Windswept deformity of the knee: prevalence and predictive factors in osteoarthritic and healthy populations

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Aims
This study examined windswept deformity (WSD) of the knee, comparing prevalence and contributing factors in healthy and osteoarthritic (OA) cohorts.

Methods
A case-control radiological study was undertaken comparing 500 healthy knees (250 adults) with a consecutive sample of 710 OA knees (355 adults) undergoing bilateral total knee arthroplasty. The mechanical hip-knee-ankle angle (mHKA), medial proximal tibial angle (MPTA), and lateral distal femoral angle (LDFA) were determined for each knee, and the arithmetic hip-knee-ankle angle (aHKA), joint line obliquity, and Coronal Plane Alignment of the Knee (CPAK) types were calculated. WSD was defined as a varus mHKA of < -2° in one limb and a valgus mHKA of > 2° in the contralateral limb. The primary outcome was the proportional difference in WSD prevalence between healthy and OA groups. Secondary outcomes were the proportional difference in WSD prevalence between constitutional varus and valgus CPAK types, and to explore associations between predefined variables and WSD within the OA group.

Results
WSD was more prevalent in the OA group compared to the healthy group (7.9% vs 0.4%; p < 0.001, relative risk (RR) 19.8). There was a significant difference in means and variance between the mHKA of the healthy and OA groups (mean -1.3° (SD 2.3°) vs mean -3.8°(SD 6.6°) respectively; p < 0.001). No significant differences existed in MPTA and LDFA between the groups, with a minimal difference in aHKA (mean -0.9° healthy vs -0.5° OA; p < 0.001). Backwards logistic regression identified meniscectomy, rheumatoid arthritis, and osteotomy as predictors of WSD (odds ratio (OR) 4.1 (95% CI 1.7 to 10.0), p = 0.002; OR 11.9 (95% CI 1.3 to 89.3); p = 0.016; OR 41.6 (95% CI 5.4 to 432.9), p ≤ 0.001, respectively).

Conclusion
This study found a 20-fold greater prevalence of WSD in OA populations. The development of WSD is associated with meniscectomy, rheumatoid arthritis, and osteotomy. These findings support WSD being mostly an acquired condition following skeletal maturity.

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Take home message

- Windswept deformity (WSD) is predominantly an acquired condition, and is 20 times more prevalent in osteoarthritic than healthy populations.
- Prior meniscectomy, osteotomy, and rheumatoid arthritis are the strongest factors associated with the presence of WSD.

Introduction

Windswept deformity (WSD) of the knee is characterized by varus alignment in one knee and valgus alignment in the contralateral knee.[1] Despite its distinctive presentation, a true understanding of its prevalence and causes remains limited, especially in larger-sample studies.[2] The condition has been associated with various underlying diagnoses in paediatric populations, including skeletal dysplasia, physeal disturbances, metabolic bone disorders, and post-traumatic conditions.[2] However, in adults, WSD is mostly encountered in patients with primary osteoarthritis (OA),[1] raising questions about its origins in the older population.

Understanding the native, or pre-arthritic, alignment of the lower limb and its interaction with OA is essential for optimizing alignment in total knee arthroplasty (TKA). In the current landscape of increasingly individualized procedures that use kinematic and functional alignment strategies, consideration of constitutional alignment patterns has gained prominence.[3,4] Exploring the aetiology and prevalence of WSD will enhance our comprehension of alignment complexities associated with OA.

This study aimed to define the prevalence of WSD in both healthy and OA adult populations. The primary hypothesis was that there would be no difference in the prevalence of WSD between these groups. Secondary hypotheses were that there would be no difference in the constitutional alignment types between healthy and OA groups, and that there are no associative factors that contribute to WSD in the OA group. This research aims to enhance our knowledge of the interplay between constitutional alignment and acquired deformity in OA.

Methods

Study group

A retrospective case-control study was undertaken to compare knee alignment in two distinct groups: a healthy population and an OA population. The healthy population consisted of 250 adults aged 20 to 27 years, derived from a previous cross-sectional study conducted by two of the authors (JB, WC).[4] Bilateral long leg radiographs (LLRs) resulted in data from a total of 500 knees. Participants were recruited from high school and university campuses, cinemas, and job recruitment bureaus in Leuven, Belgium, from October 2009 to March 2010. Of these participants, 50% (n = 125) were female, and only asymptomatic individuals with no history of orthopaedic injury or disease were included. Ethics approval for this cohort was granted by the Medical Ethics Committee of UZ Leuven, Belgium (#B32220097076).

