

Iliac and Peripheral Aneurysms

Open Versus Endovascular Repair of Patent Popliteal Artery Aneurysms in an Elective Setting: A Multicenter Retrospective Study with Long-Term Follow-Up

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Background: The aim of this study is to investigate long-term outcomes of open repair (OR) versus endovascular popliteal aneurysm repair (EPAR) for popliteal artery aneurysms (PAAs) in an elective setting.

Methods: A retrospective analysis was performed on all patients treated for a popliteal aneurysm with OR and EPAR between 2010 and 2020 in 2 high-volume centers. Primary endpoints were freedom from amputation and overall patency. Secondary endpoints included secondary patency, reinterventions rates and predictors of late failure. Follow-up protocol included clinical examination and duplex ultrasound at 1, 6, 12 months, and annually thereafter. The Chi-square test was used to assess differences in categorical outcomes and Student's *t*-test in continuous outcomes. A *P* value of less than 0.05 was considered statistically significant.

Results: Between 2010 and 2020, 143 limbs from 120 patients were treated for PAA in an elective setting: 70 limbs with OR and 73 with EPAR. Primary patency at 1, 3, and 5 years were 92.7%, 92.7%, and 81% for OR and 77.3%, 67.9%, and 64.1% for EPAR respectively ($P = 0.01$). There was a significant difference in terms of 1-year patency for patients with 2–3 runoff vessels between OR and EPAR (96.1% vs. 82.7% respectively, $P = 0.03$). Reintervention rate was different between the groups with freedom from reintervention at 1, 3, and 5 years all of 95.7% for OR and 82.2%, 70.9%, and 70.9% for EPAR ($P = 0.02$). The 1-, 3-, and 5-year secondary patency did not differ between the groups and was 100%, 97.6%, and 90.6% for OR and 94%, 91.3%, and 88.4% for EPAR ($P = 0.3$). Freedom from amputation was excellent for both groups (100% for OR and 99% for EPAR, $P = 0.5$). The presence of 2–3 runoff vessels was a relevant protective moderator with a relative risk of 0.6 ($P = 0.08$).

Conclusion: OR and EPAR are comparable therapeutic options for the treatment of asymptomatic PAAs in terms of secondary patency and freedom from amputation despite an increasing rate of late occlusions and reintervention in EPAR group. The difference in primary patency between the 2 techniques seems more significant within the first-year of follow-up for those patients with a better runoff.

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INTRODUCTION

Popliteal artery aneurysms (PAAs) are relatively rare in the general population but represent the most common peripheral artery aneurysms, with a prevalence of 1% in male subjects aged between 60 and 80 years.¹ PAAs are often associated with other aneurysms: half of the patients have a contralateral popliteal aneurysm, and 30–50% have a concomitant abdominal aortic aneurysm.² Unlike other aneurysms, rupture rarely occurs.^{3,4} The most common complication of PAAs is limb ischemia, caused by microembolization into the tibial vessels or due to acute aneurysm thrombosis.⁴ Incidence of thromboembolism is 36% in all PAAs but varies significantly across series (8–100%), with an amputation rate of 25% among symptomatic patients.^{3,5}

According to the Society for Vascular Surgery guidelines, treatment is recommended in cases of symptomatic aneurysms, asymptomatic aneurysms with a maximum diameter of ≥ 20 mm, or for those < 20 mm but with significant thrombotic wall apposition and evidence of poor runoff on imaging studies.⁴ Open surgical repair by femoropopliteal bypass and aneurysm ligation or aneurysmectomy and graft replacement is still considered the first treatment option. Endovascular popliteal aneurysm repair (EPAR) is a less invasive approach in which 1 or more stent grafts are deployed across the popliteal artery to exclude the aneurysm from the blood flow. Despite the faster recovery time with EPAR and its less invasive nature, late patency and reintervention rates seem more favorable with open surgical repair. The aim of this study is to investigate early and late outcomes of these 2 different approaches in elective setting.

