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The third gap – The forgotten space in total knee arthroplasty

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ABSTRACT

Aims: Total Knee Arthroplasty (TKA) aims to leave the proximal flange of the femoral component flush with the femoral cortex. Manually, the requisite plane is found using the anterior femoral cortex or the intramedullary canal, whereas navigation uses hip and knee centre. Presently, no system prioritises restoration of the third space or native trochlear groove height (TGH) and there is a deficiency of published data on the variation of TGH with respect to the anterior cortex. This study aims to address this deficit. Hypothetically, restoration of the third space occurs when trochlear component depth equals TGH.

Materials and Methods: Relative to the posterior femoral axis the height of the anterior femoral cortex is higher laterally than centrally. For simplicity, this study reports MRI measurements of TGH relative to the centre in 110 normal subjects.

Results: TGH varied from the anterior femoral cortex by a mean of 2.32 mm (standard deviation, SD 1.77 mm, range −1.50 mm to 6.80 mm). If a femoral component trochlear depth of 2.2 mm is assumed, then 24.5% would be either over- or understuffed by more than 2 mm.

Conclusion: There is significant variation in TGH relative to the anterior femoral cortex. Assuming a femoral component trochlear depth of 2.2 mm, approximately one quarter of patients (24.5%) will be over- or understuffed by more than 2 mm. Variation in femoral component flexion and extension combined with whether or not it is left proud or notched will add further variation. Failure to restore the third space is likely to contribute to unsatisfactory results following TKA. Future surgical workflows should address this.

1. Introduction

1.1. Background and literature review

Total knee Arthroplasty (TKA) is a successful operation, nevertheless 10–20% of patients remain unsatisfied [1,2], with persistent pain a common symptom [1]. Traditionally, surgeons have focused on balancing the flexion and extension gaps with less consideration given to the patellofemoral joint (PFJ) (the third space). Anatomically, the third space consists of the extensor hood, the PFJ, the medial and lateral retinacula fibres, the surrounding soft tissues and the quadriceps muscle [3].

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Overstuffing the PFJ has traditionally been reported as a factor contributing to postoperative patellofemoral forces, reduced range of motion and anterior knee pain [4]. However, a recent systematic review found that the overstuffing which routinely takes place is mostly within tolerable limits and does not adversely affect clinical outcomes. Nevertheless, they advised caution and recommended recreating the anatomic dimensions of the PFJ to restore the joint within the safe margin of error [5]. Similarly, Pierson et al. (2007) concluded that overstuffing the PFJ did not result in adverse outcomes [6]. Matz et al. (2019) stated that when using the measured-resection technique, the combined thickness of the prosthesis should match the combined thickness of the femoral and patellar bone cuts; otherwise, the PFJ will be overstuffed. They also stated that although increases in the size of the femoral component can lead to overstuffing in posterior-referenced systems, decreasing component size can lead to understuffing and femoral notching [7]. From a theoretical perspective, understuffing the third space will result in a reduction of anterior offset and thus a reduction of the moment arm provided by the patella, this in turn will require the quadriceps mechanism to work harder to generate a similar movement [8–10]. Overstuffing of the third space increases the anterior offset and thus results in increased soft tissue tension [8,11]. Balancing of the third space within ± 2 mm does not result in a discernible effect on the extensor apparatus. However, failure to balance the third space within ± 4 mm results in a significant effect on function and soft tissue tension in the third space [8,11]. It is theorised that patients who are understuffed may report fatigue and lack of power when undertaking functional tasks, whilst patients who are overstuffed may report tightness and discomfort on functional activities [8].

Current literature on the third gap is very limited and we were unable to find any published data on the variation of anterior trochlear height with respect to the anterior cortex. Furthermore, to date, any reported measurements relating to over- or understuffing have not been based on accurate assessment of restoration of trochlear surface height. Therefore, we feel that the true incidence of over- and understuffing with respect to the trochlear surface is unknown and should be investigated.

1.2. Study aims and objectives

The primary aim of this study was to determine the variation of trochlear surface height with respect to the anterior cortex of the femur using Magnetic Resonance Imaging (MRI) measurements. The secondary aims were to assess if there was any correlation between trochlear surface height and patient sex or femoral size and to determine hypothetically what proportion of patients would be over- or understuffed by more than 2 mm when the anterior femoral cortex was used as the reference for the anterior femoral cut as per a standard manual technique.

