Cureus
Part of SPRINGER NATURE

Open Access Original Article

Valve Embolisation During Transcatheter Aortic Valve Implantation (TAVI): Clinical Outcomes and CT-Derived Anatomical Characteristics

Review began 11/04/2026
Review ended 11/13/2026
Published 11/16/2026

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DOI: 10.7759/cureus.119743

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Abstract

Background

Transcatheter aortic valve implantation (TAVI) has transformed the management of severe aortic stenosis, offering an effective alternative for elderly patients and those at high surgical risk who are not ideal candidates for open-heart surgery. Of late, there is an expansion into intermediate- and low-risk populations as well. Transcatheter valve embolisation or migration (TVEM) is a rare but potentially fatal complication. Predictors of TVEM are incompletely understood, and there is a gap in evidence, looking specifically at the CT-derived anatomical characteristics of TVEM.

Aim

This study aimed to quantify the incidence of TVEM in a high-volume tertiary centre and characterise anatomical patterns in patients experiencing TVEM during TAVI.

Methods

This is a retrospective, single-centre study. Patients registered as having TVEM were identified using the local database from June 2014 to June 2024. Case notes of these patients were then studied to assess the management of TVEM and outcomes. For this cohort of patients, preprocedural CTs were analysed in detail, including annulus perimeter and area, qualitative leaflet calcification grading (moderate, severe, very severe), presence of annular/aorto-mitral curtain (AMC) calcification, and minimum sinus of Valsalva (SOV) diameter. Procedural data included initial embolised valve type and the bailout strategy.

Results

The incidence of TVEM was 0.51% with a 30-day mortality of 40% and average length of stay in hospital of 11.5 days, compared with the uncomplicated TAVI length of stay averaging 2.1 days. There was a periprocedural complication of stroke in 10% of patients (1 patient) and no vascular access site complication. Leaflet calcification was severe or very severe in 9/10 patients, with AMC calcification present in half. The mean minimum SOV diameter was 28.7 +/- 3.5 mm (23-34 mm), and several cases demonstrated markedly constrained aortic root anatomy. All embolised valves were self-expanding devices. In 4/10 cases, a balloon-expandable THV was used as the second device, while 6/10 were treated with another self-expanding THV.

Conclusion

Findings suggest that TVEM is a rare complication associated with substantial short-term mortality. Severe leaflet calcification, AMC calcification, and smaller SOV dimensions were frequently observed in this cohort, and all embolised valves were self-expanding. These findings are descriptive and hypothesis-generating; without a comparator group, their association with embolisation risk cannot be established. However, these anatomical findings warrant careful preprocedural assessment, while prospective comparative studies are needed to determine their association with TVEM risk.

Categories: Cardiology, Anatomy, Internal Medicine
Keywords: aortic stenosis, embolisation, sov: sinus of valsalva, tavi: transcatheter aortic valve implantation, tavi-viv: transcatheter aortic valve implantation valve-in-valve, tvem: transcatheter valve embolisation or migration

Introduction

Transcatheter aortic valve implantation (TAVI) has revolutionised therapy for severe aortic stenosis, particularly among elderly or high-risk surgical candidates who may not be suitable for open-heart surgery [1,2]. TAVI follows a structured sequence, beginning with detailed pre-procedural planning, usually guided by CT imaging to assess annular dimensions, leaflet calcification, coronary heights and vascular access suitability, which informs valve type, size and approach. The procedure is performed under local anaesthesia

with sedation or general anaesthesia, with arterial and venous access established alongside insertion of a temporary pacing wire. Transfemoral access is most commonly used, with large-bore sheaths placed under fluoroscopic and ultrasound guidance. The stenotic aortic valve is then crossed with a catheter and guidewire, which is exchanged for a stiff wire to support valve delivery. Balloon aortic valvuloplasty may be performed, particularly for heavily calcified valves or when using balloon-expandable devices, often under rapid ventricular pacing to minimise cardiac motion. The transcatheter heart valve (THV) is advanced to the annulus and carefully positioned under fluoroscopic (and sometimes echocardiographic) guidance before deployment. After deployment, angiography and echocardiography confirm valve position, coronary patency and paravalvular leak, with post-dilation or a second valve used if required. Finally, delivery systems are removed, vascular access is closed with percutaneous devices, and patients undergo post-procedural monitoring for conduction disturbances and valve function [3-5].