MATERIALS AND METHODS

A retrospective analysis of all patients treated for PAA with OR and EPAR between 2010 and 2020 in 2 high-volume centers was conducted. Indication for treatment was done according to the Society for Vascular Surgery guidelines.⁴ If both options were equally feasible, the choice was left to surgeon's discretion, based on the patient's anatomy, clinical status, and patient's will. The endovascular approach was considered at high risk or not feasible in cases of extremely tortuous anatomies, contraindications to antiplatelet therapy (dual antiplatelet therapy was administered for at least 3 months following EPAR), severe renal insufficiency, allergic reactions to iodinated contrast media, or excessive

diameter mismatch between proximal and distal necks.

Primary endpoints were freedom from amputation and overall patency. Secondary endpoints included secondary patency, reinterventions rates and predictors of late failure. Emergency cases were excluded from the study.

Preoperative assessment included computed tomography angiography and duplex ultrasound to determine the aneurysm length and diameter, the proximal and distal neck, and the number of patent runoff vessels defined as the number of infrapopliteal vessels that provide direct vascularization to the foot.

Ethical committee approval was waived due to the retrospective nature of the study, according to local guidelines.

Open surgical procedure was performed through either a medial or posterior approach, using either the great saphenous vein (GSV) or a prosthetic graft. A prosthetic graft was used in cases of excessive size mismatch between the artery and the vein, in cases of short replacement (posterior access) or when the GSV was absent or inadequate. Postoperatively, single antiplatelet therapy along with low-molecular-weight heparin was administered until full mobilization, followed by lifelong single antiplatelet therapy. Patients on chronic anticoagulant therapy were managed with low-molecular-weight heparin in the early postoperative period followed by an oral anticoagulant.

Endovascular procedure was performed with a contralateral femoral access (either percutaneous or surgically exposed). Appropriate landing zones were defined as ≥ 15 mm of healthy tissue, free from aneurysmal involvement, both proximally and distally to the aneurysm. In all cases of EPAR, a Viabahn self-expanding stent graft (W.L. Gore and Associates, Inc., Flagstaff, Arizona) was used. In cases requiring more than 1 stent graft, a 2-cm overlap was ensured. A flexion angiogram was performed in all EPAR procedures to prevent release of the stent graft in a tortuous area and to visualize any kinking after deployment. Dual antiplatelet therapy was administered for 3 months, followed by single antiplatelet therapy.

Postoperative Period and Follow-Up

Data regarding intervention, postoperative complications, length of hospital stay and follow-up were collected. Follow-up protocol consisted on clinical examination and duplex ultrasound at 1, 6, and 12 months, and annually thereafter. In cases of symptoms onset or imaging suggestive for graft/

Table I. Characteristics of the study population

Data	OR (<i>n</i> = 70)	EPAR (<i>n</i> = 73)	<i>P</i> value
Age	73.7 (8.2)	74.9 (8.4)	0.4
Male sex	62 (88.6)	72 (98.6)	0.03
Smoke	50 (68.5)	53 (73.6)	0.87
Hypertension	60 (85.7)	66 (90.4)	0.54
Dyslipidemia	34 (48.5)	32 (43.8)	0.69
Diabetes	11 (15.7)	15 (20.5)	0.59
CAD	19 (37.2)	20 (27.4)	0.99
Atrial fibrillation	12 (17.1)	4 (5.5)	0.05
CKD	13 (18.5)	18 (24.6)	0.50
Aneurysm diameter	31.5 IQR 13.5	27 IQR 12.75	0.009 ^a
Patent runoff vessels			
0–1	19 (27.1)	21 (28.7)	0.82
2–3	51 (72.8)	52 (71.2)	0.82

CAD, coronary artery disease; CKD, chronic kidney disease.

^aStatistically significant.

endograft failure, computed tomography angiography or diagnostic angiography was performed. Patients with a loss to follow-up > 1 year were contacted by phone call and clinical status was updated.

Data Collection and Statistical Analysis

Categorical data are presented as numbers and percentages (%). Continuous variables are expressed as means and standard deviations or as medians and interquartile ranges (IQRs) when not normally distributed, as determined by the Shapiro–Wilk test and graphical analysis of data distribution. The Chi-square test, with Bonferroni correction for continuity or Fisher’s exact test, was used to assess differences in categorical outcomes. The Student’s *t*-test or the Wilcoxon test were used to assess differences in continuous outcomes, depending on whether the data met normality assumptions. The follow-up index was defined as the ratio of the actual follow-up period to the potential follow-up period at the study’s end date, as proposed by von Allmen et al.⁶

Survival analysis was performed using Kaplan–Meier methods, and the log-rank test was used to assess statistical significance. Cox regression (both univariate and multivariate) was employed to identify significant predictors of patency loss and reintervention over time. Factors with a *P* value of less than 0.15, along with known predictors from the literature (e.g., the number of patent runoff vessels), were included in the multivariate analysis. Stepwise regression was then performed to identify significant predictors, with factors that altered the estimates of other variables by 10% or more being

retained in the final model. A *P* value of less than 0.05 was considered statistically significant. All statistical analyses were performed using R version 4.0.2 (R Core Team, 2017).

