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ORIGINAL ARTICLE

# Off-Pump Plicating Ascending Aortoplasty With External Wrapping: Magnum in Parvo

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**Background** Isolated, fusiform aneurysms, exclusively affecting the tubular portion of the ascending aorta, are rare. Surgical treatment aims to change their natural course, reducing individual and cumulative risks of rupture, dissection and death. Open tubular graft replacement still remains the procedure of choice, despite significant risks. In permanent pursuit for optimal, alternative surgical strategy in high-risk patients, less invasive and off-pump plicating ascending aortoplasty with modified external Dacron graft wrapping seems to be a reliable choice.

**Methods** Two consecutive patients were operated on. The same preoperative calculations and slightly different operative techniques were applied regarding surgical exposure and wrapping graft orientation. Immediate and late follow-up (5 years) results were compared.

**Results** Absolute and indexed target ascending aortic diameters remained acceptable (<2.1 cm/m$^2$ considered the upper normal range for adults). There were no significant changes in proximal and distal aortic diameters. Ascending aortic silhouette on contrast enhanced multi-detector CT was better with Dacron wrapping graft tailored to have its grooves in the longitudinal direction. Upper mini-sternotomy was quite appropriate for this procedure, from a surgical point of view, and was safe for the patient.

**Conclusions** Careful patient selection and using the current model of preoperative calculations and surgical technique resulted in acceptable and stable ascending aortoplasty in high-risk patients 5 years after surgery.

**Keywords** Ascending aorta • Aneurysm • Aortoplasty • Off-pump

## Introduction

Isolated and fusiform aneurysms, exclusively affecting the tubular portion of the ascending aorta (AA), are relatively rare, comprising 13.5% of all patients with aneurysms of the thoracic aorta [1].

For the vast majority of patients, without any evident connective tissue and/or aortic valve disease, open tubular graft replacement remains the procedure of choice. However, there is a considerable risk of perioperative mortality (1.5%–10.0%) and stroke (6.7%–8.0%) associated with this standard procedure, being highest among elderly and polymorbid patients [2]. Therefore, different alternative surgical techniques for an ascending aortoplasty (AAp), with or without external support, have been proposed [2].

In a very precisely selected group of patients with isolated AA aneurysms, off-pump plicating ascending aortoplasty (PAAp) with external Dacron graft wrapping (i.e., Arsan's

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technique) [3], preferably using a minimally invasive approach, appears to be reliable choice with sustainable long-term results.

This study presents and compares two illustrative and consecutive cases of isolated AA aneurysms treated by off-pump PAAp with modified external Dacron graft wrapping. The cases were followed-up for >5 years. This study intended to emphasise the importance of the meticulous preoperative evaluation and surgical technique that were performed for these cases.

# Methods

Two (2) consecutive patients were operated on. The same preoperative calculations were applied but they had slightly different operative techniques for surgical exposure and wrapping graft orientation. Immediate and late follow-up (5 years) results were compared.

All necessary preoperative measures were obtained by either echocardiogram (ECHO) (transthoracic or transoesophageal) or multidetector computed tomography (MDCT). Wrapping Dacron graft dimensions should fit both measured length and calculated diameter of the AA. Graft length is measured as axial distance between the sino-tubular junction (STJ, D1) and brachiocephalic trunk (D2) planes. Target AA diameter (Dx), in a plane of maximal aneurysmal diameter (Dmax), is calculated as the arithmetic mean of diameters measured at the level of STJ (D1) and just below the brachiocephalic trunk (D2). To reduce actual aortic diameter for $x$ cm, it is necessary to reduce its perimeter by $x\pi$ (3.14) cm. In (rare) cases of symmetrically fusiform aneurysms, excessive aortic wall is equally distributed along the longitudinal AA axis (a = b). More often, excessive tissue is slightly wider on the convex margin of the AA (a>b). Figure 1 (slices 1–3) depicts crucial steps in preoperative measurements and planning.

Surgical exposure of the AA via less invasive, partial upper (inverse-T) sternotomy, preferably down to the fourth intercostal space, makes for a safe and comfortable operative field and allows an easy eventual on-pump switch. The other benefits of this approach are well established [4].

