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Longer-term rates of survival and reintervention after thoracic endovascular aortic repair (TEVAR) for blunt aortic injury: a retrospective population-based cohort study from Ontario, Canada

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ABSTRACT

Objectives Blunt aortic injury (BAI) is associated with a high rate of mortality. Thoracic endovascular aortic repair (TEVAR) has emerged as the preferred treatment option for patients with BAI. In this study, we compare the longer-term outcomes of patients receiving TEVAR with other treatment options for BAI.

Methods We conducted a retrospective cohort study using administrative health data on patients with BAI in Ontario, Canada between 2009 and 2020. Patients with BAI and who survived at least 24 hours after hospital admission were identified using diagnostic codes. We classified patients as having received TEVAR, open surgical, hybrid repair, or medical management as their initial treatment approach based on procedure codes. The primary outcome was survival to maximum follow-up. Secondary outcomes included aorta-related mortality or aortic reintervention. Cox's proportional hazards models were used to estimate the effect of TEVAR on survival.

Results 427 patients with BAI were followed for a median of 3 years (IQR: 1–6 years), with 348 patients (81.5%) surviving. Survival to maximum follow-up did not differ between treatment groups: TEVAR: 79%, surgical repair: 63.6%, hybrid repair: 85.7%, medical management: 83.3% (p=0.10). In adjusted analyses, TEVAR was not associated with improved survival compared with surgical repair (HR: 0.6, 95% CI: 0.3 to 1.6), hybrid repair (HR: 1.4, 95% CI: 0.5 to 3.6), or medical management (HR: 1.5, 95% CI: 0.8 to 2.6). Aortic reinterventions were required in only 2.6% of surviving patients but were significantly more common in the TEVAR group (p<0.01).

Conclusions The longer-term survival from BAI appears highly favorable with low rates of reintervention and death in the years after injury, regardless of the initial treatment approach.

Level of evidence IV, Therapeutic study.

INTRODUCTION

In most countries, including Canada, injury remains the leading cause of death in the first four decades of life and accounts for more productive years of life lost than any other disease process.[1 2] Blunt thoracic aortic injury (BAI) is the second most common cause of death in blunt trauma (exceeded only by traumatic brain injury), and 80% of patients die at the scene of injury.[3–6] If left untreated, many patients will die of aortic rupture.[6]

Treatment of BAI varies with the severity of injury. In general terms, all BAI types are managed medically with strict blood pressure control ('impulse control') to reduce aortic shear wall stress and lower the probability of rupture.[7 8] Impulse control alone is likely adequate for low-grade injuries,[7] but all higher-grade injuries typically require either thoracic endovascular aortic repair (TEVAR) or open surgical repair.[7] In the last two decades, the shift has been towards TEVAR (an endograft stent placed in the aorta to cover the injury) rather than open surgical repair whenever possible[9] due to better short-term outcomes. TEVAR has been shown to reduce perioperative mortality (Relative risk 0.49, 95% CI 0.36 to 0.66) and morbidity, particularly stroke and spinal cord ischemia (RR 0.34, 95% CI 0.17 to 0.69), making it the recommended treatment strategy.[9]

However, during the longer term, patients receiving TEVAR are at risk of delayed complications as the aorta remodels and typically dilates around their endograft.[10 11] The medium-term and long-term risks of TEVAR including endoleaks, aneurysm formation, delayed ruptured, and requirements for reintervention are not well characterized.[12–14] The largest studies to date have come from Taiwan[15] (287 patients) and the USA (296 patients)[7] and have shown low rates of mortality in patients receiving TEVAR with relatively low rates of immediate complications, although most patients were only followed for several years after their procedure.

The issue of long-term follow-up is particularly important in trauma as most patients with BAI are young, active, and in good health prior to their injury, so understanding the quality of survivorship in this group is especially relevant. Our study will compare the longer-term outcomes of patients receiving TEVAR versus medical, surgical, or hybrid (TEVAR and surgical) treatment strategies for BAI in Ontario, Canada.

METHODS

Study design

We conducted a retrospective, population-based cohort study of all patients suffering a BAI in Ontario, Canada, between April 1, 2009 and September 30, 2020.

