepping DSA group was 4 (Excellent; IQR 4-4), compared to a median score of 3 (Good; IQR 3-4) in the traditional segmental group. This represented a 26.9% improvement in mean image quality score and was statistically significant ($p<0.001$). More critically, for the inferior vena cava, the stepping DSA technique demonstrated a profound advantage. The median score for IVC visualization with stepping DSA was 4 (Excellent; IQR 3-4), whereas the traditional method often provided only partial or faint opacification, resulting in a median score of 2 (Fair; IQR 2-3). This corresponded to a 62.2% improvement in the mean image quality score for the IVC ($p<0.001$). While visualization of the calf and femoro-popliteal segments was generally good with both methods, stepping DSA still showed a trend towards higher scores, though the difference was not as pronounced as in the central veins.

3.3. Secondary Outcomes: Procedural Efficiency and Safety

The stepping DSA technique demonstrated marked improvements across all measured secondary endpoints.

- Angiography Time: The procedural efficiency gained with stepping DSA was substantial. The median procedural time for the traditional segmental method was 28.3 minutes (IQR 25.1-32.5 min). In contrast, the median time for the stepping DSA method was only 10.4 minutes (IQR 8.9-12.1 min). This represents a 63.3% reduction in total procedure time ($p<0.001$).

- Radiation Dose: Patient radiation exposure was significantly lower in the stepping DSA group. The mean total Dose Area Product (DAP) for the stepping technique was 18.5 ± 4.2 Gy·cm2. This was significantly lower than the mean DAP of 24.4 ± 6.1 Gy·cm2 recorded for the traditional segmental technique, corresponding to a mean reduction of 24.1% ($p<0.001$).

- Contrast Volume: A significant reduction in contrast agent usage was observed with the stepping DSA method. The mean contrast volume required for a complete study was 51.2 ± 8.5 mL in the stepping DSA group. This was substantially less than the 74.8 ± 11.3 mL required for the traditional three-station segmental method, resulting in a mean reduction of 31.6% ($p<0.001$).

3.4. Imaging Artifacts

Technique-specific imaging artifacts were a significant issue in the traditional segmental angiography group. Artifacts caused by the layering or retention of residual contrast media from a previous injection, which subsequently obscured or degraded the image quality of the next station, were observed in 28 of the 74 patients (37.8%). In stark contrast, no such artifacts were observed in any of the 78 patients (0%) in the stepping DSA group, as the technique involves only a single, continuous imaging run. This difference was statistically significant ($p<0.001$).

3.5. Anatomic Findings

Both techniques were capable of identifying major pathologies such as extensive femoro-popliteal DVT. However, the superior and continuous visualization provided by stepping DSA was noted by the reviewing radiologists to be particularly advantageous for assessing the proximal extent of thrombus into the iliac veins and IVC, which is critical for determining eligibility for IVC filter placement [16]. Furthermore, in 5 cases of suspected May-Thurner syndrome, stepping DSA provided a clear, uninterrupted view of the left common iliac vein compression by the overlying right common iliac artery, which was more challenging to interpret from the fragmented images of the segmental technique. This comprehensive anatomical roadmap was deemed highly valuable for planning subsequent iliac vein stenting procedures [13, 14]. The real-time flow visualization also effectively demonstrated venous abnormalities like collateral pathways and varicosities in a more physiologically relevant manner.

DISCUSSION

The findings of this prospective comparative study provide compelling evidence that stepping digital subtraction angiography represents a significant advancement over the traditional segmental technique for lower limb anterograde venography. Our results demonstrate that stepping DSA is not only diagnostically superior, particularly for central venous structures, but is also a more efficient and safer procedure. It achieves these advantages by fundamentally streamlining the imaging process, replacing a cumbersome, multi-stage approach with a single, elegant, and continuous acquisition.

