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Iliopsoas tendonitis after total hip arthroplasty

AN IMPROVED DETECTION METHOD WITH APPLICATIONS TO PREOPERATIVE PLANNING

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Aims
Iliopsoas impingement occurs in 4% to 30% of patients after undergoing total hip arthroplasty (THA). Despite a relatively high incidence, there are few attempts at modelling impingement between the iliopsoas and acetabular component, and no attempts at modelling this in a representative cohort of subjects. The purpose of this study was to develop a novel computational model for quantifying the impingement between the iliopsoas and acetabular component and validate its utility in a case-controlled investigation.

Methods
This was a retrospective cohort study of patients who underwent THA surgery that included 23 symptomatic patients diagnosed with iliopsoas tendonitis, and 23 patients not diagnosed with iliopsoas tendonitis. All patients received postoperative CT imaging, postoperative standing radiography, and had minimum six months' follow-up. 3D models of each patient's prosthetic and bony anatomy were generated, landmarked, and simulated in a novel iliopsoas impingement detection model in supine and standing pelvic positions. Logistic regression models were implemented to determine if the probability of pain could be significantly predicted. Receiver operating characteristic curves were generated to determine the model's sensitivity, specificity, and area under the curve (AUC).

Results
Highly significant differences between the symptomatic and asymptomatic cohorts were observed for iliopsoas impingement. Logistic regression models determined that the impingement values significantly predicted the probability of groin pain. The simulation had a sensitivity of 74%, specificity of 100%, and an AUC of 0.86.

Conclusion
We developed a computational model that can quantify iliopsoas impingement and verified its accuracy in a case-controlled investigation. This tool has the potential to be used preoperatively, to guide decisions about optimal cup placement, and postoperatively, to assist in the diagnosis of iliopsoas tendonitis.

Cite this article: ***Bone Jt Open*** **2023;4-1:3–12.**

Keywords: Iliopsoas impingement, Iliopsoas tendonitis, Soft tissue, THA, Total hip arthroplasty

Introduction
With its low revision rates, total hip arthroplasty (THA) is broadly viewed as a highly successful operation for relieving pain and restoring mobility after osteoarthritis (OA) of the hip.[1] However, revision rates do not provide a holistic understanding of patient outcomes as they do not capture postoperative pain or dissatisfaction rates,[2,3] which may persist for several reasons.[4] These include infection, instability, or soft-tissue complications,[4] such as greater trochanteric pain syndrome and iliopsoas tendonitis.[5] Iliopsoas tendonitis can occur due to protruding

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doi: 10.1302/2633-1462.41.BJO-2022-0147.R1

Bone Jt Open 2023;4-1:3–12.

Table I. Deidentified details of the symptomatic patient cohort, including age, sex, implant sizes, method of diagnosing iliopsoas tendonitis, and the treatment the patient underwent.

Patient ID	Surgeon	Age, yrs	Sex	Side	Cup size	Head size	Diagnosis	Treatment
1	1	98	F	Right	50	32	Active hip flexion test	Cortisone injections and iliopsoas release
2	1	73	F	Right	50	28	Active hip flexion test	Cortisone injection
3	1	70	M	Right	62	48	Active hip flexion test	Cortisone injection
4	1	63	F	Left	50	36	Active hip flexion test	Cortisone injection and iliopsoas release
5	1	68	F	Left	48	32	Active hip flexion test	Cortisone injection and iliopsoas release
6	1	83	F	Right	48	36	Active hip flexion test	Cortisone injections and iliopsoas drainage
7	1	78	M	Left	54	36	Active hip flexion test	Cortisone injection
8	1	61	F	Left	56	28	Active hip flexion test	Cortisone injection
9	1	76	M	Right	58	28	Active hip flexion test	Cortisone injection and iliopsoas release
10	1	57	M	Right	58	48	Active hip flexion test	Cortisone injection
11	1	72	F	Left	48	28	Active hip flexion test	Iliopsoas release
12	1	75	M	Left	60	48	Active hip flexion test	Cortisone injection
13	1	79	F	Right	52	32	Active hip flexion test	Cortisone injection
14	1	61	F	Right	48	32	Active hip flexion test	Cortisone injection
15	2	49	F	Left	52	36	Pain in extension, bicycle test	Cup revision
16	2	51	F	Right	48	32	Pain in flexion, bicycle test	Conservative treatment, including physiotherapy
17	2	53	F	Left	52	36	Pain in flexion, bicycle test	Cup and stem revision
18	2	41	F	Left	50	42	Pain in flexion and extension, bicycle test	Cup revision and iliopsoas release
19	2	63	F	Left	54	36	Pain in flexion, bicycle test	Iliopsoas release with cup revision planned
20	2	46	F	Left	48	40	Pain in flexion, bicycle test	Conservative treatment, including physiotherapy
21	2	26	F	Right	48	36	Pain in flexion, bicycle test	Iliopsoas tenotomy
22	2	64	M	Right	54	36	Pain in flexion, bicycle test	Iliopsoas tenotomy
23	2	39	F	Left	48	36	Pain in flexion, bicycle test	Iliopsoas tenotomy