RESULTS

Demographics

Between 2010 and 2020, 143 limbs from 120 patients were treated for PAA in an elective setting. Of these, 70 limbs were treated with open repair (OR), while 73 were treated with EPAR. Patient demographics, comorbidities, and anatomical features of PAAs at diagnosis are summarized in [Table I](#).

Intraoperative and Early Outcomes

In case of surgical repair, 48 (69%) aneurysms were treated with a posterior approach. All of these patients underwent aneurysmectomy and surgical replacement with prosthetic graft. Medial approach was chosen in 22 (31%) cases. Of these, 12 (55%) subjects underwent replacement with autologous GSV and 10 (45%) with prosthetic graft. EPAR was performed through percutaneous access in 58 (79.5%) cases, while 15 (20.5%) patients underwent surgical exposure of the femoral vessels. One endograft was used in 29 (40%) cases, 2 endografts in 36 (49%) and 3 or more endografts in 8 (11%) cases. Mean arterial covered length was 209 mm. Early complications were more frequent in OR group without statistical significance (10% OR vs. 7% EPAR; *P* value 0.51). Data on postoperative complications and length of stay are reported in [Table II](#).

Table II. Early and late outcomes of OR and EPAR group

Data	OR (<i>n</i> = 70)	EPAR (<i>n</i> = 73)	<i>P</i> value
Early results			
Death	0	0	-
Complications	7 (10%)	5 (7%)	0.51
Early occlusion	1 (1.4%)	4 (5.5%)	0.2
Symptoms at occlusion			
Acute limb ischemia	1 (100%)	4 (100%)	-
Hematoma	3 (4.2%)	1 (1.3)	0.9
Wound dehiscence	1 (1.4%)	-	0.5
Surgical site infection	1 (1.4%)	-	0.5
Acute kidney injury	1 (1.4%)	-	0.5
LOS	6 IQR 3	3 IQR 1	<0.001 ^a
Late results			
Follow-up duration	29.5 IQR 43	43 IQR 69	0.05
Follow-up index	0.80	0.86	-
Lost at follow-up	22 (31.5%)	21 (29%)	0.7
Death at 2 years	4 (5.7%)	6 (8.2%)	0.4
Primary patency	60 (86%)	52 (71%)	0.04 ^a
Secondary patency	67 (96%)	66 (90.5%)	0.2
Symptoms at occlusion			
Acute limb ischemia	3 (30%)	13 (62%)	
Claudication	6 (60%)	6 (28.5%)	
Asymptomatic	1 (10%)	2 (9.5%)	0.1
Reintervention	6 (8.5%)	20 (27%)	0.003 ^a
Time to reintervention	34 IQR 79	9 IQR 33	0.52
Reason for reintervention			
Occlusion	4 (66%)	18 (90%)	
Graft infection	1 (17%)		
Anastomotic pseudoaneurysm	1 (17%)		
Endoleak		2 (10%)	
Freedom from major amputation	70 (100%)	72 (99%)	0.5

LOS, length of stay.

^aStatistically significant.

Late Outcomes

Primary patency at 1, 3, and 5 years were 92.7%, 92.7%, and 81% for OR and 77.3%, 67.9%, and 64.1% for EPAR ($P = 0.01$) as shown in [Figure 1](#). No statistical differences were found between OR and EPAR stratified by the number of direct runoff vessels to the foot ([Supplementary Figs. S1 and S2](#)). However, [Table III](#) shows a significant difference in terms of 1-year patency for patients with 2–3 runoff vessels between OR and EPAR (96.1% vs. 82.7% respectively, $P = 0.03$). Despite not reaching statistical significance, more than half of patients with EPAR occlusion presented with acute limb ischemia, while less severe symptoms were registered in OR group ([Table II](#)).