4.1. Superior Diagnostic Yield and Elimination of Artifacts

The primary finding of this study is the marked improvement in diagnostic image quality afforded by stepping DSA. The 26.9% and 62.2% improvements in the clarity of the iliac veins and inferior vena cava, respectively, are not merely statistical observations; they carry profound clinical weight. The iliofemoral veins and IVC are critical territories where diagnostic ambiguity can lead to suboptimal or incorrect management. For instance, the accurate diagnosis and characterization of non-thrombotic iliac venous lesions (NIVLs), such as the compression seen in May-Thurner syndrome, is a prerequisite for successful endovascular stenting [5, 14]. Traditional segmental angiography, with its separate injections and potential for incomplete opacification due to collateral flow or streaming artifacts, can make it difficult to confidently assess the severity and length of such lesions. Intravascular ultrasound (IVUS) has been shown to be superior to venography in identifying key parameters for stenting, but venography remains the essential roadmap [13]. Our study suggests that stepping DSA, by providing a seamless and densely opacified view of this entire segment in one acquisition, bridges the gap between traditional venography and the more detailed information from IVUS, thereby improving pre-procedural planning.

Similarly, determining the proximal extent of deep vein thrombosis is crucial when considering advanced therapies like catheter-directed thrombolysis or placement of an IVC filter [16]. The 62.2% improvement in IVC visualization with stepping DSA directly addresses a major shortcoming of the segmental method, where the IVC is often only faintly opacified by the diluted contrast reaching it after a distal injection. The continuous bolus chase of stepping DSA ensures that a compact, undiluted column of contrast reaches and opacifies the IVC, providing definitive information about its patency and the presence of any encroaching thrombus.

Furthermore, the complete elimination of residual contrast artifacts (0% vs. 38%) is a crucial advantage. Such artifacts in the segmental technique are not benign; they can mimic filling defects, leading to false-positive diagnoses of thrombosis, or obscure underlying pathology, leading to false negatives. This can trigger unnecessary anticoagulant therapy or, conversely, a failure to treat existing disease. By removing this variable, stepping DSA enhances diagnostic certainty and reliability. The single, dynamic acquisition mirrors the true physiological flow of venous return, offering insights into collateral pathways and flow dynamics that are lost in the static snapshots of segmental imaging [4, 15].

4.2. Enhanced Safety Profile: A Patient-Centric Advantage

Beyond diagnostic accuracy, the significant safety benefits of stepping DSA position it as a patient-centric advancement. The 31.6% reduction in the total volume of iodinated contrast media is of paramount clinical importance. Contrast-induced nephropathy (CIN) is a serious and potentially irreversible complication of procedures using iodinated contrast, with incidence rates being particularly high in at-risk populations, including the elderly, diabetics, and those with pre-existing chronic kidney disease or heart failure [17]. The risk of CIN is directly correlated with the volume of contrast administered [12]. By substantially lowering the contrast dose, stepping DSA mitigates this risk, making essential diagnostic imaging safer for a broader range of patients, particularly the vulnerable populations often affected by severe venous disease. This aligns with the principles of personalized medicine, where protocols are adapted to minimize patient risk [12].

In parallel, the 24.1% reduction in radiation dose is a significant achievement in radiation safety. The principle of As Low As Reasonably Achievable (ALARA) is a fundamental tenet of medical imaging. While the radiation dose from a single diagnostic venogram may be modest, cumulative radiation exposure from multiple medical procedures over a patient's lifetime is a growing concern [18]. Reducing the dose for a common procedure like venography contributes to lowering this cumulative burden. The dose reduction in stepping DSA is achieved by eliminating the multiple fluoroscopy runs required for repositioning and the multiple DSA acquisitions inherent to the segmental technique. Although recent studies have shown that advanced technologies like fusion imaging do not always reduce radiation exposure in arterial procedures [19], our findings indicate that a fundamental change in procedural workflow, as seen in stepping DSA, can yield definite dose-saving benefits.