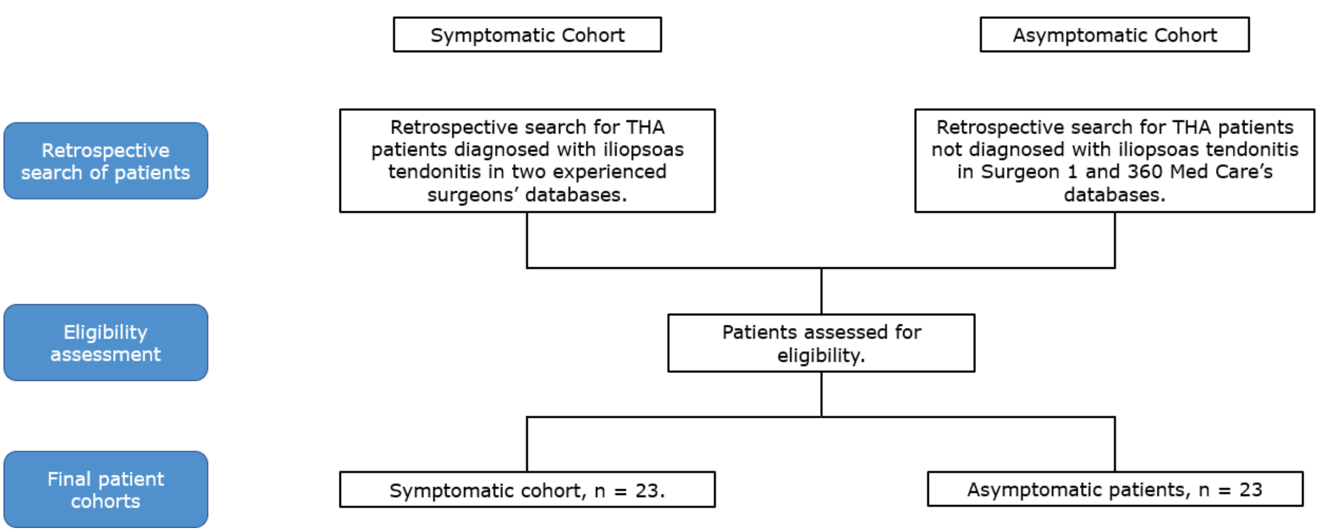

Fig. 1

Flowchart of the patient selection process for the symptomatic cohort, which includes patients who were diagnosed with iliopsoas tendonitis, and asymptomatic cohort, which includes patients who were not diagnosed with iliopsoas tendonitis. THA, total hip arthroplasty.

screws or cement,[4,6] excessive increases in offset or leg lengthening,[7] an overhanging femoral collar,[8] or large diameter femoral heads.[9-13] However, it is most frequently attributed to an anteriorly exposed acetabular component resulting from retroversion, lateralization, or oversizing of the component.[14-16]

The incidence of iliopsoas tendonitis and postoperative groin pain is reported to be up to 29% of patients