Reintervention rate was also different between the groups with an estimate freedom from reintervention at 1, 3, and 5 years all of 95.7% for OR

and 82.2%, 70.9%, and 70.9% for EPAR ($P = 0.02$), as reported in [Figure 2](#). Time to reintervention is shorter in EPAR 9 months (IQR 33) versus OR 34 months (IQR 79) ($P = 0.52$). Occlusion is the most frequent cause of reintervention in both groups as reported in [Table II](#). In OR group, graft infection and pseudoaneurysm were treated with redo surgery while occlusions were treated with fibrinolysis/thromboaspiration and balloon angioplasty/stenting if necessary. In EPAR endoleaks were treated with endovascular procedure (endograft relining) while 18 occlusions were treated as follow: 12 fibrinolysis/thromboaspiration and balloon angioplasty/stenting, 3 femoropopliteal bypass graft, 3 hybrid procedures (surgical embolectomy and balloon angioplasty/stenting).

The 1, 3, 5 years secondary patency did not differ between the groups and was 100%, 97.6%, and 90.6% for OR and 94%, 91.3%, and 88.4% for

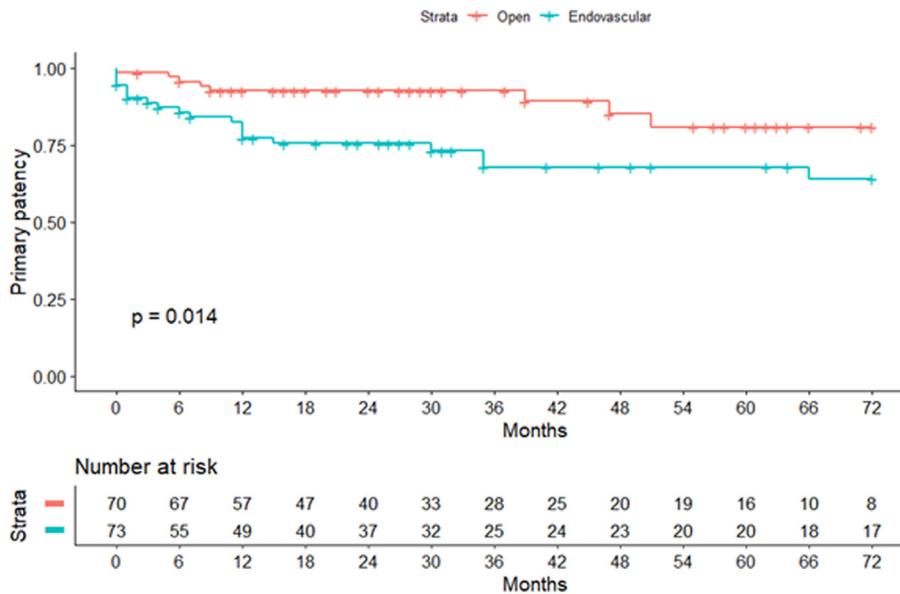


Fig. 1. Kaplan–Meier graph of primary patency. Red line = OR, green line = EPAR.

Table III. One-year and overall primary patency according to the number of runoff vessels

Primary patency				
2–3 runoff vessels	OR (51)	<i>P</i> value	EPAR (52)	Total (103)
1 year	49 (96.1%)	0.03 ^a	43 (82.7%)	92 (89.4%)
Overall	44 (86.3%)	0.1	39 (75%)	83 (80.5%)
<i>P</i> value 2–3 vs. 0–1 runoff vessels	0.1	1 year	0.3	0.08
	0.5	Overall	0.2	0.3
0–1 runoff vessels	OR (19)	<i>P</i> value	EPAR (21)	Total (40)
1 year	16 (84.3%)	0.3	15 (71.5%)	31 (77.5%)
Overall	16 (84.3%)	0.1	13 (62%)	29 (72.5%)

Comparisons have been made between OR and EPAR with the same number of runoff vessels or between patients with 2–3 runoff vessels versus 0–1 runoff vessels who undergo the same treatment.

^aStatistically significant.