2. Material and methods

Following ethical approval from our institution (Ref: 23053DB-SW), measurements were taken for 110 patients, with equivalent number of males and females, who most recently had undergone an MRI knee in our institution (dates of MRI ranged between 1st July 2022 to 20th November 2022) according to the following inclusion and exclusion criteria. Patients were included if they had reached skeletal maturity and had a routine protocol MRI knee on the 3 T scanner at our institution. Patients were excluded if their MRIs showed; non-routine sequences, patella dislocation (any current or past history), significant movement artefact, non-routine positioning, lesion disrupting PFJ or MRI evidence of patellofemoral osteoarthritis. A routine study included sagittal T1 weighted images and 3 plane proton density fat saturated images, with the sagittal sequences aligned perpendicular to the posterior condylar axis. The following measurements were taken:

- The point referenced for the trochlear groove was the lowest point of the trochlear groove at 3 cm cephalad to the tibial plateau (yellow X in Figure 1 a-b)
- Trochlear groove height (TGH) at lowest point anterior femoral cortex relative to the posterior condylar axis (mm) (A)
- Femoral size

A subset of 10 randomly chosen MRIs underwent repeat measurements by the same observer and by another independent observer to assess intra- and inter-observer reliability.

The ATTUNE™ knee system has been used to illustrate our results. Although the ATTUNE™ knee has a trochlear depth of 3.8 mm the actual depth relative to the anterior cortex is 2.2 mm because of the 5° anterior slope built into the component as illustrated in Figure 2. Both component trochlear depths and slopes vary across different manufacturers. For the ATTUNE™ if the initial TGH was greater or less than 2.2 mm, then the third space would be under- or overstuffed respectively when referencing off the anterior cortex.

In the above diagram, although the component trochlear depth is 3.8 mm only 2.2 mm is above the anterior cortex because of the 5° anterior slope.

2.1. Statistical analysis

Statistical analysis was carried out using SPSS version 29 software (IBM, Armonk, New York, USA). Data were assessed for normality using Shapiro-Wilk tests and histograms. Descriptive statistics were expressed as means (standard deviation, SD) for parametric data or medians (interquartile range, IQR) for non-parametric data. Differences in males and females were