Sometimes, during deployment of the THV, the prosthesis can become displaced, migrating either upward into the aorta or downward into the left ventricle [6]. Transcatheter aortic valve implantation-valve-in-valve (TAVI-ViV) is an established treatment for transcatheter valve embolisation or migration (TVEM) [3]. TAVI-ViV offers a less invasive alternative to open surgery, with evidence demonstrating favourable short-term outcomes, sustained haemodynamic improvement, and acceptable procedural safety when patients are appropriately selected [6].

Despite these advantages, the TAVI-ViV setting presents anatomical and technical complexities distinct from native-valve TAVI. These include the presence of a rigid surgical frame, reduced true internal diameter, pannus formation, leaflet calcification, and the potential for coronary obstruction [1]. There are increased intricacies of deploying a THV within a pre-existing prosthesis, with altered force dynamics and constrained expansion contributing to procedural challenges [7].

TVEM remains one of the most feared complications of TAVI procedures. Although rare, with reported incidence typically between 0.3% and 1.0% in large registries, TVEM is associated with severe haemodynamic compromise, the need for urgent bail-out strategies, increased procedural morbidity, and elevated early mortality [8]. Within TVEM scenarios, this typically involves expedited deployment of a second valve prosthesis to achieve secure anchoring, appropriate annular sealing, and restoration of competent aortic outflow when the index valve has migrated or failed to seat adequately. This is referred to as a TAVI-ViV procedure. These measures are implemented to rapidly restore haemodynamic stability and ensure effective valve function.

Several mechanisms of TVEM have been proposed, including valve malpositioning, inadequate anchoring, insufficient frictional interface between the THV and the landing zone, and over-aggressive balloon post-dilatation. Excessive radial expansion forces, particularly in heavily calcified or anatomically constrained aortic roots, may result not only in valve malexpansion but also in catastrophic complications such as annular rupture, acute aortic regurgitation, or haemodynamic collapse [9].

TVEM can be broadly classified according to the direction of migration, each with distinct haemodynamic consequences. Upward embolisation into the ascending aorta may result in partial or complete loss of valve function, severe paravalvular or transvalvular aortic regurgitation, and compromised coronary perfusion if the embolised prosthesis obstructs the coronary ostia. In some cases, embolised valves may remain partially functional but haemodynamically ineffective, complicating immediate recognition. Conversely, downward migration into the left ventricular outflow tract or left ventricle can lead to left ventricular inflow obstruction, acute mitral regurgitation, ventricular arrhythmias and rapid haemodynamic deterioration, often necessitating urgent mechanical circulatory support or emergency surgical intervention. The clinical presentation may range from transient instability to abrupt cardiovascular collapse, depending on embolisation velocity, valve orientation, and residual forward flow.

Self-expanding valves appear disproportionately represented among reported embolisation cases. These devices rely on gradual expansion and sustained radial force for anchoring rather than immediate fixation, rendering them more susceptible to instability in the presence of severe leaflet or annular calcification, hostile root anatomy, or reduced STJ (sinotubular junction) compliance. In such settings, incomplete frame expansion, delayed recoil, or interaction with bulky calcific nodules may predispose to upward displacement, particularly during rapid pacing cessation, haemodynamic normalisation, or balloon post-dilatation. This vulnerability has been highlighted in imaging and procedural analyses [10].

The haemodynamic consequences of TVEM are often profound and time-critical. Acute loss of forward flow, severe aortic regurgitation, and sudden increases in left ventricular end-diastolic pressure can precipitate cardiogenic shock, myocardial ischaemia, and multi-organ hypoperfusion. Reported in-hospital mortality rates following TVEM remain high, ranging from approximately 20-40%, particularly when embolisation is complicated by delayed recognition, coronary obstruction, or the need for emergency conversion to surgery [10]. Even when successfully managed with percutaneous bail-out strategies such as ViV implantation or snare retrieval, TVEM is associated with prolonged procedural duration, increased contrast exposure, extended hospitalisation, and worse short- and mid-term outcomes compared with uncomplicated TAVI [9].

As TAVI continues to expand globally into lower-risk and anatomically complex patient populations, understanding the anatomical, procedural, and device-specific determinants of embolisation has become increasingly important [10]. The limited evidence base, combined with the rising absolute number of TAVI procedures and increasing utilisation of ViV strategies, highlights a critical gap in contemporary risk stratification frameworks. This underscores the need for refined pre-procedural imaging-based predictors, improved procedural planning, and tailored device selection strategies to mitigate embolisation risk and improve overall procedural safety [9].