The OA population comprised 355 adults (710 knees) who underwent bilateral primary TKA as simultaneous or sequential surgeries, the latter within 18 months of the first procedure. Surgeries were performed by two of the authors (SJM, DBC) at a private hospital in Sydney, Australia (St George

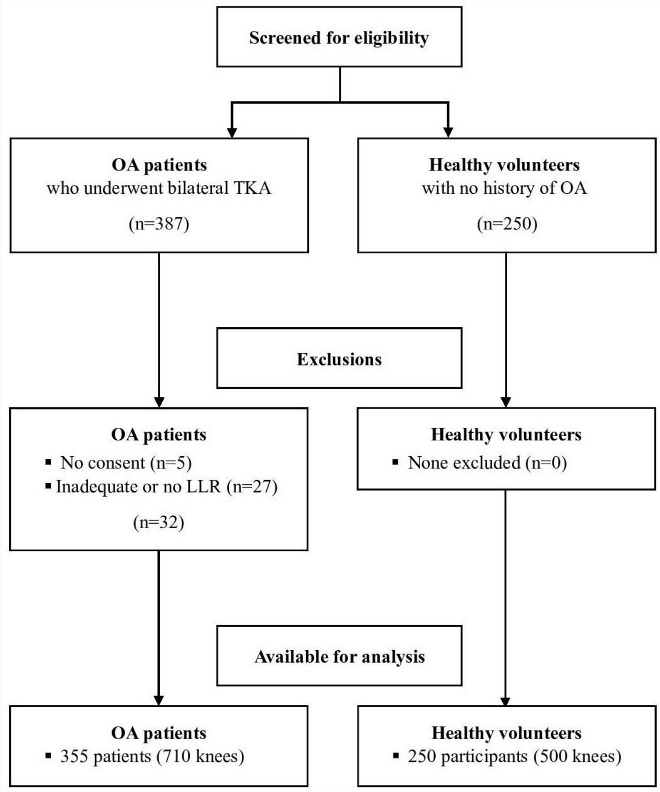


Fig. 1

Study flowchart. LLR, long leg radiograph; OA, osteoarthritis; TKA, total knee arthroplasty.

Private Hospital) between January 2018 and May 2023. The mean patient age was 70.2 years (44 to 92). All patients were included, regardless of underlying diagnosis or previous history of lower limb surgery, trauma, or deformity. Patients who did not provide consent or lacked preoperative bilateral LLRs were excluded from the analysis (Figure 1). Ethics approval for studying this cohort was granted by the Ramsay Health Care Human Research Ethics Committee A (#2023/ETH/0063).

Radiological evaluation

Radiological assessment involved examining LLRs to measure any of the following variables, by a single observer in the healthy group (WC) and by two observers in the arthritic group (JM, VAvdG).

The mechanical hip-knee-ankle angle (mHKA) was defined as the angle subtended by the mechanical axes of the femur and tibia, with a negative value for varus alignment and a positive value for valgus alignment. The joint line of the proximal tibia was determined by identifying the most distal contours on the medial and lateral tibial plateaus, and was used to calculate the medial proximal tibial angle (MPTA). Likewise, the joint line of the distal femur was determined by locating the most distal points on the medial and lateral femoral condyles, and was used to calculate the lateral distal femoral angle (LDFA). These two angles were used to calculate: 1) the constitutional alignment, or arithmetic hip-knee-ankle angle (aHKA): aHKA = MPTA − LDFA; 2) joint line obliquity angle: JLO = MPTA + LDFA; and 3) Coronal Plane Alignment of the Knee (CPAK) type.[3]

Table I. Predefined variables included as potential contributors to malalignment of the lower limb.

Variable	Medical record review	Radiological review (LLR)
Age	x	
Sex	x	
BMI	x	
SCFE	x	
Partial meniscectomy	x	
Hip fracture	x	x
Total hip arthroplasty	x	x
Prior femoral trauma	x	x
Prior tibial trauma	x	x
Osteotomy	x	x
ACL reconstruction	x	x
Cartilage procedure	x	x
Ankle arthrodesis	x	x
Ankle fracture	x	x
Ankle arthroplasty	x	x
Other ankle injury	x	x
Osteogenesis imperfecta	x	
Paget's disease	x	x
Rickets	x	
Other metabolic disorder	x	
Rheumatoid arthritis	x	
Other inflammatory disorder	x	

ACL, anterior cruciate ligament; LLR, long leg radiograph; SCFE, slipped capital femoral epiphysis.