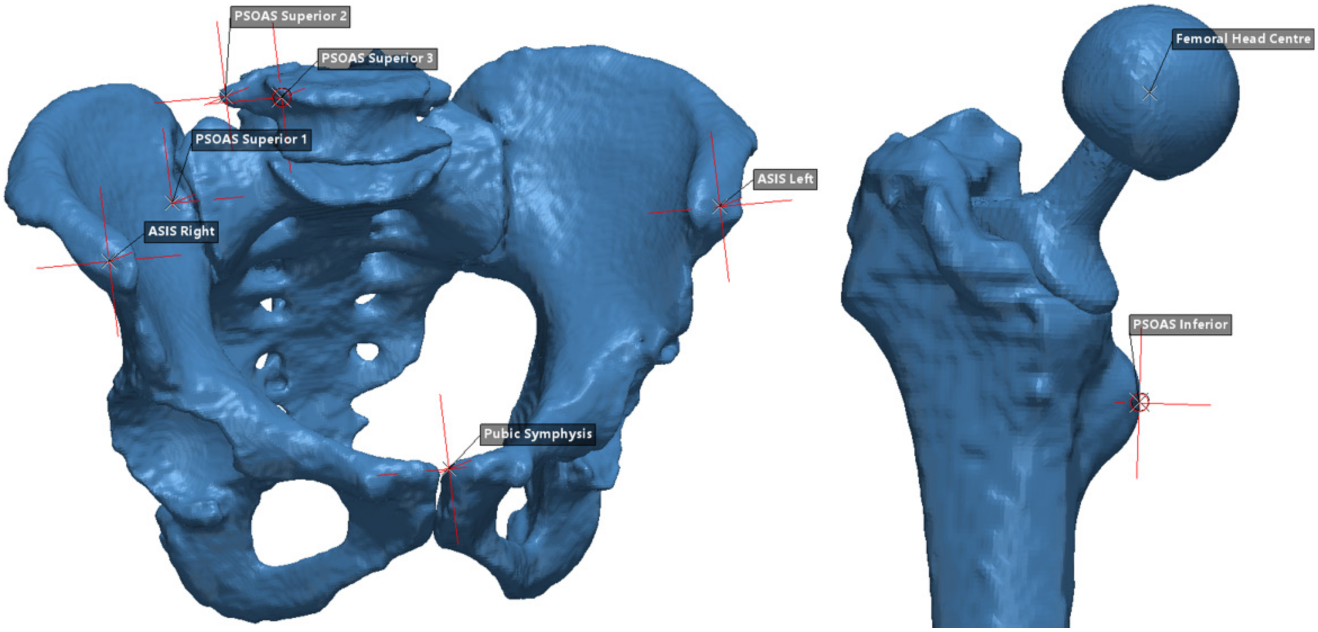

Fig. 2

Illustration of the landmarks taken for the simulation. The anterior superior iliac spine (ASIS) points and pubic symphysis form the anterior pelvic plane (APP) and allow calculation of the supine pelvic tilt. Psoas Superior 1 to 3 and Psoas Inferior represent the 'attachment sites' of the iliopsoas. The femoral head centre was used as the point at which the pelvis rotates around.

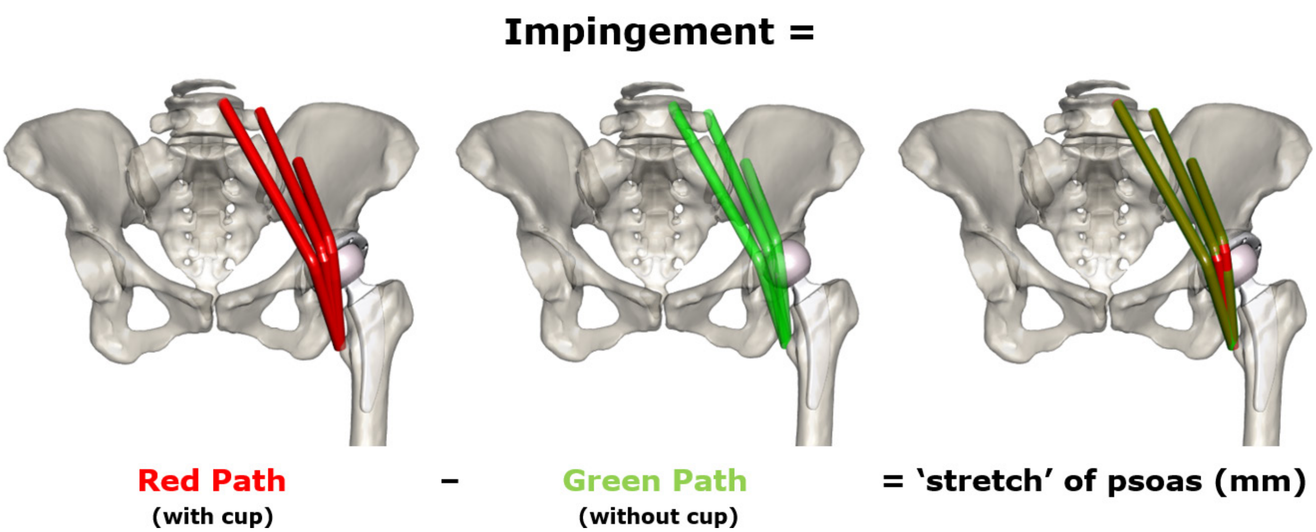

Fig. 3

Schematic of the iliopsoas impingement simulation in a patient's standing pelvic position. Three segments were chosen as they approximate the width of the iliopsoas and the location it passes over the acetabular margin. These segments are composed of two paths: a green and a red path. The green path does not include the cup and the red path does. The difference between these paths is equal to the impingement, and could be considered the 'stretch' of the iliopsoas due to the cup.

after THA,[4,7,9,14,17-19] and up to 32% of patients after hip resurfacing arthroplasty (HRA).[9,11,19] It should be noted that several of the most frequently cited papers investigating the incidence of iliopsoas impingement after THA have found the incidence to be below 5%.[7,14,17] However, these studies were limited by small samples of symptomatic patients,[7,14,17] were retrospective,[7,14,17] and are now two decades old.[7,14] Large variability in rates of reported incidence may be explained by the heterogeneity with regard to the duration of follow-up and varying criteria of pain for inclusion.[20] Therefore, it may be that the true and current incidence of iliopsoas impingement is unknown, particularly given the widespread adoption of larger diameter femoral heads and different surgical approaches in recent years.[10,13,21,22]

Table II. Implant, patient, cup prominence, and iliopsoas impingement results for both cohorts of patients.