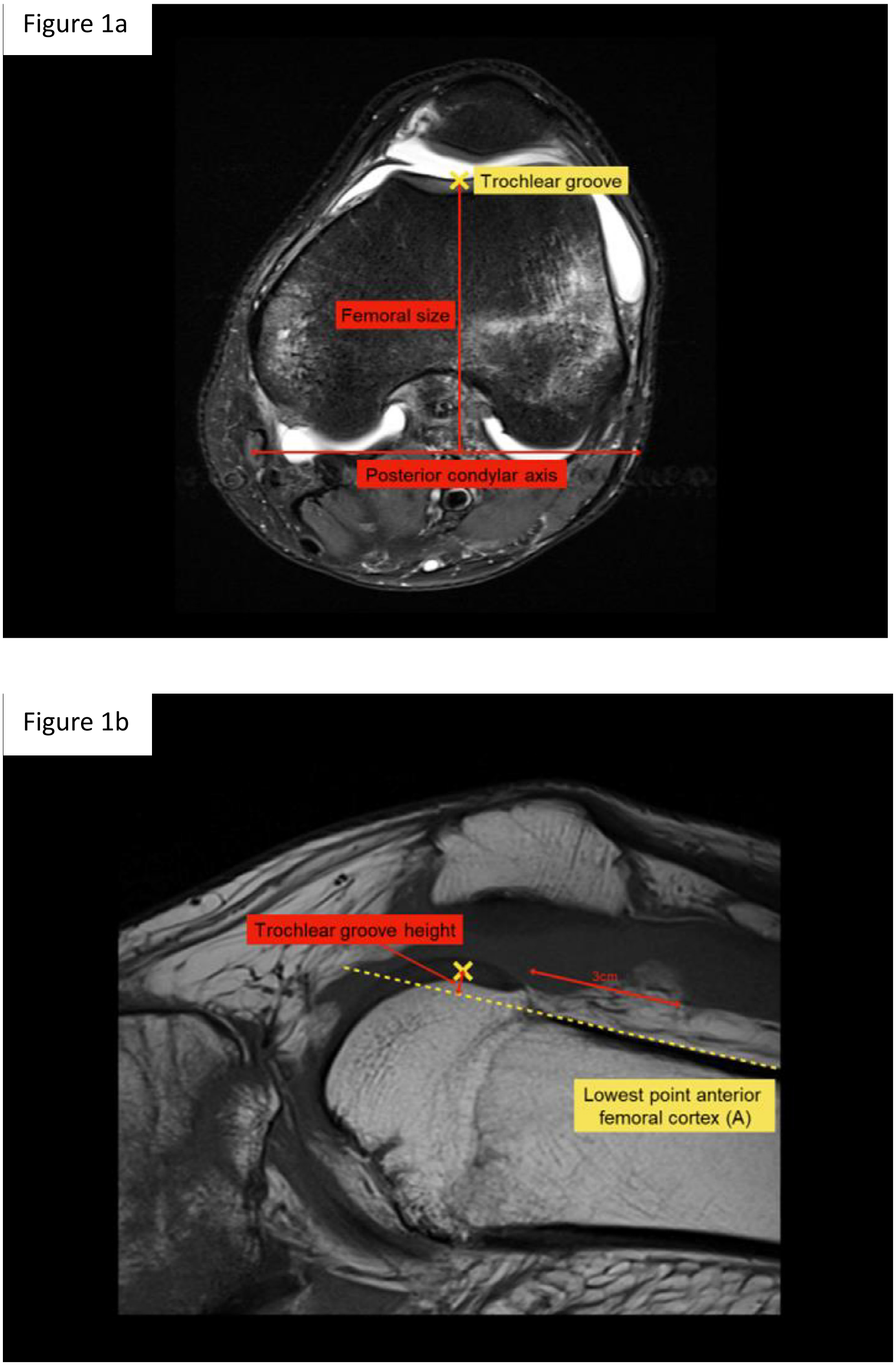

Figure 1. A-b show the measurements taken in axial (a) and sagittal planes (b).

assessed with the Independent Samples *T*-Test for parametric continuous variables and Mann-Whitney *U* test for non-parametric continuous variables. Spearman correlation coefficients were used to determine any associations between TGH at lowest point anterior femoral cortex and femoral size of total cohort and divided by males and females to determine any gender-specific associations. Intra- and inter-observer error were calculated using the intraclass correlation coefficient. Statistical significance was set at $p < 0.05$.