Two-stage suturing technique (Figure 1, slices 4 and 5) without any aortic incision or excision preserves spatial continuity of fibrillar (i.e., elastic and collagen), muscular and blood vessel constituents within the aortic wall, which plays an important role in its further stability. Additionally, this technique (originally proposed by Arsan et al.) [3] ensures excessive AA aneurysmal tissue plication and eversion (interrupted ''mattress'' U-stiches) without any residual free space within it (continuing ''over-and-over'' X-stitches). Upon completion, the entire AA is covered with fibrin sealant (Beriplast P Combi-Set 3 mL, CSL Behring GMBH, Germany).

The ability to adjust wrapping Dacron graft dimensions (i.e., length and width) to the actual and desirable dimensions of the AA is usually limited by the maximal diameter of commercially available tubular grafts (e.g., Vascutek Gelweave Straight Grafts, Scotland, UK – maximal diameter is 38 mm). Using the wrap with its grooves in the axial instead of the transverse direction may solve this problem. In addition, similar to knitted prostheses, this will allow a certain degree of aortic systolic expansion, preventing the ''hammer (i.e., intraluminal blood pressure) and anvil (i.e., external wrapping graft compliance) effect'' on native aortic wall. Finally, longitudinal groove orientation results in less pronounced aortic corrugation over the concave AA margin (Figure 1, slice 6).

A controlled intraoperative hypotension protocol (i.e., 30% reduction of baseline mean arterial pressure), starting before the placement of aortic U-stitches and ending up with continuous ''over-and-over'' graft stitching, included: target controlled infusion of remifentanil hydrochloride and/or propofol, with additional titration of blood pressure level using esmolol hydrochloride (and/or nitroglycerine, trimetaphan camsilate).

# Results

## Case One

A 68-year-old male (body surface area [BSA] = 2.3 $m^2$, body mass index [BMI] = 32.77 $kg/m^2$), with a history of occasional mid-chest pain associated with hypertension for the last 6 years, was scheduled for elective surgery. The following risk factors existed: age, gender, obesity, and smoking. Family history of connective tissue and/or aortic diseases was negative. The following comorbidities existed: chronic obstructive lung disease, peripheral vascular disease (Fontaine classification: IIb). The preoperative transthoracic echo (TT-ECHO) aortic measures are listed in Table 1. Mild aortic (+) and mitral (+) valve regurgitation did not require surgical correction. Left ventricular (LV) cavity size and function were preserved (LV-end-diastolic diameter (LV-EDD) = 5.2 cm, LV-end-systolic diameter (LV-ESD) = 3.0 cm, LV-ejection fraction (LV-EF) = 60%). Carotid colour Doppler scan and coronary angiography did not reveal any significant occlusive atherosclerotic lesion.

Although the maximal AA diameter did not reach the surgical threshold recommended by guidelines [5], elective surgery was advised because of poor compliance on antihypertensive therapy and symptoms, which became more frequent. Off-pump PAAp with external Dacron graft (Vascutek Gelweave) wrapping, via full-length median sternotomy, was performed (Figure 2, slices 4–6). Due to late postoperative instability, sternal reinforcement was achieved with thermoreactive nitinol clips (Flexigrip, Praesidia SRL, Bologna, Italy). The rest of the hospital stay was uneventful.

Five (5) years after surgery, the patient remained well without any chest pain and/or heart failure symptoms. Postoperative TT-ECHO aortic measures are listed in Table 1. Apart from stable reduction of absolute and indexed AA diameter, there were no significant changes in proximal and distal aortic diameters.

This patient was operated on via a full median sternotomy, with the external Dacron wrapping graft in natural orientation and with its grooves in the transverse direction.