Setting and sources of data

Ontario is Canada's most populated province, with over 14 million inhabitants,[16] mixed urban,

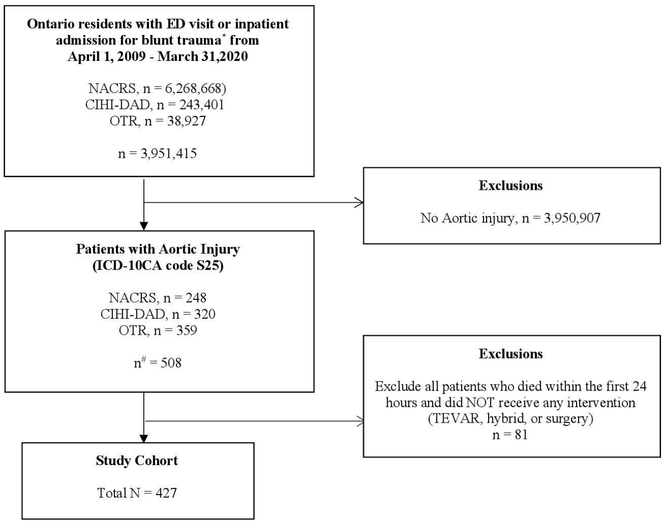

Figure 1 Data creation flow chart. *See online supplemental appendix 2 for ICD-10-CA codes corresponding to blunt trauma and for Canadian Classification of Interventions codes corresponding to the different repair types. #This is the number of unique patients with an aortic injury (some patients had aortic injury codes in more than one database). CIHI-DAD, Canadian Institute for Health Information Discharge Abstract Database; ED, emergency department; ICD-10-CA, International Classification of Diseases 10th Edition; NACRS, National Ambulatory Recording System; OTR, Ontario Trauma Registry; TEVAR, thoracic endovascular aortic repair.

suburban, and rural landscapes[17] and a universal health insurance program (Ontario Health Insurance Program: OHIP) that ensures access to emergency care services.

OHIP-related electronic health data are captured and maintained by the Institute of Clinical and Evaluative Sciences (ICES), an independent, non-profit research organization, funded by Ontario's Ministry of Health and Long-Term Care. The ICES electronic data holdings include all OHIP-insured health service events for the complete population of Ontario enrolled in OHIP linked to other data sources using an anonymous unique identifier for each patient. The ICES databases used in the study are described in the online supplemental table 1. These databases have previously been shown to be inclusive of our province's entire emergency system (covering >99% of emergency departments), have high data linkage rates (>95%) as well as internal diagnostic validity (>90% compared with medical record abstraction).[18 19]

Study population

BAI cases were defined as patients with an International Classification of Diseases 10th Edition external cause of injury code corresponding to blunt trauma and a diagnosis code indicating aortic injury (S25.0 in National Ambulatory Recording System, Canadian Institute for Health Information Discharge Abstract Database, or the Ontario Trauma Registry (OTR) (figure 1, online supplemental file 1).

We extracted baseline characteristics for patients including age, sex, socioeconomic status and rurality (based on postal codes and the Rurality Index for Ontario),[20] comorbidities 2 years prior to BAI using the Elixhauser comorbidity index score,[21] mechanism of injury, aortic injury severity, Injury Severity Score (ISS), and associated injuries. Aortic injury grades were captured in the OTR as Abbreviated Injury Scale (AIS). Although AIS scores are used extensively in trauma registries, they are not as widely reported in modern BAI literature. We used previously published methods[22] to translate the AIS grades into Society for Vascular Surgery (SVS) grades.[23] Patients were excluded if they died within the first 24 hours of hospital admission and had *not* received an intervention within that period of time.

Exposures

Patients with BAI were classified as patients having received TEVAR, hybrid repair (TEVAR and surgical repair), surgical repair, or medical management ('impulse control') based on Canadian Classification of Interventions procedure and/or OHIP billing codes (online supplemental table 2). Hybrid repair patients received TEVAR and a surgical repair, typically for complex injuries requiring reconstruction of the aortic arch or descending aorta and in some cases branch vessels (vertebral, subclavian, etc). Patients were considered to have been medically managed if they had no codes corresponding with either TEVAR or surgical repair.