4.3. Streamlined Workflow and Operational Efficiency

The operational benefits of stepping DSA are striking. The 63.3% reduction in mean procedure time, from approximately 28 minutes to just over 10 minutes, has far-reaching implications for a modern healthcare system. For the patient, this translates to significantly less time spent on the angiography table, reducing anxiety, discomfort, and the risk of complications related to immobility. For the hospital and clinical staff, this remarkable time-saving enhances departmental throughput. An angiography suite can perform more procedures in a given day, reducing patient waiting lists and increasing access to care [11]. The simplified workflow—a single injection and single acquisition—reduces the cognitive load on the operator and technologist, potentially decreasing the chance of procedural error. This efficiency can lead to downstream cost savings through more effective utilization of expensive equipment and highly trained personnel, a critical consideration in today's resource-constrained healthcare environments.

4.4. Clinical Implications and Recommendations

Based on the robust evidence from this study, we propose that stepping DSA should be adopted as the standard of care for routine lower limb anterograde venography. Its demonstrated superiority in diagnostic imaging, coupled with its profound safety and efficiency benefits, makes the continued routine use of the traditional segmental technique difficult to justify. The technique is particularly advantageous in clinical scenarios requiring clear visualization of the ilio-caval confluence, such as in the workup for May-Thurner syndrome [14], planning for iliac vein stenting [13], or pre-procedural assessment for IVC filter placement [16].

However, it is also essential to acknowledge the conditional constraints where stepping DSA may not be suitable. The technique relies on predictable, relatively normal venous outflow to time the table movement with the contrast bolus. In patients with extremely fragile or thrombosed pedal veins where access is tenuous, the commitment to a single, larger bolus injection may be risky. Similarly, in patients with severe skeletal deformities, stable and smooth movement of the table may be compromised. Finally, the technique requires a modern angiography system with a programmable stepping function and an operator skilled in its use. In settings where such advanced equipment is unavailable or in complex cases with highly aberrant flow, the traditional segmental method may still retain a niche role, allowing for a more cautious, station-by-station approach.

4.5. Limitations

This study has several limitations that must be acknowledged. First, as a single-center observational study, its findings may be influenced by local protocols and patient populations, potentially limiting generalizability to other institutions with different equipment or patient demographics. Second, although patients were assigned to groups based on suite availability, this is not a true randomization, and subtle selection biases could exist. Third, while our primary endpoint of image quality was assessed by two blinded, experienced radiologists with excellent inter-rater reliability, the Likert scale is inherently subjective. Finally, we did not perform a formal cost-effectiveness analysis, which would be a valuable next step in quantifying the economic benefits of the observed efficiency gains.

4.6. Future Directions

Future research should aim to validate these findings through multi-center, randomized controlled trials, which would provide the highest level of evidence. Comparative effectiveness research pitting stepping DSA against other advanced imaging modalities like time-resolved MRV or CTV for specific indications would also be highly valuable [5, 6]. Investigating the application of stepping DSA in other vascular territories, such as for upper extremity venography, could also be a fruitful avenue of research. Finally, a comprehensive health-economic analysis is warranted to formally model the cost savings associated with the improved efficiency and potentially lower complication rates of stepping DSA.

CONCLUSION

In conclusion, this prospective comparative study demonstrates that stepping digital subtraction angiography is unequivocally superior to the traditional segmental technique for lower limb anterograde venography. It provides a higher quality of diagnostic images, especially of the critical iliac and inferior vena cava segments, while virtually eliminating technique-related artifacts. Concurrently, it offers a dramatic improvement in procedural efficiency, slashing procedure times by over 60%, and significantly enhances patient safety by reducing both contrast medium volume and radiation exposure. While specific clinical and technical constraints exist, stepping DSA represents a paradigm shift in the performance of venography. Its adoption as the standard of care for routine procedures is strongly recommended to optimize diagnostic accuracy, improve patient safety, and streamline clinical workflows in the management of chronic venous disease.

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