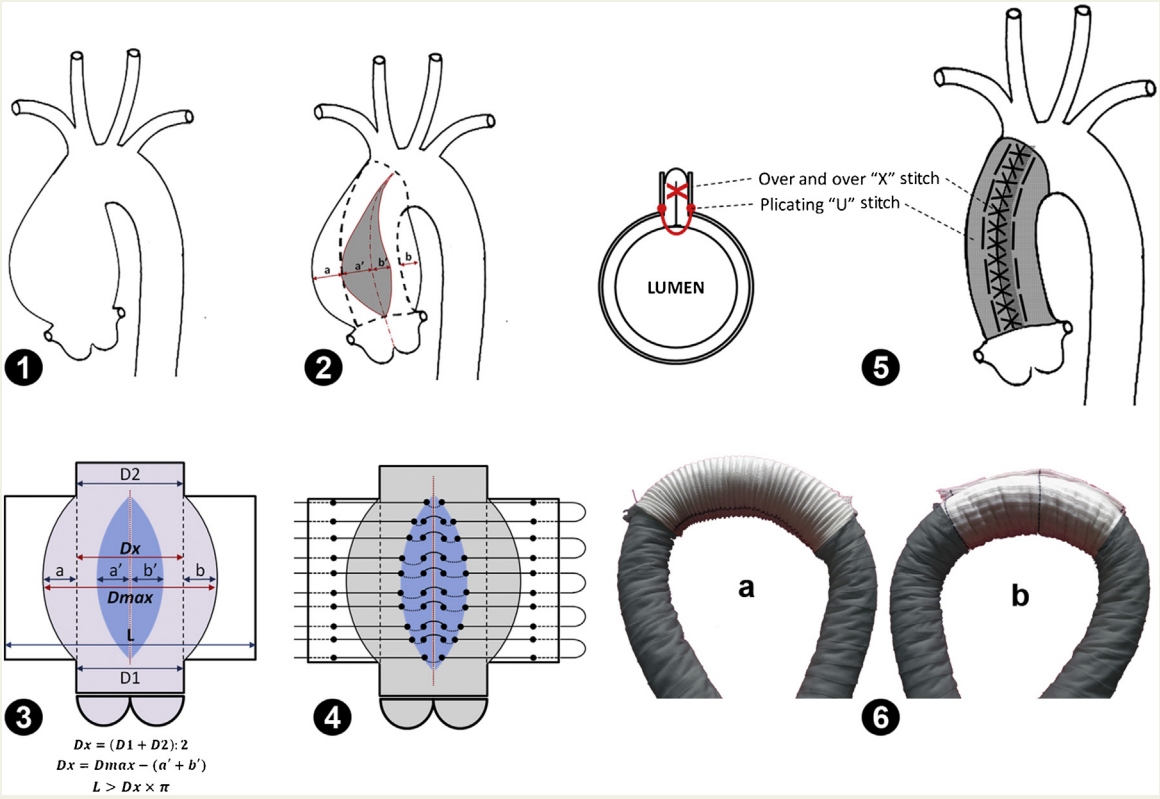


**Figure 1** Plicating reduction ascending aortoplasty – schematic: (1) Contour of the fusiform ascending aortic aneurysm; (2 and 3) Reduction geometry plan and calculations (explanation in text) – projected (desirable) aortic contour (black dotted line) and aortic longitudinal axis (red dotted line); (4) External plicating ''U'' stitches; (5) Position of stitches in transverse section (left) and in situ (right); (6) Dacron woven graft orientation.
*a*, grooves in transverse direction; *b*, grooves in axial direction.

**Table 1 Preoperative and postoperative transthoracic ECHO aortic diameters.**

| Case 1 | Preoperative | Follow-up (5 years) |
|---|---|---|
| Maximum AA diameter | 5.3 cm | 3.3 cm |
| AA/BSA[a] | 2.3 cm/m$^2$ | 1.4 cm/m$^2$ |
| Aortic annulus diameter | 2.9 cm | 3.0 cm |
| Sinus Valsalva diameter | 3.7 cm | 3.6 cm |
| STJ diameter | 3.6 cm | 3.5 cm |
| Arch diameter | 3.0 cm | 3.3 cm |
| **Case 2** | **Preoperative** | **Follow-up (5 years)** |
| Maximum AA diameter | 5.4 cm | 3.4 cm |
| AA/BSA* | 3.0 cm/m$^2$ | 1.9 cm/m$^2$ |
| Aortic annulus diameter | 2.9 cm | 2.9 cm |
| Sinus Valsalva diameter | 3.9 cm | 3.5 cm |
| STJ diameter | 3.4 cm | 3.2 cm |
| Arch diameter | 3.4 cm | 3.5 cm |

[a]AA/BSA, an indexed diameter of 2.1 cm/m$^2$ in adults has been considered the upper normal range.
Abbreviations: AA, ascending aorta; BSA, body surface area; STJ, sinotubular junction.