Variable	Cohort	Mean	Range	SD	p-value
APP inclination	Symptomatic	43.4	30.3 to 59.5	7.1	NS*
	Asymptomatic	42.7	34.1 to 55.2	4.9	
APP anteversion	Symptomatic	18.0	-16.4 to 45.0	11.3	NS*
	Asymptomatic	20.0	1.4 to 36.3	8.0	
Supine pelvic tilt	Symptomatic	2.1	-15.1 to 15.5	7.2	NS*
	Asymptomatic	2.7	-6.0 to 9.4	4.0	
Standing pelvic tilt	Symptomatic	-3.3	-19.8 to 13.3	7.9	NS*
	Asymptomatic	-4.5	-14.8 to 3.3	4.7	
Head size	Symptomatic	35.7	28 to 48	6.1	NS†
	Asymptomatic	33.5	22 to 36	3.4	
Cup size	Symptomatic	52.0	48 to 62	4.3	NS†
	Asymptomatic	51.7	48 to 60	3.2	
Cup prominence	Symptomatic	9.1	0 to 18.5	3.9	0.006*
	Asymptomatic	5.7	0 to 13.1	4.0	
Supine mean impingement	Symptomatic	0.3	0.0 to 1.8	0.4	0.001*
	Asymptomatic	0.0	0.0 to 0.1	0.0	
Standing mean impingement	Symptomatic	0.4	0.0 to 2.1	0.5	0.001*
	Asymptomatic	0.0	0.0 to 0.1	0.0	
Supine maximum impingement	Symptomatic	0.7	0.0 to 3.7	0.8	0.002*
	Asymptomatic	0.0	0.0 to 0.2	0.0	
Standing maximum impingement	Symptomatic	0.7	0.0 to 4.2	0.9	0.001*
	Asymptomatic	0.0	0.0 to 0.2	0.0	

*Independent-samples *t*-test.
†Chi-squared test.
NS, not significant; SD, standard deviation.

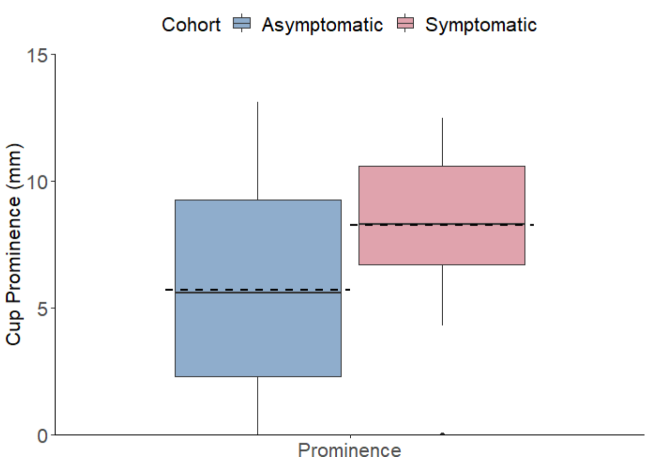

Fig. 4

Cup prominence results for the symptomatic and asymptomatic cohorts. The symptomatic cohort had significantly greater cup prominence values. The edges of the box represent the 25th and 75th percentiles, the solid line within the box represents the median, the dashed line represents the mean, the lines represent the ranges, and the dot represents an outlier

Despite its relatively high incidence, iliopsoas tendonitis is difficult to diagnose with certainty, can require multiple iterations of treatment, and is lacking in attempts to computationally model. As far as the authors are aware, only one previous study has attempted to quantify impingement between the iliopsoas and cup.[23] This in vitro cadaveric study concluded that impingement increased as cup anteversion decreased, and offset head centre cups with anterior recess reduced iliopsoas impingement.[23] However, being a cadaveric study, it had several limitations. First, the authors could not determine whether the impingement between the iliopsoas and acetabular component would result in irritation and groin pain. Second, the iliopsoas was simplified as a single wire and wire clearance was used as a proxy for impingement. Finally, the study did not assess if and by how much the impingement altered in functional positions.

We sought to develop an in-silico model that could quantify impingement between the acetabular component and iliopsoas and then validate its utility by simulating impingement in a case-controlled investigation of symptomatic and asymptomatic patients. The secondary aim was to identify anatomical and surgical parameters that correlate with impingement. Our primary hypothesis was that the simulation, using anatomical and kinematic information about the pelvis, femur, and acetabular component, would detect a significantly greater level of iliopsoas impingement in the symptomatic cohort. Our secondary hypothesis was that the simulation would be a better predictor of iliopsoas tendonitis than the traditional cup prominence measurement.