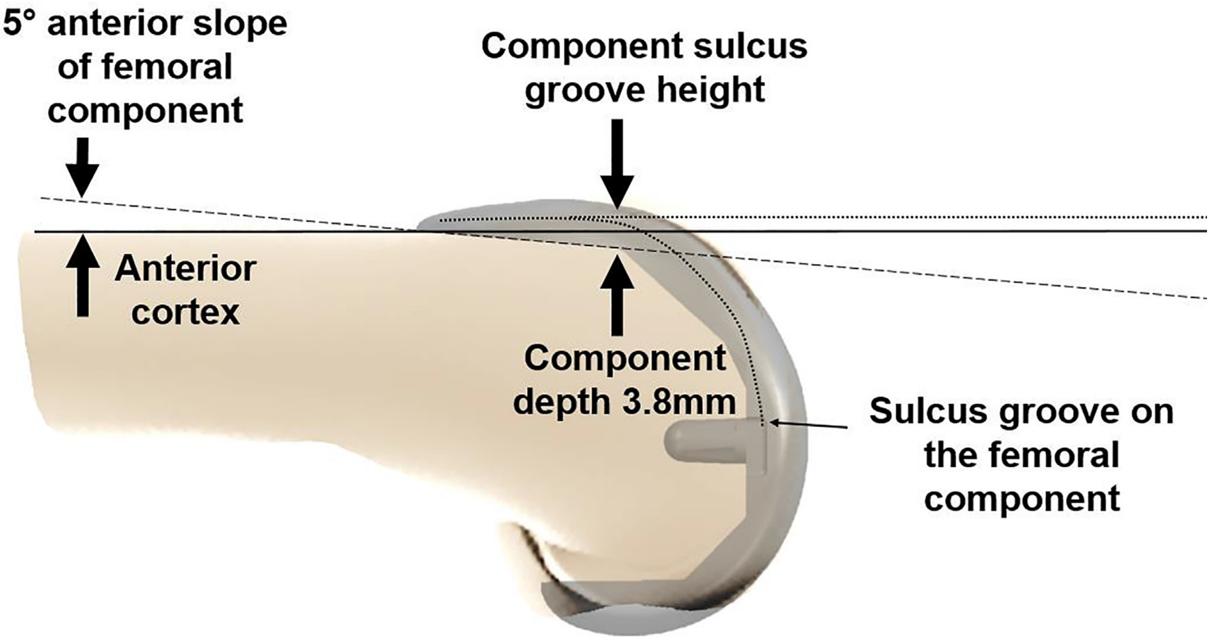

Figure 2. Component trochlear depth of ATTUNE™.

3. Results

Table 1 shows the demographics and measurements of 110 normal subjects who had MRI knees. There was a significant difference in age and femoral size between males and females. The TGH showed a weak positive correlation with femoral size across the population (0.201, p = 0.035). When split by patient sex, there was a statistically significant weak positive correlation in females only (0.332, p = 0.013) (Table 2). Figure 3 provides the distribution of over- and understuffing taking into account 2.2 mm. In 10% and 14.5% of patients, the PFJ would be over- or understuffed, respectively, by 2 mm or more. The intraclass correlation coefficient for the TGH at lowest point anterior femoral cortex between repeated measurements for the same observer was 0.973 (95% CI 0.89–0.99) indicating excellent reliability and for repeated measurements between observers was 0.652 (95%CI −0.40–0.91) indicating moderate reliability.

4. Discussion

When comparing the native trochlear groove surface to the component sulcus groove height, we found that in 25 patients (24.5%) the difference was greater than ± 2 mm and in 2 patients (1.8%) it was greater than ± 4 mm. We were unable to find any other published data on the variation of anterior trochlear height with respect to the anterior cortex. In this study, the TGH was deemed positive if the trochlear groove was anterior to the anterior cortex of the femur, and deemed negative if it was posterior to the anterior cortex of the femur. When performing the anterior cut during TKA it was not routine to measure the depth of the resected trochlear surface. In the example of the ATTUNE™ only a resected depth of 2.2 mm will restore trochlear height or the third gap [8]. This value is component specific and will depend on individual components anterior

Table 1
Demographics and measurements of total cohort and split by females and males.

	Females (n = 55)	Males (n = 55)	Total patients (n = 110)	p-value
Age, median (IQR; range)	51.00 (35.00–60.00; 20.00–82.00)	30.00 (26.00–41.00; 18.00–62.00)	38.50 (28.00–52.25; 18.00–82.00)	**<0.001***
TGH at lowest point anterior femoral cortex (A), mm, Mean (SD; range)	2.26 (1.70; −1.50–6.20)	2.39 (1.85; −1.40–6.80)	2.32 (1.77; −1.50–6.80)	0.712
TGH at lowest point anterior femoral cortex (A), accounting for 2.2 mm, Mean (SD; range)	0.06 (1.70; −3.70–4.00)	0.19 (1.85; −3.60–4.60)	0.12 (1.77; −3.7–4.6)	0.712
Femoral size, Mean (SD; range)	59.80 (3.60; 52.70–72.50)	64.66 (3.93; 55.00–73.80)	62.2 (4.47; 52.70–73.80)	**<0.001***

TGH; trochlear groove height.
* Significant difference between males and females.

Table 2
Correlation of TGH at lowest point anterior femoral cortex and femoral size of total cohort and split by females and males.