Although postoperative AA dimensions (absolute and indexed) and haemodynamics remained satisfactory, it is noteworthy that pronounced angulation was present over the concave AA margin, bearing a risk of coarctation physiology. Bearing in mind that the graft length and target AA diameter were precisely measured, a possible explanation is the pronounced corrugation of the transverse grooves over the curvilinear concave AA margin (Figure 1, slice 6a). In addition, body mass index (BMI) and chronic obstructive lung disease were the reasons for mechanical sternal dehiscence, which required additional intervention.

## Case Two

A 68-year-old female (BSA = 1.8 m$^2$, BMI = 25.71 kg/m$^2$) with a history of frequent mid-chest pain associated with hypertension, for the last 4 years, was scheduled for elective surgery. The following risk factors existed: age and obesity. Family history of connective tissue and/or aortic diseases was negative. Chronic obstructive lung disease was a comorbidity. The preoperative TT-ECHO aortic measures are listed in Table 1. Mild aortic stenosis did not require surgical correction. Left ventricular cavity size and function were preserved (LV-EDD = 5.1 cm, LV-ESD = 3.1 cm, LV-

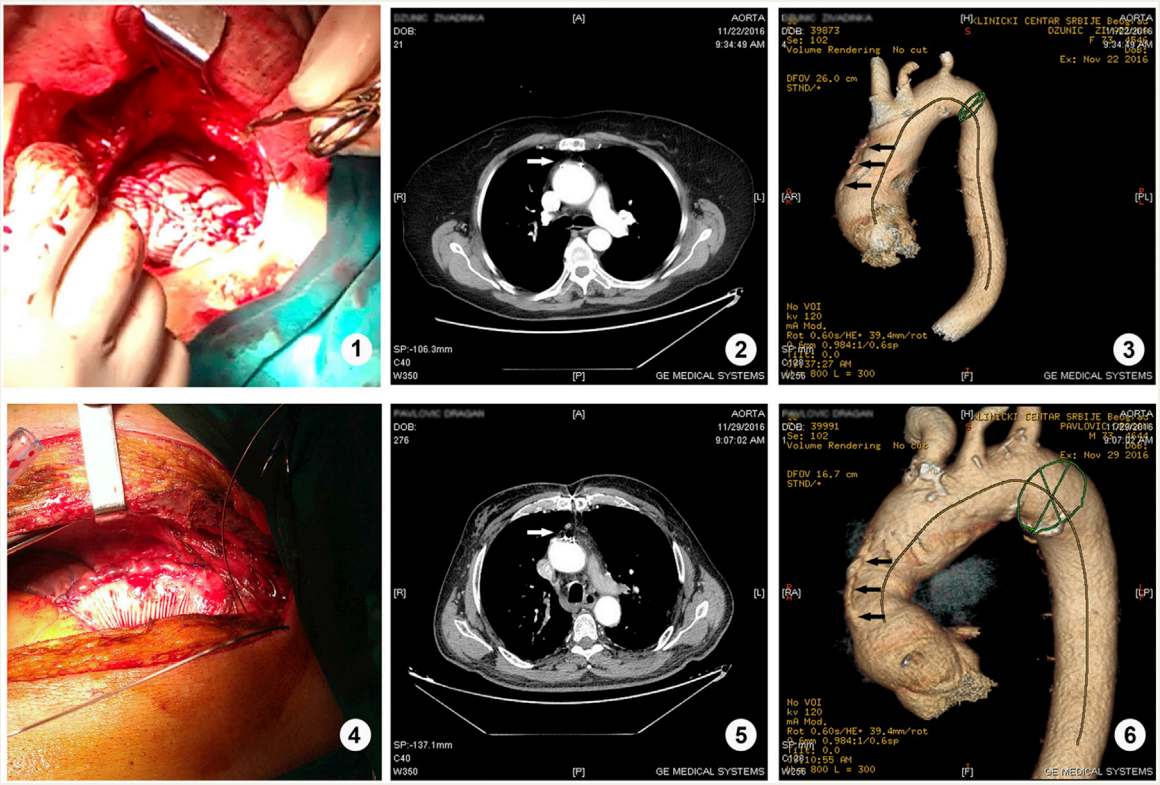


**Figure 2** Intraoperative images and follow-up multidetector computed tomography (MDCT) scans. (1–3) Case 2: Mini-sternotomy patient; (4–6); Case 1: Standard median sternotomy patient.
Solid arrows on MDCT scans depict the external plicating suture lines.