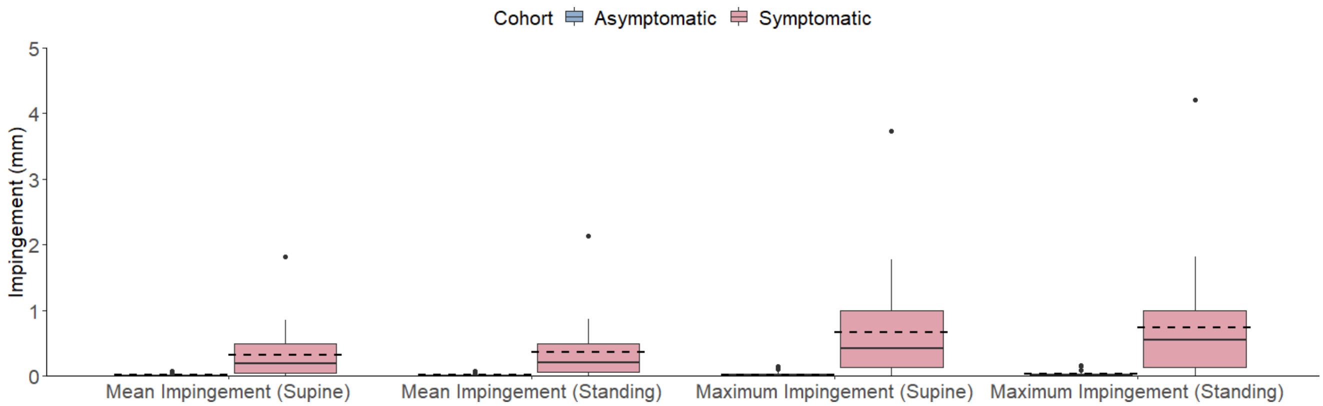

Fig. 5

Mean and maximum impingement results for the symptomatic and asymptomatic cohorts in supine and standing positions. The symptomatic cohort had significantly greater mean and maximum impingement values in both standing and supine.

Table III. Logistic regression model for predicting the probability of iliopsoas tendonitis with cup prominence.

Parameter	SE	Coefficient	p-value
Intercept	0.75	-1.68	0.024
Cup prominence	0.09	0.23	0.013

SE, standard error.

Table IV. Logistic regression model for predicting the probability of iliopsoas tendonitis with standing mean impingement.

Parameter	SE	Coefficient	p-value
Intercept	0.50	-1.50	0.003
Standing mean impingement	11.90	27.94	0.019

SE, standard error.

Table V. Logistic regression model for predicting the probability of iliopsoas tendonitis with standing maximum impingement.

Parameter	SE	Coefficient	p-value
Intercept	0.51	-1.2	0.003
Standing maximum impingement	5.26	12.42	0.018

SE, standard error.

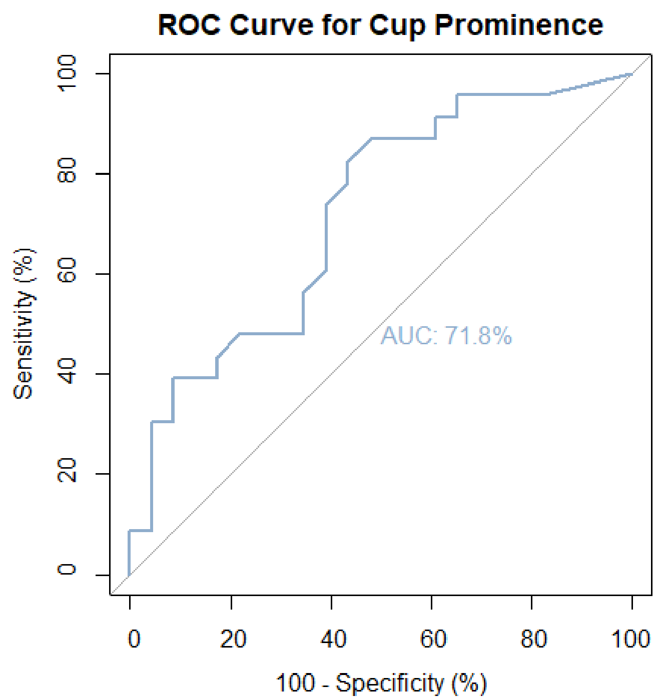

Fig. 6

Receiver operating characteristic (ROC) curve for the cup prominence logistic regression model. AUC, area under the curve.

Methods

This was a retrospective cohort study comparing iliopsoas impingement between a cohort of symptomatic patients who were diagnosed with iliopsoas tendonitis after THA surgery, and a cohort of asymptomatic patients who were not diagnosed with iliopsoas tendonitis after THA. The primary outcome was a difference in detected impingement values. Secondary outcomes were differences in cup prominence, cup size, pelvic tilt, and cup orientation. This retrospective study was approved by the Bellberry Human Research Ethics Committee (study number 201203710).

Patient population. A retrospective search for THA patients who were diagnosed with iliopsoas tendonitis was conducted in two experienced surgeons' (WLW and JB) databases. Inclusion criteria were that patients had undergone primary THA with postoperative CT imaging, postoperative standing radiograph, minimum six months' follow-up, and to have a hemispherical acetabular component implanted. Exclusion criteria included hip resurfacing implants, metal-on-metal (MoM) implants, and dual-mobility cups. After application of inclusion and exclusion criteria to these

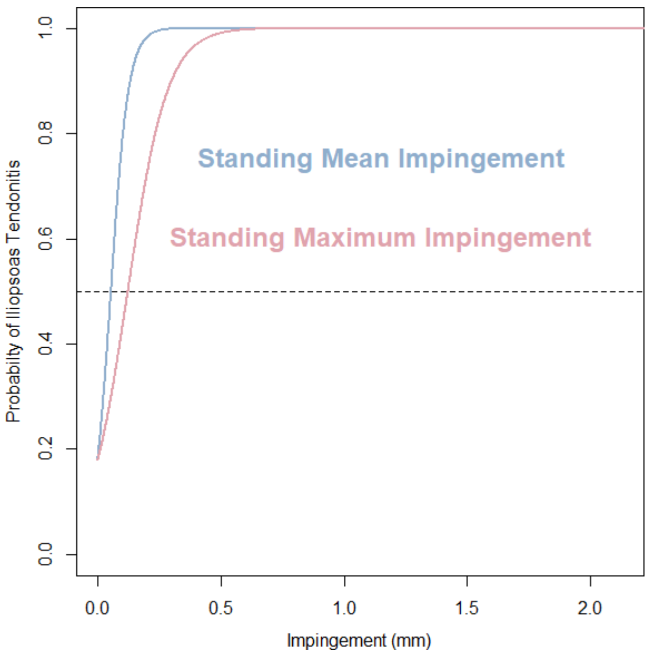

Fig. 7

Logistic regression models for standing mean and standing maximum impingement to predict iliopsoas tendonitis. Both significantly predicted the probability of iliopsoas tendonitis ($p = 0.019$ and $p = 0.018$, respectively).