EPAR ($P = 0.3$) as shown in Figure 3. Freedom from amputation was excellent for both groups (100% for OR and 99% for EPAR, $P = 0.5$) with a single major amputation occurred in EPAR after unsuccessful revascularization of acute endograft occlusion.

Predictors of primary patency are reported in Table III. In multivariate analysis, EPAR (relative risk (RR) 2.64) was associated with worse outcomes, while age >65 years (RR 0.26) and diabetes (RR 0.25) were independently associated with longer primary patency. The presence of 2–3 runoff vessels was a relevant protective moderator with a relative risk (RR) of 0.6 ($P = 0.08$).

DISCUSSION

The best treatment option for asymptomatic PAA remains controversial. Despite the increasing number of published studies, the robustness of data and the certainty in the comparative estimates is too low, owing to the observational nature of the studies and the small sample size.^{3,7} Results from our study are comparable with the outcomes of the recent meta-analysis of Beushel et al.,³ confirming that OR is associated with higher primary patency at 1 year, lower embolic and thrombotic occlusions at 30 days and lower

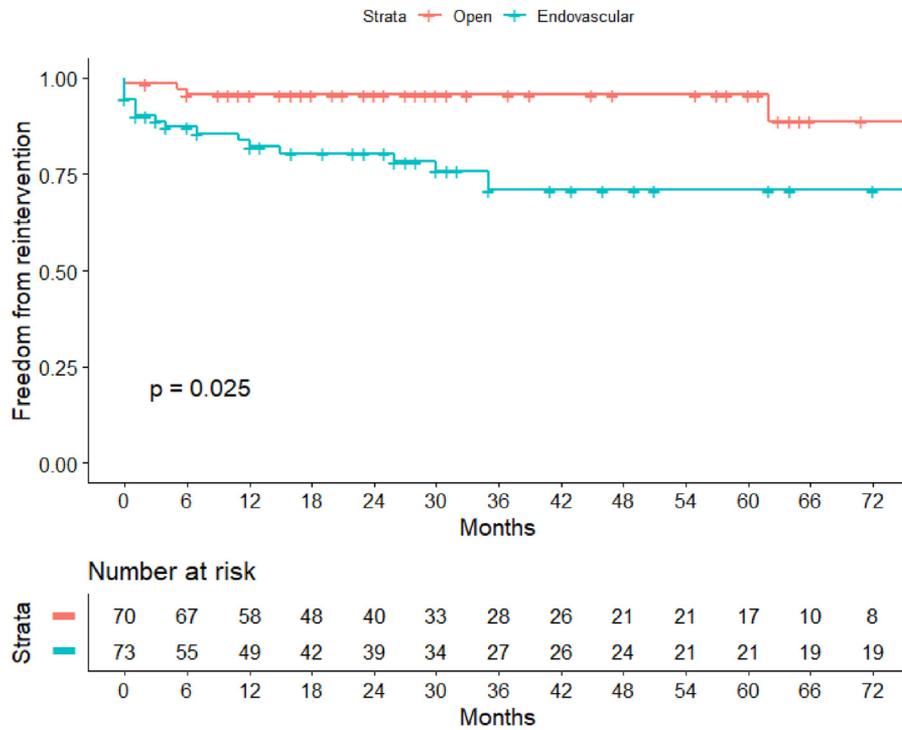


Fig. 2. Kaplan–Meier graph of freedom from reintervention. Red line = OR, green line = EPAR.