EF = 70%). Moderate LV septal (LV-S) and posterior (LV-PV) wall hypertrophy (LV-S = 1.1, LV-PV = 1.1 cm) was present due to chronic arterial hypertension. Carotid colour Doppler scan and coronary angiography did not reveal any significant occlusive atherosclerotic lesion.

Maximal AA diameter and presence of symptoms were the rationale for this elective surgery. Off-pump PAAp with external Dacron graft (Vascutek, Gelweave) wrapping, via partial upper (inverse-T) sternotomy, was performed (Figure 2, slices 1–3, Video S1 in Supplementary Material in the online version, at DOI: 10.1016/j.hlc.2018.10.018). Postoperative course was uneventful.

Five years after surgery, this patient also remained well without any chest pain and/or heart failure symptoms. Postoperative TT-ECHO aortic measures are listed in Table 1. Absolute and particularly indexed AA diameter remained acceptable. There were no significant changes in proximal and distal aortic diameters.

Unlike the previous patient, this one was operated on via a less invasive approach, with the external Dacron wrapping graft tailored to have its grooves in a longitudinal direction (Figure 1, slice 6b). Upper mini-sternotomy was quite appropriate for this procedure, from a surgical point of view, and safe for the patient (Video S1 – Supplementary Material in the online version, at DOI: 10.1016/j.hlc.2018.10.018). The results of off-pump PAAp with external Dacron graft wrapping, after 5 years, were satisfactory, including the AA silhouette on contrast enhanced MDCT. The target AA/BSA of 1.9 cm/m$^2$ (preoperatively 3.0 cm/m$^2$) remained under the upper normal range of 2.1 cm/m$^2$ for adults.

## Discussion

Surgery for isolated AA aneurysms intends to change their natural course and thus reduce individual and cumulative risks of rupture, dissection and death. In that sense, it must be emphasised that the absolute size of the AA not only matters, but also the primary cause and other conditions predicting its progressive dilatation, including: male sex, smoking, diastolic blood pressure, renal failure, fibrocalcified aortic valve, and LV wall motion assynergy [6,7].

In permanent pursuit of optimal, alternative surgical strategies for high-risk patients with isolated AA aneurysms, several things appear to be important. First is to avoid cardio-pulmonary bypass and circulatory arrest, with all known detrimental influences on patient's general condition. Second, and no less important, is to reduce actual AA diameter and thus decrease the natural risk of dissection or rupture. Third is to stop and prevent further advanced AA remodelling (i.e., re-dilatation of the aortic root with STJ widening and consecutive aortic valve insufficiency and/or

dissection). Minimally invasive exposure, with partial upper (inverse-T) sternotomy, may provide additional benefits in the postoperative period [4].

Apart from these general strategic considerations, certain particular issues should be taken into consideration in order to ensure safety, efficacy and reproducibility of the off-pump PAAp with external Dacron graft wrapping. Patients with evident or suspected connective tissue disease are definitively not candidates for this kind of procedure. The same is true for patients with diffuse and severely calcified plaques and/or thrombus within the AA. Further, AA aneurysms with diameters ≥6 cm should be avoided, mostly because of their thin and markedly remodelled walls. This procedure is unsuitable for patients with either concomitant aortic valve or coronary artery surgery. In both instances, structural integrity of the AA is affected by the procedure itself (i.e., aortotomy, proximal anastomosis, aortic cannulation, and cross-clamping).

Applying all of these criteria to an already rare group of patients with isolated AA aneurysms certainly decreases the number in whom off-pump PAAp with external Dacron graft wrapping would remain applicable. Current experience with two such patients since 2011 clearly depicts the previous statement. However, this is the only way to avoid pitfalls and justify this useful technique in current surgical practice. The outcome and follow-up data of high-risk patients support current willingness to use this procedure in future with similar cases. For more reliable conclusions, more institutional cases are required, or a multicentric prospective study must be conducted.