database searches, 23 patients remained. The details of this patient cohort can be found in Table I.

The asymptomatic cohort similarly consisted of 23 patients. A total of 14 of these patients were randomly selected from Surgeon 1's database of patients after ensuring that they were not diagnosed with postoperative iliopsoas tendonitis and met the inclusion and exclusion criteria. The remaining nine patients were randomly selected from a database of patients referred to 360 Med Care for postoperative THA analysis for non-groin pain-related causes, ensuring they also met the inclusion and exclusion criteria. A flowchart of the retrospective cohort selection process can be found in Figure 1.

Diagnosis of iliopsoas tendonitis. Prior to both surgeons' clinical examination and diagnosis of iliopsoas tendonitis, a patient history was taken with patients indicating groin pain with active hip flexion activities, such as pain lifting their leg onto a bed or into a car. Patients also often reported groin pain with sneezing or coughing.

Diagnosis for Surgeon 1 was confirmed via the active hip flexion test in supine. Diagnostic criteria included no pain at rest, no pain with passive flexion of 10°, and pain with active flexion of 10° with a straight leg raise. The same tests were performed in seated without flexion as a secondary confirmation.

Diagnosis of iliopsoas tendonitis for Surgeon 2 was similarly confirmed via clinical examination of the patient. Pain at flexion in a bicycle test indicated anterior impingement between the iliopsoas and acetabular component leading to inflammation. Pain from an apprehension test (extension and external rotation) or at extension in the bicycle test indicated the iliopsoas may be functioning as an anterior stabilizer to the hip joint, causing overuse and irritation of the iliopsoas.

Generation and landmarking of 3D models of the bony anatomy and prostheses. All CT scans had a Z-direction pixel thickness of 1.25 to 1.5 mm and in-plane resolution of 0.8 to 1 mm × 0.8 to 1 mm. Segmenting and landmarking was performed in ScanIP R-2020.09 (Synopsys, USA) to generate 3D models of the patients' bony anatomy and prostheses with quality checks of the segmentation and landmarks by qualified surgical planning engineers to ensure accuracy. Segmentation was performed semi-automatically using in-built functions augmented with manual segmentation to finalize the models. The 3D models included the pelvis, operative femur, acetabular component, and femoral stem. A hemispherical cup was registered to all acetabular cups to reduce inaccuracies associated with flare in the CT distorting the segmented model.

Landmarks (Figure 2) were taken manually of the patient's left and right anterior superior iliac spine (ASIS), left and right pubic symphysis (PS), the femoral head centre, three superior iliopsoas attachment sites, and one inferior iliopsoas attachment site. The ASIS and PS points were taken to determine the patient's anterior pelvic plane (APP), which was used to measure their supine pelvic tilt and reference the cup orientation to. The iliopsoas insertion sites included one point on the lateral superior plateau of the patient's L5 vertebrae, the lateral-most point on the patient's L5 transverse process, a point approximately 3 to 5 mm lateral of the patient's sacroiliac joint, and the medial-most point of the patient's lesser trochanter (LT).

Simulating iliopsoas impingement. The simulation, which was developed in R Studio v1.3.1903 (USA), began by importing the bony and prosthetic 3D models in their supine (CT) positions. A representation of the iliopsoas was generated with a novel algorithm by tracing the shortest path from each superior attachment site around the acetabular margin of the pelvis to the inferior attachment site. These three points were chosen as they provided a reproducible and accurate representation of the width of the iliopsoas and the location it passes over the acetabular margin.[24]

Each segment was composed of two paths: a green path and a red path. The green path did not include the acetabular component and the red path did. Impingement, which could be considered the 'stretch' of the iliopsoas due to the acetabular component, was calculated as the difference in lengths of the green and red paths for each segment (Figure 3). Therefore, in cases with no iliopsoas impingement, the path lengths were