This study focuses on addressing a key knowledge gap: the anatomical and imaging characteristics of the aorta associated with THV embolisation during TAVI procedures.

Materials And Methods

This study was designed as a retrospective, single-centre study evaluating all patients who experienced THV embolisation during the TAVI procedure and were treated with the TAVI-ViV procedure during the same sitting. As a retrospective review of anonymised data, without prospective intervention or new patient contact, the study adhered to institutional governance requirements for service evaluation and did not require separate ethics approval under University Hospitals of Leicester policy. A letter was provided by the ethics committee to state this. This study included data across 10 years, June 2014 through June 2024. The analysis focuses on describing procedural, anatomical, and imaging characteristics associated with TVEM; because all included cases experienced embolisation, the study is descriptive and hypothesis-generating rather than hypothesis-testing, and no inferential statistical modelling is undertaken.

The study was conducted at a UK tertiary cardiac centre with a mature structural heart service. Pre-procedural contrast-enhanced CT was performed according to a standardised TAVI planning protocol. Acquisition comprised ECG-synchronised imaging of the aortic root, including systolic-phase assessment for annular sizing, and CT angiography extending from the subclavian arteries to the superficial femoral arteries for vascular access assessment. Intravenous iodinated contrast was administered using a protocol tailored to patient characteristics and scanner capabilities, with bolus tracking in the ascending aorta. Aortic root images were reconstructed at a slice thickness of ⩽1 mm, with multiphasic reconstructions at intervals of ⩽10% of the R-R interval across the acquired cardiac window. Access-vessel images were reconstructed at a slice thickness of ⩽1.5 mm. Double-oblique multiplanar reconstructions were used to assess annular area and perimeter, minimum SOV diameter, leaflet calcification and AMC calcification. Both self-expanding and balloon-expandable THVs are used at the centre, reflecting contemporary practice.

The inclusion and exclusion criteria are summarised in Table *1*.

Criteria Type	Eligibility Criteria
Inclusion	Age ≥ 18 years. Experienced THV embolisation or migration during the initial TAVI procedure. Required implantation of a second (“bail-out” THV to restore valve function. Had complete, analysable pre-procedural CT imaging allowing for measurement of annular and root dimensions, SOV, leaflet calcification, and valve geometry.
Exclusion	Underwent successful TAVI for native aortic stenosis. Did not experience embolisation of the index valve. Pre-procedural CT imaging was incomplete or of insufficient quality to permit accurate measurements.

TABLE 1: Inclusion and exclusion criteria

THV: transcatheter heart valves, TAVI: transcatheter aortic valve implantation, SOV: sinus of Valsalva, CT: computed tomography

A total of 10 patients who experienced TVEM were identified over a 10-year period (June 2014 through June 2024). All index embolised valves were self-expanding THVs. Each patient received a second THV (either balloon-expandable or self-expanding) during the same procedure, and all had full CT imaging datasets available for analysis.

Pre-procedural ECG-gated contrast-enhanced CT scans were analysed. A structured reporting template was used to record annulus area and perimeter, minimum SOV diameter, leaflet calcification grading, presence/absence of AMC/annular calcification, and geometry of the failed valve bioprosthesis (e.g., stent-post orientation). Annular measurements were obtained during systole using double-oblique multiplanar reconstructions. The virtual basal annular plane was defined by aligning the most basal attachment points of the right, left, and non-coronary aortic valve cusps. The annular luminal contour was traced in this plane to determine cross-sectional area and perimeter.

Results

The incidence of TVEM was 0.51%, occurring in 10 of 1,968 TAVI procedures performed during the study period. Patients experiencing TVEM during a TAVI procedure had a 30-day mortality of 40%, substantially higher than the 1.4% 30-day mortality observed among patients undergoing TAVI without TVEM at our tertiary centre. TVEM was also associated with a markedly prolonged hospital stay, with a mean length of stay of 11.5 days compared with 2.1 days following uncomplicated TAVI. These findings highlight the considerable adverse clinical impact of TVEM, despite its relatively low incidence.