Outcomes

The primary outcome was survival to maximum follow-up. The secondary outcomes were the percentage of patients experiencing aorta-related mortality (death from aortic rupture or complication), aortic reintervention (receipt of TEVAR or surgical repair after initial hospital discharge), endoleak, stroke, spinal cord ischemia, or chronic renal failure requiring dialysis.

Statistical analysis

We performed cross-tabulations and descriptive statistics for patient characteristics, primary, and secondary outcomes. We created Kaplan-Meier survival curves and used the log-rank test to assess for differences in survival based on treatment approach. We used Cox's proportional hazards models to estimate HRs and 95% CIs comparing TEVAR with hybrid repair, surgical repair, or medical management for survival to maximum follow-up. The model included the following covariates: age, Elixhauser comorbidity index score, ISS, presence of traumatic brain injury, and severity of aortic injury, based on existing literature.[24] A p value of <0.05 was taken as the threshold for statistical significance.

RESULTS

Study cohort characteristics

The study cohort included 427 patients with BAI (figure 1). One hundred sixteen (27.2%) of the patients were female and the median age was 46 years (IQR: 30–62 years). The patients came from a balanced range of income quintiles (approximately 20% of patients in each quintile) but came from predominately urban areas (79.9%). Most patients (48.2%) were healthy (Elixhauser comorbidity index score=0) prior to their injury (table 1).

Most patients were injured in motor vehicle collisions (73.8%) and the median ISS of 30 (IQR 24–41) was high, indicating the cohort were severely injured. Most patients had significant associated injuries including traumatic brain injury/skull fracture (34.0%), abdominal visceral injury (20.6%), other severe chest injuries (14.1%), or open long bone fractures (12.4%). There was a spectrum of aortic injury in the cohort from intimal tear (33.0%) through to transection and/or major rupture (14.3.1%) (table 2). The repair strategies for BAI were medical management (251 patients, 58.8%), TEVAR (105 patients, 24.6%), hybrid repair (49 patients, 11.5%), and surgical repair (22 patients, 5.2%).

Table 1 Characteristics of patients treated for blunt aortic injury by repair type in Ontario between April 1, 2009 and March 31, 2020

Characteristic	TEVAR n=105 (no, %)	Surgical repair n=22 (no, %)	Hybrid repair n=49, (no, %)	Medical management n=251 (no, %)	All patients n=427 (no, %)	P value
Age (median, IQR)	41 (27–55)	48 (33–65)	34 (26–49)	53 (34–65)	46 (30–62)	<0.0001
Sex—female	23 (21.9)	6 (27.3)	10 (20.4)	77 (30.7)	116 (27.2)	0.24
Rurality (no, %)						
Rural (population <10 000)	15–19*	1–5*	7 (14.3)	52–56*	81–85*	0.59
Urban (population >10 000)	84–88*	17–21*	42 (85.7)	194 (77.3)	341 (79.9)	
Missing	1–5*	0 (0.0)	0 (0.0)	1–5*	1–5*	
Elixhauser comorbidity index score (no, %)						
0	50 (47.6)	6 (27.3)	18 (36.7)	132 (52.6)	206 (48.2)	0.04
1	34 (32.4)	9 (40.9)	22 (44.9)	61 (24.3)	126 (29.5)	
2 or more	21 (20.0)	7 (31.8)	9 (18.4)	58 (23.1)	95 (22.2)	

*Cells with less than six patients are suppressed to protect patient privacy.
TEVAR, thoracic endovascular aortic repair.

Outcomes

The median duration of follow-up for the cohort was 3 years (IQR: 1–6 years). Overall, 348 (81.5%) patients survived to maximum follow-up. Of the 79 deaths, 35 (44.3%) occurred in hospital (more than 24 hours after admission) and 44 (55.7%) occurred post-discharge. Survival to maximum follow-up did not differ between treatment groups (table 3). Deaths due to aortic rupture or complication (aorta-related mortality) were very uncommon and were comparable between treatment groups. Similarly, stroke, spinal cord ischemia, endoleak, or renal failure requiring dialysis were very uncommon (less than six patients for each outcome) in the study cohort and did not differ between treatment groups. Aortic reinterventions were required in only 2.6% of surviving patients but were significantly more common in the TEVAR group (p<0.01). Of the 11 total patients who had a reintervention in the follow-up period, 5 underwent either primary or redo TEVAR, 5 had surgery, and 1 underwent a hybrid repair.