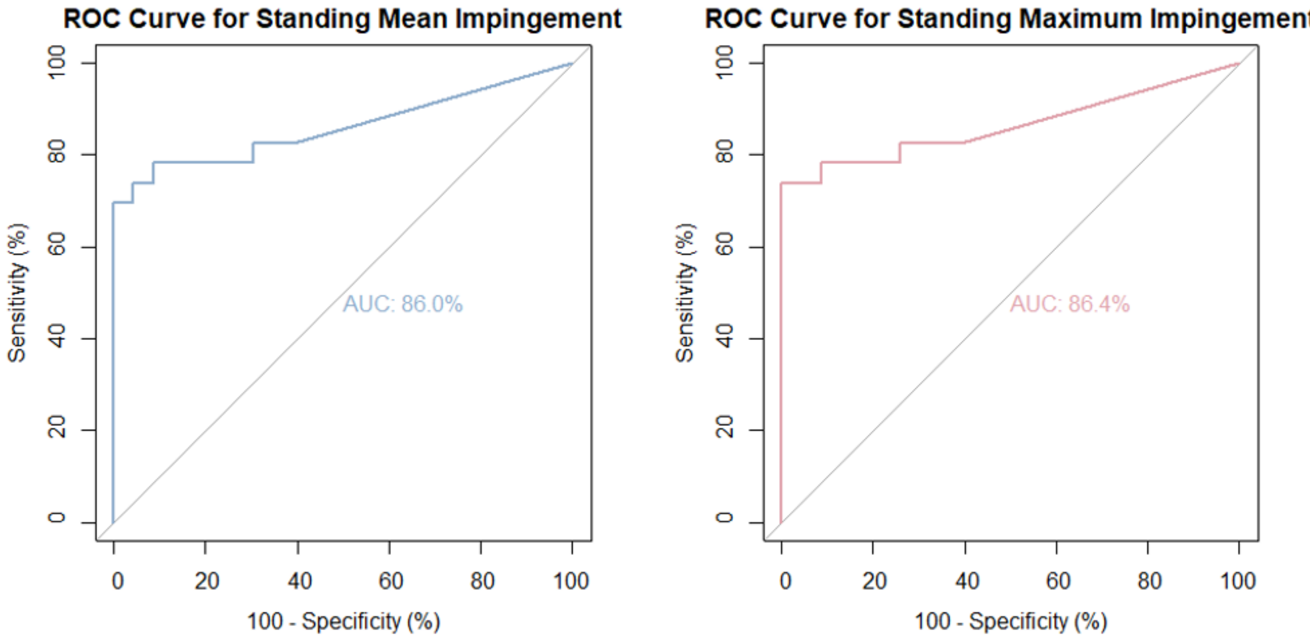

Fig. 8

Receiver operating characteristic (ROC) curves for the standing mean impingement and standing maximum impingement logistic regression models. AUC, area under the curve.

of equal length. In cases with impingement, the red path was lengthened relative to the green path.

Three separate impingement values (one for each segment) were calculated in supine and reported as the mean and maximum of these values: supine mean impingement and supine maximum impingement. The pelvis was then rotated to its standing pelvic orientation using the difference in supine and standing pelvic tilts, and the same impingement detection algorithm was performed. These standing impingement values were reported as standing mean impingement and standing maximum impingement.

Calculating cup prominence. Cup prominence was measured using the same method proposed by Cyteval et al[25] as the most protruded length of acetabular component that was exposed anteriorly on 2D CT images in the axial plane.

Statistical analysis and power calculation. Statistical analysis was performed in R Studio. An α value of 0.05 was used to determine clinical significance. Two-way, independent-samples *t*-tests were used to determine significant difference for continuous variables and chi-squared tests for categorical variables. Logistic regression models were used to test if cup prominence, standing mean impingement, or standing maximum impingement values predicted the probability of iliopsoas tendonitis. Receiver operator characteristic (ROC) curves were generated to determine the simulation's area under the curve (AUC) and optimal predictive threshold for sensitivity and specificity. A post hoc power calculation with an α of 0.05 determined that samples of 23 patients in each cohort had a power of 95% to detect a difference in maximum impingement of 0.75 mm. The final sample sizes were therefore deemed sufficient.

Results

No statistically significant difference between symptomatic and asymptomatic cohorts was found for cup anteversion, cup inclination, cup size, femoral head size, supine pelvic tilt, or standing pelvic tilt (Table II). The mean cup prominence for the symptomatic cohort was 9.1 mm (standard deviation (SD) 3.9) and 5.7 mm (SD 4.0) for the asymptomatic cohort. The difference was statistically significant ($p = 0.006$, independent-samples *t*-test) (Figure 4). The mean supine impingement for the symptomatic cohort was 0.3 mm (SD 0.4) and 0.0 mm (SD 0.0) for the asymptomatic cohort. The difference was statistically significant ($p = 0.001$, independent-samples *t*-test). The mean standing impingement for the symptomatic cohort was 0.4 mm (SD 0.5) and 0.0 mm (SD 0.0) for the asymptomatic cohort. The difference was statistically significant ($p = 0.001$, independent-samples *t*-test). The mean supine maximum impingement for the symptomatic cohort was 0.7 mm (SD 0.8) and 0.0 mm (SD 0.0) for the asymptomatic cohort. The difference was statistically significant ($p = 0.001$, independent-samples *t*-test). The average standing maximum impingement for the symptomatic cohort was 0.7 mm (SD 0.9) and 0.0 mm (SD 0.0) for the asymptomatic cohort. The difference was statistically significant (p = 0.001, independent-samples *t*-test) (Figure 5).