Table II. Baseline characteristics of healthy and osteoarthritis groups.

Variable	Healthy group	OA group
Mean age, years (SD)	23.8 (1.2)	70.2 (7.6)
Mean BMI, kg/m^2 (SD)	22.1 (2.9)	29.7 (4.8)
Female sex, % (n)	50 (125)	54 (193)

OA, osteoarthritis.

Data collection

A list of predefined predictor variables that could lead to WSD (Table I) was established through consensus among four authors (SJM, DBC, JM, VAvdG). Both radiographs and medical records were assessed to identify presence of any of these variables.

Outcomes

The study's primary outcome was the proportional difference in WSD between healthy and OA groups. WSD was defined as a varus mHKA of < 2° in one limb and a valgus mHKA of > 2° in the other. The secondary outcomes were: 1) the proportional differences between healthy and OA groups with constitutional WSD phenotypes; and 2) associations between the predefined variables and WSD within the OA group.

Table III. Comparison of radiological data of healthy and osteoarthritis groups.

Variable	Healthy group	OA group	p-value
WSD, n (%)	1 (0.4)	28 (7.9)	< 0.001*
Mean MPTA° (SD)	87.0 (2.1)	87.3 (3.0)	0.277†
Mean LDFA° (SD)	87.9 (1.8)	87.8 (2.6)	0.415†
Mean mHKA° (SD)	-1.3 (2.3)	-3.8 (6.6)	< 0.001†
Mean aHKA° (SD)	-0.9 (2.6)	-0.5 (4.6)	< 0.001†
Mean JLO ° (SD)	174.9 (2.9)	175.1 (3.3)	0.429†

*Chi-squared test.
†Independent-samples *t*-test.
aHKA, arithmetic hip-knee-ankle angle; JLO, joint line obliquity; LDFA, lateral distal femoral angle; mHKA, mechanical hip-knee-ankle angle; MPTA, medial proximal tibial angle; OA, osteoarthritis; WSD, windswept deformity.

Statistical analysis

Descriptive statistics were used to summarize the data, and normality was assessed using histograms, Q-Q plots, Shapiro-Wilk test, and Kolmogorov-Smirnov test. Differences between groups were analyzed using chi-squared tests for categorical data, independent-samples *t*-tests for normally distributed continuous data, and Mann-Whitney U tests for non-parametric continuous data. The logistic regression analysis involved identification and selection of predictor variables from a predefined list of potential contributors to WSD (Table I), followed by logistic regression to evaluate if a relationship exists between these variables and the occurrence of WSD. Predictors with fewer than two events were excluded from the model to ensure the reliability and stability of the regression estimates. The following variables were included in the model: age, sex, BMI, meniscectomy, anterior cruciate ligament reconstruction, previous osteotomy, and rheumatoid arthritis (RA). Significance was set at $p \leq 0.05$. Statistical analyses were conducted using IBM SPSS Statistics v. 27 (IBM, USA) and R v. 4.3.0 (R Foundation for Statistical Computing, Austria).

Results

Study groups

Table II compares healthy and OA groups per their baseline characteristics, and Table III compares the groups' radiological data. There was a significant difference in means and variance of the mHKA between healthy and OA groups (healthy mean mHKA -1.3° (SD 2.3); OA mean mHKA -3.8° (SD 6.6); p < 0.001, independent-samples *t*-test) (Figure 2). However, the difference between the mean and distribution of the aHKA of the healthy and OA groups was 0.4° and not likely to be of clinical significance (healthy mean aHKA -0.9 (SD 2.6); OA mean aHKA -0.5 (SD 4.6); p < 0.001, independent-samples *t*-test) (Figure 3). Figure 4 illustrates differences in CPAK types between groups.