Notably, only 3 (3.8%) of the patients of the 79 patients who died were confirmed to have undergone autopsy. Sixty-nine (87.3%) were confirmed not to have undergone autopsy and a further seven (22.5%) patients had an incomplete autopsy status field in the Ontario Registrar General Database by the time of publication.

The Kaplan-Meier survival plot for survival probability in the four treatment groups is presented in figure 2. There were no significant differences in survival to maximum follow-up between the four treatment groups (log-rank test, p=0.08). In

Table 2 Injury-related characteristics of the study population by aortic repair type

	TEVAR n=105 (no, %)	Surgical repair n=22 (no, %)	Hybrid repair n=49, (no, %)	Medical management n=251 (no, %)	All patients n=427 (no, %)	P value
External cause of injury (no, %)*						
Motor vehicle collision	80 (76.2)	14 (63.6)	39 (79.6)	182 (72.5)	315 (73.8)	0.47
Other transport collisions	1–5†	1–5†	1–5†	19 (7.6)	29 (6.8)	0.74
Person struck	1–5†	1–5†	1–5†	9 (3.6)	15 (3.5)	0.99
Fall from height	13 (12.4)	1–5†	1–5†	24 (9.6)	42 (9.8)	0.67
Other	1–5†	1–5†	1–5†	18 (7.2)	28 (6.6)	0.07
Injury Severity Score (median, IQR)	34 (29–48)	38 (29–45)	38 (29–45)	29 (20–36)	30 (24–41)	<0.01
Associated injuries (no, %)*						
Skull fracture and/or traumatic brain injury	45 (42.9)	1–5†	14–18†	81 (32.3)	145 (34.0)	0.12
Cervical spine fracture and/or cervical spinal cord injury	18 (17.1)	1–5†	2–6†	37 (14.7)	62 (14.5)	0.46
Severe chest injury	18 (17.1)	9 (40.9)	9 (18.4)	24 (9.6)	60 (14.1)	<0.01
Severe abdominal visceral injury	29 (27.6)	1–5†	13–17†	41 (16.3)	88 (20.6)	0.07
Open fracture of a long bone	16 (15.2)	1–5†	10–14†	22 (8.8)	53 (12.4)	0.02
Grade of aortic injury (no, %)						
Grade I: intimal tear	37–41†	1–5†	12–16†	88 (35.1)	141 (33.0)	0.03
Grade II: intramural hematoma	14–18†	1–5†	8–12†	10 (4.0)	36 (8.4)	<0.01
Grade III: contained transection or pseudoaneurysm	1–5†	1–5†	1–5†	13 (5.2)	23 (5.4)	0.06
Grade IV: uncontained transection (rupture)	32–36†	10 (45.5)	11–15†	2–6†	61 (14.3)	<0.01
Thoracic aortic injury not further specified	1–5†	0 (0.0)	1–5†	21 (8.4)	27 (6.3)	0.12

*Some patients had more than one mechanism of injury or more than one associated injury coded.
†Cells with less than six patients are suppressed to protect patient privacy.
TEVAR, thoracic endovascular aortic repair.

Table 3 Outcomes for blunt aortic injury study cohort (N=427), by repair type

Outcome (no, %)	TEVAR n=105 (no, %)	Surgical repair n=22 (no, %)	Hybrid repair n=49, (no, %)	Medical management n=251 (no, %)	All patients n=427 (no, %)	P value
Survival to maximum follow-up	83 (79.0)	14 (63.6)	42 (85.7)	209 (83.3)	348 (81.5)	0.10
Aorta-related mortality	1–5*	0 (0.0)	0 (0.0)	0 (0.0)	1–5*	0.38
Aortic reintervention	6 (5.7)	1–5*	1–5*	0 (0.0)	11 (2.6)	<0.01
Stroke	1–5*	0 (0.0)	1–5*	6 (2.4)	9 (2.1)	0.90
Spinal cord ischemia	1–5*	0 (0.0)	0 (0.0)	0 (0.0)	1–5*	0.38
Endoleak	1–5*	1–5*	0 (0.0)	1–5*	1–5*	0.14
Chronic renal failure with dialysis	0 (0.0)	0 (0.0)	0 (0.0)	1–5*	1–5*	0.70

*Cells with less than six patients are suppressed to protect patient privacy.
TEVAR, thoracic endovascular aortic repair.

the adjusted analyses, TEVAR was not associated with improved survival to maximum follow-up when compared with either medical management, hybrid repair, or surgical repair (figure 3).