The mean age was 84.1 years (range 78-91), and 50% (n=5) were female, as shown in Table *2*. Two patients (20%) had previously undergone coronary artery bypass grafting (CABG). Thirty-day mortality occurred in 4/10 cases. There was a complication of left middle cerebral artery infarct in one patient that occurred within 24 hours of the procedure. There were no vascular access site complications. Tables *3*-*7* depict the types of THV embossed in these patients along with parameters such as annular measurements, minimum SOV diameters, leaflet calcification severity, and AMC calcification. The mean annular area was 445.3 ± 77.7 mm^2 (range 336-540 mm^2), and the mean annular perimeter was 77.5 ± 5.9 mm (range 68-84 mm). All embolised THVs were self-expanding; however, self-expanding valves accounted for 92.8% of all TAVI procedures performed at our tertiary centre during the study period.

Variable	Value
Number of patients	10
Mean age (years)	84.1 (range 78–91)
Female sex	5 (50%)
Previous CABG	2 (20%)
Vascular complications	1 (10%)
30-day mortality	4 (40%)

TABLE 2: Baseline characteristics of patients who underwent TAVI-VIV

TAVI-VIV: transcatheter aortic valve implantation-valve-in-valve; CABG: coronary artery bypass graft

Case	Embolised THV (Self-Expanding)	Treating THV	Treating Valve Type
1	29 mm CoreValve	29 mm CoreValve	Self-expanding
2	26 mm EvolutPro+	26 mm EvolutPro+	Self-expanding
3	23 mm CoreValve	23 mm CoreValve	Self-expanding
4	29 mm EvolutR	29 mm EvolutR	Self-expanding
5	Accurate Neo2	23 mm Edwards S3 Ultra	Balloon-expandable
6	26 mm CoreValve	26 mm CoreValve	Self-expanding
7	26 mm Evolut FX	23 mm Edwards S3 Ultra	Balloon-expandable
8	29 mm Evolut FX	29 mm Evolut FX	Self-expanding
9	ACURATE Neo2	26 mm Edwards S3	Balloon-expandable
10	26 mm Evolut FX	23 mm Edwards Resilia	Balloon-expandable

TABLE 3: Embolised and treating THV types

THV: transcatheter heart valve

Case	Annulus Area (mm²)	Annulus Perimeter (mm)
1	510	83
2	336	79
3	362	68
4	516	83
5	496	80
6	430	75
7	345	69
8	504	81
9	540	84
10	414	73

TABLE 4: Annulus measurements

Case	Min SOV (mm)
1	32
2	27
3	23
4	29
5	34
6	25
7	29
8	28
9	33
10	27

TABLE 5: Minimum SOV diameters

SOV: sinus of Valsalva

Case	Leaflet Calcification
1	Severe
2	Severe
3	Moderate
4	Severe
5	Severe
6	Very severe
7	Severe
8	Very severe
9	Severe
10	Very severe

TABLE 6: Leaflet calcification severity

Case	AMC Calcification
1	No
2	Yes
3	No
4	No
5	No
6	Yes
7	No
8	Yes
9	Yes
10	Yes

TABLE 7: AMC calcification

AMC: aorto-mitral curtain

Discussion

This study revealed four principal observations that collectively enhance the understanding of embolisation mechanisms in the TAVI setting. First, all embolised valves were self-expanding devices, a finding consistent with earlier work demonstrating that self-expanding THVs are disproportionately represented among reported cases of TVEM [3,8]. Second, severe or very severe leaflet calcification was present in 9 of the 10 patients, highlighting the prevalence of hostile leaflet pathology in embolisation cases. Third, most patients exhibited a small minimum SOV diameter typically <30 mm and in some instances as low as 23-27 mm, indicating constrained root anatomy. Finally, annular or AMC calcification was documented in half the cohort. Together, these findings suggest that a constellation of unfavourable anatomical features, namely, heavy leaflet calcification, restricted SOV geometry, and the presence of annular or AMC calcification, may compromise anchoring stability and predispose to embolisation, particularly when self-expanding THVs are used.