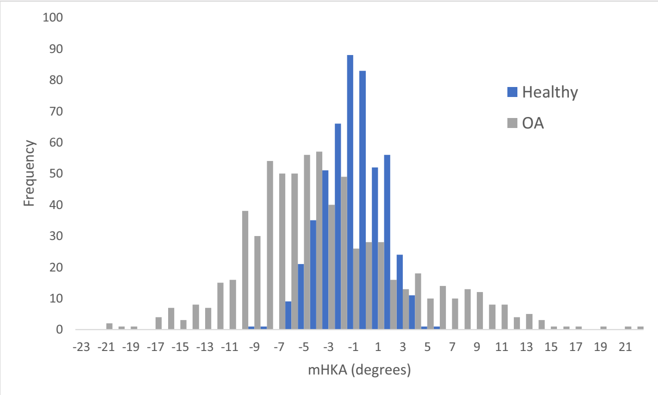


Fig. 2
Distribution of mechanical hip-knee-ankle angles (mHKAs) of healthy and osteoarthritis (OA) groups. Negative values on horizontal axis represent varus, with positive values representing valgus.

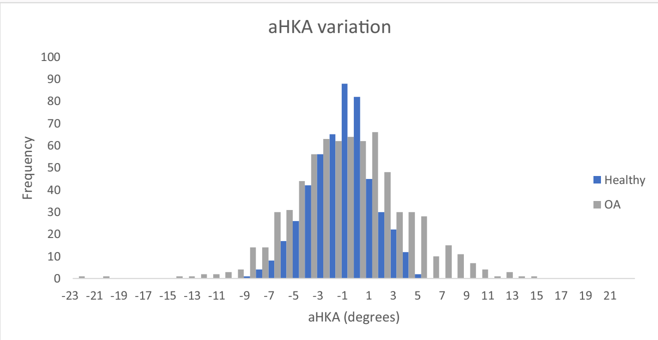


Fig. 3
Distribution of arithmetic hip-knee-ankle angle (aHKA) angles comparing healthy and osteoarthritis (OA) groups. Negative values on horizontal axis represent varus, with positive values representing valgus.

Table IV. Association between meniscectomy type and windswept deformity in the osteoarthritis group.

Meniscectomy type	Meniscectomy patients, n	Meniscectomy patients with WSD, n (%)
Total patients with previous meniscectomy	106	15 (14.2)
Unilateral knee meniscectomy	46	7 (15.2)
Medial	38	3 (7.9)
Lateral	7	3 (42.3)
Medial/lateral	1	1 (100)
Bilateral knee meniscectomy	28	5 (17.9)
Medial and medial	19	0 (0.0)
Medial and lateral	7	5 (71.4)
Lateral and lateral	2	0 (0.0)
Unknown	32	3 (9.3)

WSD, windswept deformity.

Table V. Radiological measurements for medial and lateral meniscectomy patients in windswept deformity osteoarthritis group.

Variable	Medial meniscectomy	Lateral meniscectomy
Mean MPTA, ° (SD)	86.6 (2.7)	89.4 (2.5)
Mean LDFA, ° (SD)	88.2 (2.4)	85.9 (3.0)
Mean mHKA, ° (SD)	-5.6 (4.5)	5.1 (6.1)
Mean aHKA, ° (SD)	-1.7 (3.7)	4.5 (3.6)
Mean JLO, ° (SD)	174.9 (3.4)	175.4(3.2)

aHKA, arithmetic hip-knee-ankle angle; JLO, joint line obliquity; LDFA, lateral distal femoral angle; mHKA, mechanical hip-knee-ankle angle; MPTA, medial proximal tibial angle.

Primary outcome

In the healthy cohort, 0.4% (1/250) of participants demonstrated WSD. Conversely, the OA cohort exhibited a 7.9% (28/355) prevalence of WSD ($p < 0.001$, chi-squared test). The relative risk (RR) of WSD occurring in the OA cohort compared to the healthy cohort was 19.8.

Secondary outcomes

In the healthy group, there was a 2.0% incidence of a varus CPAK types in one limb and valgus CPAK types in the contralateral limb. In the OA cohort, there was a 5.4% incidence of this phenomenon ($p = 0.039$), with an increased RR of 2.7 in the OA cohort.

The logistic regression model showed no evidence of multicollinearity with all variance inflation factors below 1.3. Overall model fit was good, with an area under the receiver operating curve of 0.72. The model summary is displayed in Figure 5. It showed strong evidence that the odds of WSD increase for osteotomy and meniscectomy, and although the effect of meniscectomy is smaller, it still represents a four-fold increase in the odds of presenting with WSD. There also is good evidence for a substantial effect of RA. The other variables (sex, BMI, age, and anterior cruciate ligament reconstruction) did not show a significant association in the model.