DISCUSSION

In this study, we describe the contemporary management and longer-term outcomes of patients suffering BAI in Ontario, Canada. We found that patients were managed with a number of different treatment approaches, but that medical management (58.8%) or TEVAR (24.6%) was the most common. Regardless of the initial management strategy, patients with BAI had a favorable longer-term prognosis, with 81.5% of patients surviving to maximum follow-up, and only 2.6% of patients requiring aortic reintervention. Rates of delayed aorta-related mortality, endoleaks, strokes, and other delayed complications were exceedingly uncommon, providing reassurance that contemporary BAI management strategies are benefiting patients well beyond their survival to hospital discharge. Given the observational nature of our data, we cannot be certain that all patients with a particular grade of aortic injury would do similarly well with any of the treatment approaches. We can, however, be confident that within our trauma system, surgeons are exercising sound clinical judgment in selecting individual treatment approaches for their patients, as evidenced by the favorable outcomes we have observed.

Our study adds to several smaller studies in providing evidence that TEVAR remains safe and effective in the immediate years after aortic injury. For instance, Farber *et al*[25] reported 5-year outcomes for 101 patients treated with one of two TEVAR devices. Although limited by a loss to follow-up rate of 41%, they reported a 9.1% rate of death and only two minor endoleaks during the follow-up period.[25] Prendes *et al*[26] followed 46 TEVAR patients for a median duration of 34 months, reporting a 93.3% survival rate and a 2.1% rate of late interventions. However, this study was also limited by a loss to follow-up rate of 43.2%.[26]

An additional German study that included 19 TEVAR-treated patients reported a 5% rate of aortic reintervention by 5 years but a persistently impaired quality of life, thought to be related to concomitant orthopedic and neurologic injuries.[12] Finally, Cheng *et al*[15] reported on the outcomes of 287 TEVAR patients in Taiwan, using a retrospective population-based cohort design.[15] Similar to our study, these authors reported a survival advantage to TEVAR (compared with open surgical repair) at both 1 year and 5 years post-repair and low rates of intervention (2%) during follow-up. This study included a smaller sample size than the present study and did not report outcomes for patients treated with medical or hybrid treatment options.

Overall, it seems that the mortality benefit seen with TEVAR, particularly in comparison with open surgical repair, is related to the overall lower rates of perioperative (30-day) mortality, stroke, and paraplegia[27,28] seen during the index admission and that patients who survive this tenuous period of acute care can look forward to a highly favorable prognosis, at least in the first several years after injury.

A particular challenge in studying the longer-term course of endovascular interventions like TEVAR relates to high rates of lost to follow-up, particularly in young and otherwise healthy patients. The issue compounds over time as patients' overall health continues to improve and they become increasingly

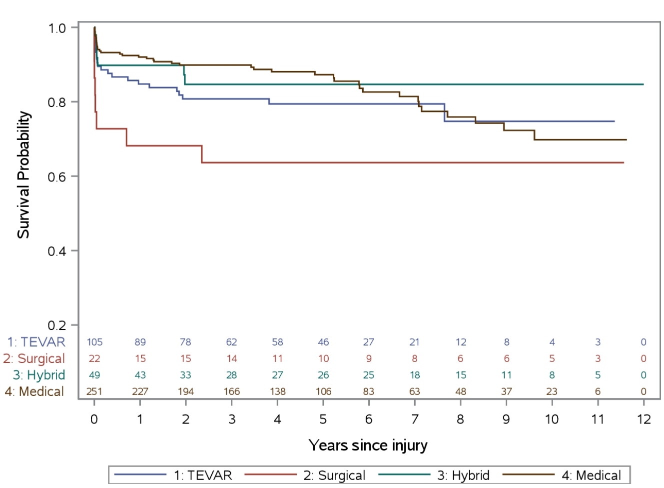

Figure 2 Kaplan-Meier survival curve for survival to maximum follow-up. TEVAR, thoracic endovascular aortic repair.