A recent study by Polonek et al. [8] added new light on stress distribution. They compared three different AA models: a non-dilated aorta, moderately dilated aorta, and wrapped aorta. They showed that inner and outer wall stress was similar in normal and wrapped AA, while it was significantly higher in moderately dilated, non-wrapped AA. Moreover, from a biomechanical point of view, the inner surface of a wrapped AA is subjected to lower stress than both a normal and moderately dilated unwrapped AA, and therefore should be less likely to dissect. Accordingly, they concluded in a meta-analysis of 17 studies (772 patients) that external wrapping of a moderately dilated AA (4.0–5.5 cm) offers the optimal balance of outcome and postoperative remodelling, in comparison to replacement [9].

Very few reports are available regarding off-pump PAAp with external Dacron graft wrapping [3,10–13]. Arsan et al. reported the largest series so far, with 84 patients in whom this procedure was performed as either isolated or (more often) concomitant to aortic valve replacement and/or coronary artery bypass surgery [12]. Of those, four cases were performed off-pump and none of them via partial sternotomy. Their initial enthusiasm decreased after three cases were reoperated on for aortic dissection in a concomitant group. At least one of them had obviously over-reduced the AA, with a coarctation effect leading to significant dilatation of the aortic root [11]. This led them to re-evaluate the indications, claiming that aortic dilatation remains a progressive disease despite external wrapping. Nevertheless, Arsan's group deserve credit for this very interesting surgical technique.

Apart from addressing important mechanical Laplacian issues (i.e., diameter, wall thickness, pressure, and stress), PAAp also necessitates certain biological properties of AA to be considered. Aortic wall degenerative changes may be enhanced after external wrapping, due to both ischaemic and inflammatory reasons [14,15]. This is particularly true when an undersized, non-compliant (e.g., Dacron) wrap is used in its natural position. It is believed that a certain degree of aortic wall degeneration is inevitable with such a procedure, mainly because of inflammation. However, appropriate surgical techniques and postoperative therapy [16] may significantly decrease ischaemic degenerative changes.

Two things have been found to be important for this particular surgical technique: one is preservation of aortic wall continuity and the other is external wrapping Dacron graft sizing and orientation. Without any aortic incision and/or excision, this technique does not interrupt spatial continuity of AA lamellar units, and does not trigger additional extensive inflammation in the reparative phase. Wrapping graft diameter should not necessarily restore normal, age-adjusted and gender-adjusted AA diameter. By doing so, in cases with initial widening of STJ and/or aortic arch, significant pressure gradients could produce a coarctation effect. Proximally, this may cause aortic root enlargement, aortic valve insufficiency and dissection. Distally, this may promote aortic arch aneurysmal remodelling due to the ''jet effect''. That is why it is recommended that a calculated wrapping graft diameter should take into account both STJ and aortic arch diameters, regardless of its final actual size. Also, the wrapping graft should start at the STJ and end at the level of brachiocephalic trunk plane. By doing so, this prevents further detrimental STJ widening and also covers the entire endovascular ''zone 0'' in case of subsequent distal aortic complications. Finally, the proposed wrapping Dacron graft orientation, with its grooves in the axial direction, does not limit circumferential AA compliance to the extent that grooves in the transverse direction do. Yet, residual AA compliance is still lower than with newly designed polypropylene/polyester meshes [10], but is beneficial in terms of balancing the risks of ischaemic degeneration and re-dilatation. Newly designed, multilayered vascular grafts would probably be more suitable, in a purely biomechanical sense, but there are no clinical data to support their use [17]. Finally, unlike many other proposed techniques, PAAp does not carry a risk of external graft migration and its consequences [15], since it practically incorporates the external wrapping graft into the AA wall by a double-layered longitudinal suture.

## Conclusion

Careful patient selection – general condition, risk factors, AA dimensions in four typical planes (absolute and indexed with

BSA, see Table 1) – along with meticulous preoperative calculation of desirable and not necessarily ideal target AA dimensions, render the off-pump PAAp with external Dacron graft wrapping a safe and efficient procedure that is feasible even via a minimally invasive approach. In an absence of biomechanically ideal external wrapping material, the proposed surgical tips may provide additional benefits in a term of durability and absence of complications. Sometimes, even small (parvus) adjustments within some surgical procedure may end up with considerable (magnum) improvements. This technique does not deserve to be abandoned [11], but needs to be better understood and even more refined in the future.

## Conflict of Interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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