Femoral size	Spearman's Correlation Coefficient		
	Females (n = 55)	**Males (n = 55)**	**Total patients (n = 110)**
TGH at lowest point anterior femoral cortex (A), mm	0.332 (**p = 0.013**)	0.137 (p = 0.320)	0.201 (**p = 0.035**)

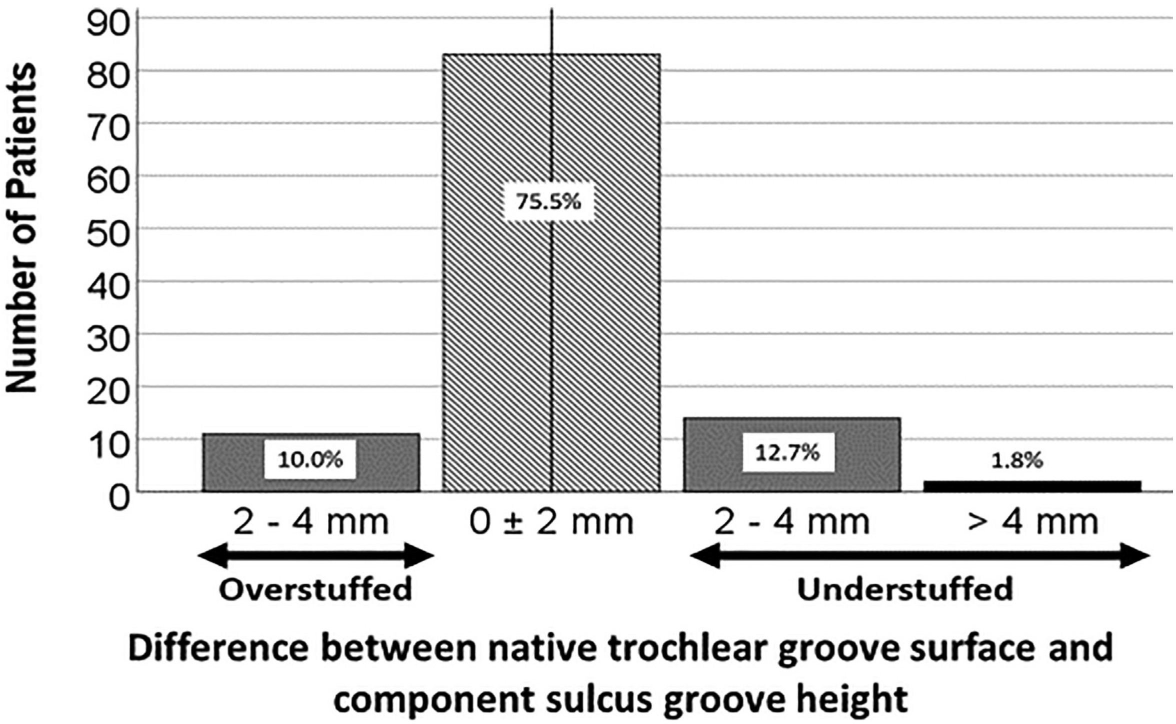

Figure 3. Over- and understuffing taking into account 2.2 mm.

slope, as well as the components sulcus groove height. It is important to note however, that the solution lies not in the implants themselves, but rather in the technique used. Our study shows that there is natural variation in the trochlear groove when compare to the anterior cortex of the femur, attempting to correct for this with implant design of various component sulcus depths results in merely shifting the bell curve one direction or another, trading less understuffing for more overstuffing or vice versa. Instead, a technique which references from the trochlear groove itself would account for the natural variation that exists.

Functional alignment has been shown to restore trochlear depth more closely than mechanical or kinematic alignment [12,13]. In 366 patients who underwent robotic-assisted TKA, implant position and trochlear restoration were compared between three groups; kinematic, mechanical and functional alignment of the femoral component [12]. Femoral alignment was significantly different between all three groups. Of kinematic alignment, 13.1% compared to 3.3% of functional alignment were considered unsafe in relation to femoral position. The limits for femoral flexion was 10° and femur coronal positioning between 6° valgus and 3° varus. For rotation, limitation relative to the transepicondylar axis was set at 3° external rotation to 6° internal rotation [14,15]. A second threshold of 3° internal rotation was also considered as this has previously been associated with patellofemoral failure following TKA [12]. The authors thought this could be why TKA by kinematic alignment had an increased incidence of patellofemoral complications. They found that the trochlear groove was translated furthest (more lateral) from native anatomy by mechanical alignment compared to kinematic and functional alignment. In full extension, functional alignment most closely restored the trochlear groove depth in all three positions of flexion [12,16].