Leaflet calcification emerged as one of the most compelling anatomical contributors to embolisation. Severe or very severe calcification substantially alters the mechanical characteristics of the landing zone and can

impair the symmetrical radial expansion required for stable THV anchoring. Self-expanding valves depend on gradual deployment and continuous outward radial force; however, asymmetric or bulky calcification distorts the expansion profile, shifts the valve frame off-axis and diminishes frictional engagement with the surrounding tissue. Similar mechanisms have been documented in studies linking leaflet calcification to THV malexpansion and procedural complications [11,12]. This combination may lead to pivot-like movement during deployment, allowing the frame to tilt and migrate either upward into the aorta or downward into the left ventricular outflow tract. Severe leaflet calcification also reduces the operator's ability to achieve coaxial positioning, as heavy deposits increase susceptibility to off-axis forces during the mid-deployment phase. Collectively, these dynamics underscore leaflet calcification as a major anatomical predictor of embolisation risk, echoing patterns observed in larger registry analyses [3].

The sinus of Valsalva plays a crucial role in device stability, providing the spatial environment necessary for complete and uniform THV expansion. A small or restricted SOV significantly limits expansion space, diminishing the radial force available to engage the valve ring. In this study, most patients had minimum SOV diameters below 30 mm, with several in the 23-27 mm range, confirming a tendency toward constrained root anatomy. Restricted SOV geometry accentuates asymmetric loading, promoting device tilt or rotation, and has been associated in computational models with reduced anchoring friction and an increased likelihood of upward recoil [11]. These findings align closely with contemporary anatomical risk frameworks, reinforcing the central role of SOV dimensions in predicting embolisation risk [6].

Annular and AMC calcification further contribute to instability by reducing landing zone distensibility. Half of the patients in this series demonstrated AMC calcification, which can impair circular expansion of the THV and increase the likelihood of malposition or pivoting at the time of deployment. Rigid calcified segments amplify the effects of leaflet calcification and introduce areas of asymmetric resistance that compromise uniform device expansion. These observations mirror findings in TAVI populations, where annular calcification has been associated with underexpansion and landing-zone instability [13]. Together, the presence of leaflet, annular and AMC calcification forms a hostile anatomical substrate that markedly increases embolisation risk.

The predominance of self-expanding devices among embolisation cases reflects multiple procedural and mechanical vulnerabilities inherent to this valve design. Self-expanding valves exert lower acute radial force compared with balloon-expandable devices, relying instead on gradual expansion to achieve fixation. Self-expanding valves are also more sensitive to irregular landing zones, where calcific nodules or surgical frame distortions can produce uneven contact forces and increase the likelihood of slippage. Accurate depth control is essential, as shallow implantation heightens the risk of upward embolisation [8]. Moreover, the "rebound" phenomenon described following partial deployment or recapture may predispose to displacement in anatomies with poor frictional engagement. These considerations collectively underscore the limitations of self-expanding valves in anatomically challenging TAVI cases.

In this cohort, balloon-expandable valves were selected as bailout devices in four cases, reflecting their advantageous deployment characteristics in compromised anatomies. Their higher radial force, predictable expansion profile, and shorter stent frame offer improved anchoring and reduced interaction with restricted or calcified root structures. Balloon-expandable valves also have the capability to stabilise or "pin" a migrated self-expanding frame, a finding consistent with the redo-TAVR registry, where they were frequently used in device-migration scenarios [13]. The remaining six cases successfully used a second self-expanding valve, demonstrating that rescue with the same platform remains feasible when the mechanism of initial embolisation is well understood and corrected.

Collectively, this study supports a comprehensive mechanistic model in which anatomical, device-related, and procedural factors interact to precipitate embolisation. Anatomical contributors include severe leaflet calcification, annular or AMC calcification, small SOV diameter, and overall hostile root geometry. Device-related factors include the inherently lower acute radial force of self-expanding valves, greater sensitivity to asymmetric expansion, susceptibility to recoil and instability during partial deployment. Procedural influences, such as suboptimal coaxiality, shallow implantation depth, and interaction between the delivery system and calcific structures, further compound these risks. The combined effect of these elements results in reduced frictional anchoring, asymmetric loading, and ultimately device displacement or embolisation. This mechanistic model is consistent with findings from the TRAVEL registry [8].