The study identified a significant association between medial meniscectomy and varus mHKA ($p = 0.002$), while no notable association was found between medial meniscectomy and varus aHKA ($p = 0.289$). Additionally, a marked association was observed between lateral meniscectomy and both valgus mHKA ($p \leq 0.001$) and valgus aHKA ($p \leq 0.001$). Table IV shows the association between meniscectomy type and presence of WSD in the OA group, and Table V displays the radiological measurements for the medial and lateral meniscectomy patients in the WSD OA group.

Discussion

The most important finding of this study was the 20-fold increase in the proportion of WSD in the OA group compared to the healthy group. To our knowledge, this is the first study to quantify and compare the prevalence of WSD in these two distinct populations. Further, this disproportionate WSD prevalence in the OA group, along with the increased odds of

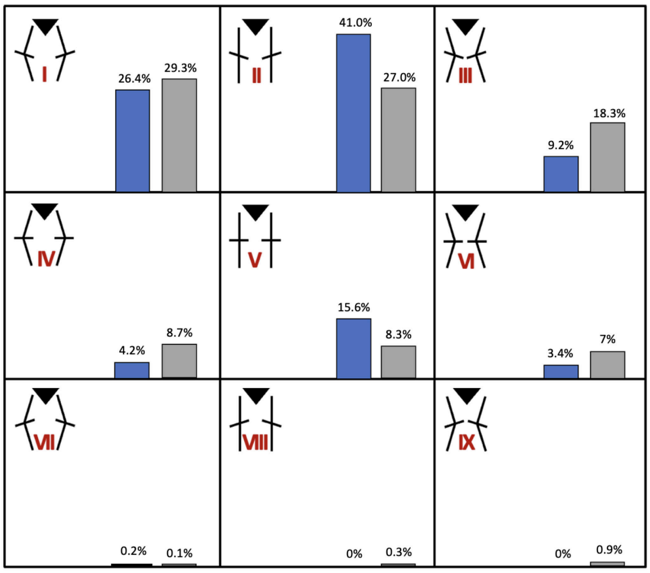
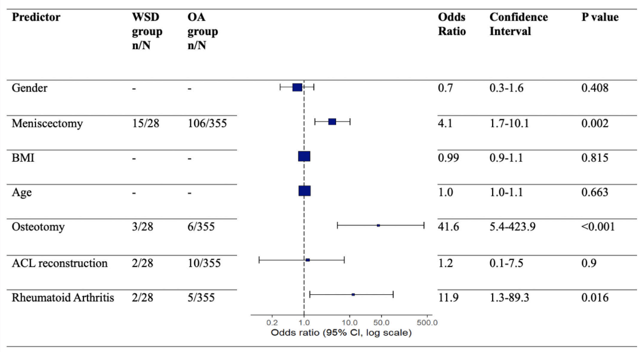


Fig. 4

Distribution of the proportions of patients in each Coronal Plane Alignment of the Knee phenotype, comparing healthy and osteoarthritis groups.



Predictor	WSD group n/N	OA group n/N	Odds Ratio	Confidence Interval	P value
Gender	-	-	0.7	0.3-1.6	0.408
Meniscectomy	15/28	106/355	4.1	1.7-10.1	0.002
BMI	-	-	0.99	0.9-1.1	0.815
Age	-	-	1.0	1.0-1.1	0.663
Osteotomy	3/28	6/355	41.6	5.4-423.9	<0.001
ACL reconstruction	2/28	10/355	1.2	0.1-7.5	0.9
Rheumatoid Arthritis	2/28	5/355	11.9	1.3-89.3	0.016

Fig. 5

Logistic regression forest plot examining potential predictors for windswept deformity in the osteoarthritis group. ACL, anterior cruciate ligament; WSD, windswept deformity.

WSD associated with prior meniscectomy, osteotomy, and RA, suggests that this condition is likely an acquired trait.

In contrast to prior studies by Shetty et al,[5] Howell et al,[6] and Hsu et al,[7] which incidentally reported on WSD in patients awaiting TKA, this study deliberately investigated and compared the prevalence of WSD in distinct populations. Shetty et al[5] explored the mHKA and valgus correction angle, reporting a 1.6% WSD prevalence in an original series of 4,000 patients. However, the radiological assessment used to identify WSD was not described, which could clarify their lower observed proportion.