Chalmers et al. compared the intramedullary axis of the femur to the navigation axis which is used as a reference point in some robotic surgery. They found that by referencing the centre of the femoral head as compared with the intramedullary canal of the femur, computer-navigated or robotic TKA, will usually result in a femoral component that is approximately 1.4° extended relative to when referencing the intramedullary axis [17]. This highlights that it is important to use the same anatomical reference points, as the implanted position of the femoral component differs when an alternate reference is used.

Despite considerable interest in robotic surgery, most TKAs in the medium term will continue to be carried out using manual techniques. Within this context, to say that over- or understuffing of the PFJ is only down to over- or under sizing of the femoral component is an over simplification. With respect to over- or understuffing of the femoral side of the PFJ, the key target should be restoration of the trochlear surface. Surgically, this is determined distally, by the depth of distal femoral resection and anteriorly, by the depth of the anterior cut with respect to the trochlear sulcus, not simply the anterior femoral cortex. Theoretically, resurfacing cuts on both surfaces, i.e. the same depth as the component, will restore the trochlear surface. With a manual technique this is more straightforward distally, but perhaps critically, is more problematic anteriorly. The problem is that all manual systems, whether anterior or posterior referencing, use the anterior femoral cortex as a surrogate for the trochlear surface. This assumes two things, firstly, that anterior trochlear height is constant with respect to the anterior cortex, and secondly, that this constant closely relates to the anterior trochlear depth of the femoral component. There is no published evidence that we can find to support these assumptions.

This study had several limitations. Firstly, the routine MRI protocol had image slices measuring 3 mm. As a result, when determining the lowest point on the axial view and then choosing the corresponding sagittal slice, the sagittal slice chosen may be up to 1.5 mm off from where we would ideally measure, this introduced a degree of inaccuracy to our values which was evidenced in the moderate reliability of the inter-observer error margins. Secondly, we used the ATTUNE™ Knee system as an example due to its use in our institution. Other manufacturers' implants will have different component trochlear depths and different anterior slopes; thus, the results would be different. In this study we solely focused on the femoral side of the patella-femoral joint. Over or under stuffing can also occur due to inaccurate patella resurfacing, or not resurfacing a worn patella that has lost height. Finally, due to our MRI images being *peri*-articular, our ability to comment on the effect of alignment was negated, the alignment of the limb may have an effect on the trochlear groove height as defined in our methods.

However, a strength of the imaging was that our institution routinely used the posterior condylar axis to determine the coronal plane and subsequently the sagittal plane. More commonly MRI knee protocols reference the direction of the anterior cruciate ligament (ACL) fibres to determine the sagittal plane. The use of the posterior condylar axis when determining the coronal and subsequent sagittal planes during reconstruction of the MRI sequences allowed us to provide the exact TGH as defined in methods, rather than having to correct for the angle introduced by the direction of ACL fibres had our institution referenced from them. Another strength of this study was that our cohort had no existing PFJ arthritis and the use of MRI allowed us to factor in the PFJ cartilage, this was unique in the current literature.

Current literature was lacking in relation to over- or understuffing based on accurate assessment of restoration of trochlear surface height. Hypothetically, restoration of trochlear height (the third space) may decrease the number of patients who are unsatisfied. Future research should aim to examine this hypothesis.

5. Conclusions

There is anatomical variation of the native trochlear groove surface with respect to the anterior femoral cortex at the central femur, resulting in this being an unreliable surrogate for restoring the anatomy of the third space during TKA. Use of the anterior femoral cortex as a surrogate for the trochlear surface may result in up to 24.5% of patients having their third space over- or understuffed by more than 2 mm using traditional techniques. Future manual instrumentation should seek to address this issue.

CRediT authorship contribution statement

William Brown: Writing – review & editing, Writing – original draft, Investigation, Data curation. **Nicola Gallagher:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Dai Roberts:** Writing – review & editing, Investigation, Data curation. **Richard Napier:** Writing – review & editing. **David Barrett:** Writing – review & editing, Supervision, Methodology, Conceptualization. **David Beverland:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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