Across published literature, several consistent patterns emerge regarding the mechanisms underlying TVEM. Self-expanding valves appear to be disproportionately represented among embolisation events, as demonstrated in the multicentre TRAVEL registry, where 88% of TVEM cases involved self-expanding devices, a finding mirrored in this series with 10 out of 10 initial implants being self-expanding [8]. Calcific burden is also a key contributor to prosthesis instability, with an association between heavy calcification and migration risk; similarly, 9 of 10 cases in this study exhibited severe or very severe leaflet calcification [13]. Root geometry further influences anchoring behaviour, with smaller SOV linked to increased procedural complexity and root constraint. This is supported by both review-level evidence and in vitro experimental findings demonstrating compromised expansion when the minimum SOV diameter is <30 mm [6,11]. Annular calcification has additionally been implicated as a destabilising factor, reducing uniform anchoring forces, consistent with the observation of AMC calcification in 5 of 10 cases in this cohort [14]. Finally,

balloon-expandable valves have been shown to be effective rescue devices following embolisation, as evidenced in multicentre registry data, reflected here where 4 of 10 bailout valves were balloon-expandable [12]. Summary of the above is shown in Table *8*. These parallels suggest that this single-centre UK tertiary-centre database reflects widely recognised anatomical-mechanical risk patterns described across the published TVEM literature.

Theme from Literature	Evidence	Match in This Study
Self-expanding valves overrepresented in embolisation	Kim et al. (2019) [8]: multi-centre TRAVEL registry: 88% of TVEM cases involved self-expanding devices	10/10 self-expanding
Calcification predicts instability/migration	Ribeiro et al. (2018) [13]: multi-centre registry study	9/10 severe/very severe
SOV size predicts complexity/root constraint	Cao et al. (2024) [6]: review article; Hatoum et al. (2019)[11]: experimental in-vitro study	Minimum SOV < 30 mm
Annular calcification reduces anchoring	Landes et al. (2021) [12]: multi-centre registry study	5/10 AMC calcification
Balloon-expandable valves effective for bailout	Landes et al. (2021) [12]: multi-centre registry study	4/10 treated valves

TABLE 8: Published literature on TVEM

TVEM: transcatheter valve embolisation and migration

Strengths and limitations

This study has several notable strengths. It represents the first UK case series to provide a detailed CT-based analysis of transcatheter valve embolisation in the TAVI setting, offering unique insight into a complication that is both rare and poorly characterised. The mechanistic analysis is grounded in both imaging and procedural detail, enabling a comprehensive evaluation of how anatomical features and device behaviour interact during TAVI deployment.

However, several limitations should be acknowledged. Given the small sample size (n=10), the conclusions should be interpreted as hypothesis-generating rather than definitive. There was a potential selection bias arising from the inclusion requirement for bailout THV implantation and availability of complete CT datasets. The absence of a comparator cohort of non-embolisation TAVI cases further restricts the capacity to quantify relative risk or identify independent predictors. Additionally, the dataset originates from a single centre, which limits broader applicability. Moreover, the embolisation events are intrinsically heterogeneous, which can make it difficult to establish consistent anatomical or procedural patterns. Finally, the device technology and implantation techniques continue to evolve, and some findings may not fully reflect outcomes associated with newer-generation valves and contemporary practice. Standardised endpoint definitions should be used in future studies to improve comparability across cohorts [15].

Conclusions

Findings suggest that TVEM is a rare complication associated with substantial short-term mortality. Severe leaflet calcification, AMC calcification, and smaller SOV dimensions were frequently observed in this cohort, and all embolised valves were self-expanding. These findings are descriptive, and without a comparator group, their association with embolisation risk cannot be established. However, these anatomical findings warrant careful preprocedural assessment, while prospective comparative studies are needed to determine their association with TVEM risk.

Although limited by small sample size and the absence of a matched non-embolisation control group, this analysis offers meaningful anatomical insights and underscores the need for improved CT-based risk stratification tools in TAVI practice. Since this was a single-centre study from Glenfield Hospital, the findings should be seen as hypothesis-generating. Larger, multicentre studies are needed to confirm whether these anatomical-mechanical patterns hold true elsewhere and to help develop a reliable CT-based risk stratification tool for TVEM.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Dominic Dalip, Raj Rajendra, Amerjeet Banning

Acquisition, analysis, or interpretation of data: Dominic Dalip, Raj Rajendra, Amerjeet Banning

Drafting of the manuscript: Dominic Dalip

Critical review of the manuscript for important intellectual content: Dominic Dalip, Raj Rajendra, Amerjeet Banning

Supervision: Raj Rajendra

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **AI use statement:** The authors have declared that no AI tools were used during the work or in the drafting of this article. The authors take full responsibility for the work. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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