Howell et al[6] reported on 19 patients with medial joint space narrowing in one knee and lateral joint space narrowing in the contralateral knee, all of whom underwent sequential TKA. The WSD cohort was identified from a series of 2,430 consecutive TKA cases, but measurements were only included from the 19 patients. Similarly, Hsu et al[7] presented data on 33 patients with WSD without including any measurements from the series of 1,250 patients. Additionally, in the study by Howell et al,[6] preoperative radiological analysis was performed on standing anteroposterior (AP) knee radiographs. This view affords a smaller field of reference than LLRs; several previous studies have demonstrated the relative inadequacy of AP radiographs in accurately measuring coronal alignment,[8-10] which, in turn, raises concern about the reliability of using AP radiographs to assess WSD.

There was a 2.0% and 5.4% prevalence of patients with an aHKA < 2° (varus CPAK Type I, IV, and VII) in one knee and an aHKA > 2° (valgus CPAK Type III, VI, and IX) in the contralateral knee in the healthy and OA groups, respectively. This difference in constitutional alignment (2.7-fold increase) is significantly less than the difference in mechanical alignment using the mHKA between the two groups (20-fold increase). This finding adds further support to the theory that WSD is mostly acquired following skeletal maturity.

In our study, 53.6% of patients with WSD (15/28) had undergone meniscectomy, contrasted with 29.9% (106/355) in the overall OA cohort. We identified a correlation between the type of meniscectomy and the resulting mHKA. Individuals with a history of medial meniscectomy were more likely to exhibit a varus mHKA, while those with a prior lateral meniscectomy tended towards a valgus mHKA. While there was a statistically significant association between a medial meniscectomy and having a varus mHKA, there was no association between a medial meniscectomy and a varus aHKA. This suggests that increasing varus deformity arises post-meniscectomy. A lateral meniscectomy had a significant association with a valgus mHKA and aHKA, implying less of a clear relationship between valgus alignment and lateral meniscectomy. An isolated lateral meniscectomy or a lateral meniscectomy with a contralateral medial meniscectomy were the meniscectomy types that were most associated with WSD.

Pengas et al[11] reported that a meniscectomy may lead to altered alignment, with an increased varus alignment four decades after a medial meniscectomy. Previous studies have also reported on altered knee kinematics post-meniscectomy, indicating changes in alignment and a mechanical pathway to knee OA.[12-14] Other studies have demonstrated that OA can also lead to a progression of the mHKA.[15–18] Colyn et al[17] compared consecutive full-length radiographs in the same patients with varus alignment. The mHKA angle increased according to the arthritic progression noted in their study. Felson et al[18] previously reported that valgus malalignment may be a potent cause of lateral compartment OA and lateral meniscal damage.

This study has several limitations. First, the retrospective nature of the investigation and reliance on existing medical records presents inherent limitations, including potential selection bias. Second, while we observed a significant association between previous meniscal surgery and the presence of WSD, the study design precludes us from establishing a causal relationship or exploring the specific mechanisms underlying this association. Third, this study did not report the percentage of meniscus removed in each arthroscopic procedure, nor were we able to report patients with meniscal pathology who were treated non-surgically. Fourth, although both groups showed a similar distribution of CPAK types, both populations were from different geographical regions, a factor which has been shown to impact the distribution of CPAK Types, particularly in OA groups. [14] Finally, the overall sample size of patients with WSD was quite small. While this introduces the potential for a type II error on any sub-analysis of these patients, WSD is an uncommon condition, and gathering a large sample size is therefore challenging.

In conclusion, this study sheds light on the complex interplay between OA and the development of WSD, suggesting that it is predominantly an acquired condition following skeletal maturity. Prior meniscectomy, osteotomy, and rheumatoid arthritis are the strongest factors associated with the presence of WSD.

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J. A. Wood: Data curation, Methodology, Project administration, Validation, Visualization, Writing – review & editing.
P. Humburg: Formal analysis, Writing – review & editing.
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J. Bellemans: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing.
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Data sharing

The data that support the findings for this study are available to other researchers from the corresponding author upon reasonable request.

Ethical review statement

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