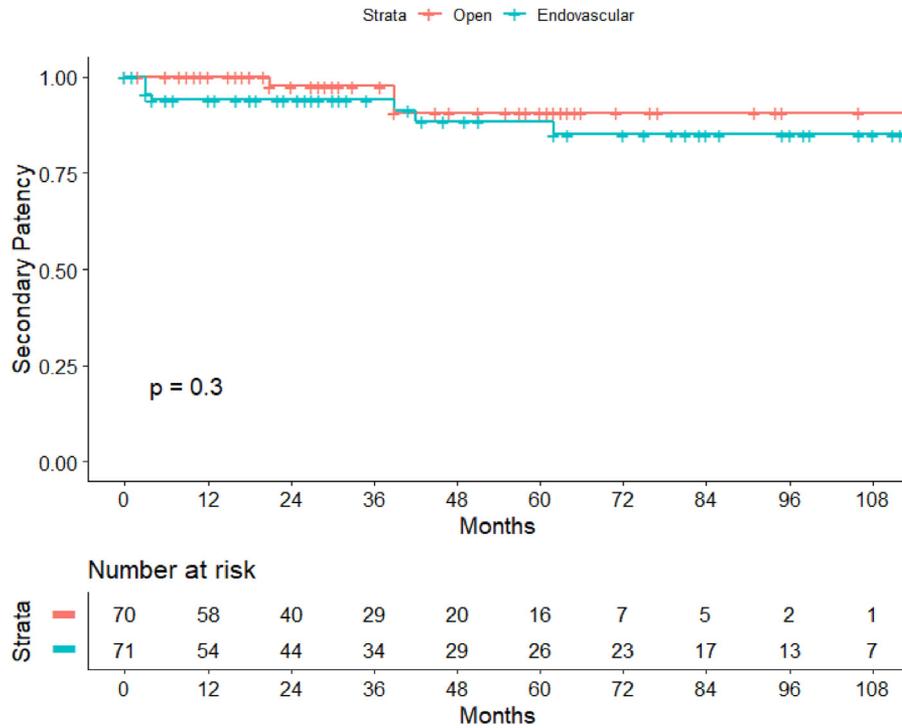


Fig. 3. Kaplan–Meier graph of secondary patency. Red line = OR, green line = EPAR.

reintervention rates, but more wound complications and longer hospitalization. The number of runoff vessels sensibly affects the long-term patency.^{6,8} However, there are no data in literature on how runoff vessels may impact on the choice of treatment. Despite the limited number of cases and the potential influence of confounding factors, this study reports a significant better 1-year patency rate in patients with 2 or more runoff vessels when treated with OR. Reintervention rate is more frequent with EPAR and occurs earlier at follow-up. This result seems in contrast with the recent publication of Satam et al.⁹ in which a propensity match-analysis of Vascular Quality Initiative-Medicare population of patients treated for elective PAAs was conducted. The study concluded there are comparable results in terms of 1-, 3-, and 5-year reintervention rates for OR and EPAR, even when GSV is used as conduit. This incongruity may be due to a supposed different posterior access versus medial access ratio in case of open surgery. In fact, the multicenter study of Troisi et al.¹⁰ comparing posterior access OR and EPAR, confirms higher 1-, 3-, and 5-year reintervention rates in the endovascular group. The majority of reinterventions were managed endovascularly as well documented in literature.⁹ Low amputation rate of patients undergoing elective repair of PAA is comparable to data in literature and may reflect the progressive reduction in diameter threshold and increased PAA characterization with high-risk features that allow vascular surgeons to consider intervention before peripheral microembolization occurs.

Study Limitations

The retrospective design of the study and the small study population are a clear limitation to the study. Moreover, the choice of the most appropriate treatment per each case according to principles above mentioned, may have introduced some selection bias. It's not always possible, retrospectively, to determine the exact reason behind the treatment choice, neither the percentage of patients that were eligible for both options. Loss at follow-up, which is one of the most critical aspects for this kind of studies, may also represent a limitation by underestimating late adverse events.

CONCLUSIONS

OR and EPAR are comparable therapeutic options for the treatment of asymptomatic PAAs in terms

of secondary patency and freedom from amputation despite an increasing rate of late occlusions and reintervention for those treated with endografts. The difference in primary patency between the 2 techniques seems more significant within the first-year of follow-up for those patients with a better runoff.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Matteo Ripepi: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lorenzo Gibello:** Writing – original draft, Visualization, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Emanuele Ferrero:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation. **Marianna Scevola:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Formal analysis, Data curation. **Paola Manzo:** Resources, Methodology, Investigation, Data curation. **Gianfranco Varetto:** Methodology, Investigation, Formal analysis, Data curation. **Simone Quaglino:** Resources, Methodology, Investigation, Data curation. **Lorenza Chiera:** Visualization, Methodology, Investigation, Data curation. **Michele Boero:** Software, Methodology, Formal analysis, Data curation. **Michelangelo Ferri:** Visualization, Validation, Supervision. **Andrea Gagliano:** Visualization, Validation, Supervision. **Fabio Verzini:** Visualization, Validation, Supervision, Project administration.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.avsg.2025.03.023>.

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