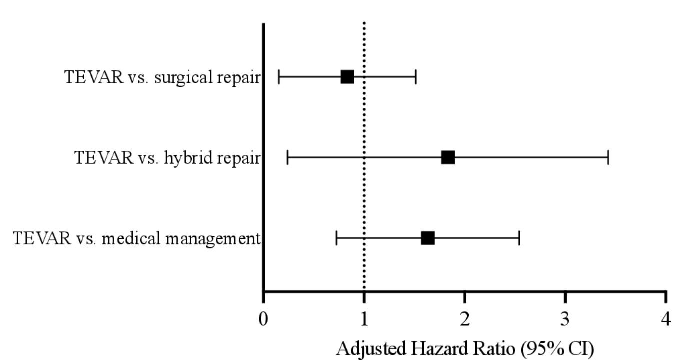

Figure 3 Adjusted HRs for survival to maximum follow-up between TEVAR and alternative repair strategies. TEVAR, thoracic endovascular aortic repair.

less inclined to return for follow-up visits and surveillance imaging.[25 26] As noted in several studies above, loss to follow-up rates of 30%–40% are not uncommon in this patient population, and some studies have reported that 37.6% of TEVAR-treated patients do not return for stent surveillance imaging.[29] It is this loss to follow-up issue that population-based studies like ours are uniquely positioned to address. Our study presents complete outcome data (no loss to follow-up) for a very large population of patients with BAI, thereby providing robust information on the longer-term prognosis of patients receiving TEVAR versus comparator treatment approaches.

In addition to the large sample size and completeness of follow-up, other strengths of our study are the inclusion of patients receiving all the different management strategies for BAI (medical/impulse control, hybrid, open surgical repair), a population that is representative of the entire province of Ontario (11 different treating trauma centers), and the quantification of other important secondary outcomes including aorta-related mortality, endoleaks, stroke, spinal ischemia, and renal failure requiring dialysis, which were all very low.

There are several limitations associated with our study design. First, aortic injury severity was based on AIS codes used in the provincial trauma registry. There is always the possibility of data coding errors resulting in misclassification of aortic injury severity but that would be unlikely to affect the overall findings of the study, particularly as other similar studies have not even included aortic injury severity in their regression models.[30] We also had to translate the AIS grades into SVS aortic injury grades using previously described methods and misclassifications of injury grade are possible.

Another limitation is in our definition of 'medical management' of an aortic injury. We considered patients as having received this treatment approach if there were no codes to indicate that they had a TEVAR or surgical intervention, however, data coding errors remain possible. Similarly, the included databases do not provide detailed information on the specific treatments a patient being treated with 'impulse control' would have received (ie, a particular beta-blocker medication, target heart rate or blood pressure target, duration of therapy, etc) and there was no standardization of medical treatments across trauma centers during the period of study. It is possible that some patients in the 'medical management' group would have been eligible for an alternative aortic repair strategy (eg, TEVAR), but did not survive long enough to receive it. We attempted to address this by excluding patients who did not receive TEVAR or open repair and who died within the first 24 hours of admission, but residual confounding could still exist.

Also, in terms of our estimate of aorta-specific mortality (deaths from aortic rupture or complication), it is possible that some patients were misclassified in their cause of death, given that the confirmed autopsy rate was only 3.8% for the entire cohort. This low autopsy rate is partly explained by the inclusion of in-hospital deaths, for which a very lower autopsy rate would generally be expected since essentially all patients would have already had advanced imaging (to confirm they had an aortic injury) and that would have already documented their additional injuries. In this scenario, the cause of death would likely be more clinically apparent (eg, severe traumatic brain injury), and make it much less likely the investigating coroner would request an autopsy to confirm the cause of death.

CONCLUSIONS

The longer-term survival from BAI appears highly favorable with low rates of reintervention and death in the years after injury, regardless of the initial treatment approach.

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Contributors CCDE conceived the study. CCDE, WL, and SB developed the methods and wrote the study protocol. CCDE, WL, MY, and SB revised the methods. WL completed the data analysis. All authors contributed to the data interpretation. CCDE wrote the first draft of the article and the remaining authors revised and contributed to the final version of the article. CCDE accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish.

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Competing interests None declared.

Patient consent for publication Not required.

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Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

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