Cup prominence (p = 0.024) significantly predicted the probability of iliopsoas tendonitis in a logistic regression model (Table III). The optimal cut-off point for cup prominence as a predictor of iliopsoas tendonitis was 6.50 mm. Using this cut-off point, the logistic regression model showed a sensitivity of 83%, specificity of 57%, and an AUC of 0.72 (Figure 6).

Standing mean impingement (p = 0.019) and standing maximum impingement (p = 0.018) significantly predicted the probability of iliopsoas tendonitis in logistic regression models (Figure 7, Table IV, and Table V). The optimal cut-off point for mean impingement as a predictor of iliopsoas tendonitis was 0.04 mm (Figure 8). Using this cut-off point, the logistic regression model showed a sensitivity of 78%, specificity of 91%, and an AUC of 0.86. The optimal cut-off point for maximum impingement as a predictor of iliopsoas tendonitis was 0.16 mm (Figure 8). Using this cut-off point, the logistic regression model showed a sensitivity of 74%, specificity of 100%, and an AUC of 0.86.

Discussion

We have demonstrated that our novel simulation can detect symptomatic iliopsoas tendonitis via a retrospective, case-controlled investigation with the symptomatic patients exhibiting significantly greater levels of simulated impingement. Impingement measured by our simulation was also a stronger predictor of iliopsoas tendonitis than the conventional cup prominence measurement.

We found similar levels of cup prominence in the symptomatic cohort to previous investigations into patients with iliopsoas tendonitis.[6,25-27] However, as illustrated through the logistic regression models, cup prominence did not predict iliopsoas tendonitis as well as our simulation. This may be due to inaccuracies associated with taking measurements on 2D slices from CT studies to investigate 3D structures.[28,29] For example, despite several patients in the asymptomatic cohort having relatively high cup prominence values, no impingement between the iliopsoas and cup was observed in these patients. This indicated that the simulation could differentiate between cup prominence that results in impingement and cup prominence that does not. These findings are likely due to these patients' combined pelvic and femoral kinematics preventing the iliopsoas from impinging with the acetabular component. If this belief is correct, it would shed light on the kinematic relevance of spinopelvic and pelvic-femoral motion to iliopsoas irritation.

Interestingly, three symptomatic patients had no impingement detected by the simulation ('false negatives') but relatively high cup prominence values and very large diameter femoral heads (> 40 mm) with monoblock cups. In these cases, the femoral head was preventing the iliopsoas and cup from impinging by 'lifting' the iliopsoas off the exposed cup. Despite no impingement between the iliopsoas and cup, these patients were still diagnosed with iliopsoas tendonitis and there may be multiple other reasons for their diagnosis. First, large diameter femoral heads may irritate the iliopsoas by 'stretching' it.[9,10,13] Second, a high combined functional anteversion may lead the iliopsoas to function as an 'anterior stabilizer' to the prosthetic joint, causing overuse and irritation,[4,30,31] or leading to posterior prosthetic impingement that irritates the iliopsoas through repeated anterior micro-instability. Third, there may have been excessive lengthening or offset changes made intraoperatively.[7] The existence of these patients led to the baseline risk of approximately 18% chance of iliopsoas tendonitis after THA, despite zero impingement. This reflects the multicausal nature of postoperative groin pain, which may be caused by reasons other than impingement with the cup.[4,6-13] Similarly, four asymptomatic patients had very little impingement (< 0.15 mm) detected by the simulation ('false positives'), which may indicate a threshold level of impingement for irritation to occur or may represent the margin of error of the simulation.

Our study had several limitations. First, the retrospective nature of the study meant that not all patients had the requisite imaging, necessitating exclusion from the study. The retrospective nature of the study also presented limitations regarding the lack of preoperative data. After removal of the native femoral head and insertion of the femoral and acetabular components from THA surgery, the pathway traced by the iliopsoas will change, and the extent of this change may also be a contributing factor to the onset of tendonitis. For example, it is known that excessive lengthening at the hip or changes to offset can irritate the iliopsoas;[7] however, there may be other pre- to postoperative changes that also irritate the iliopsoas, such as changes in functional femoral rotation. The availability of preoperative CT scans would have allowed for simulation of the preoperative iliopsoas and comparison to the postoperative iliopsoas, which might have given insight into the other sources of tendonitis. Second, sample size-related limitations are likely the reason for not observing a statistically significant difference in cup anteversion or cup size, as these have been shown to be a risk factor for iliopsoas impingement.[21] Third, although we did report the treatment for the symptomatic patients, we did not report on the outcomes and success of these treatments. Approaches to treating iliopsoas tendonitis are well documented in previous literature, and this was not an objective of the study. However, an investigation of the relationship between the level of impingement and the success of different treatments paths may be warranted. Finally, we did not address changes in functional femoral rotation from supine to standing, which has been shown to have significant variation.[32,33]

Further research may involve investigating the impingement values in cohorts of symptomatic and asymptomatic patients with hip resurfacing arthroplasties. This may provide insight into differing mechanisms of groin pain as these two operations have been reported to have significantly different incidences of groin pain.[7,9,11,12,14,17] However, ultimately, the ambition for this simulation is to assist with preoperative planning for THAs by guiding decisions about optimal cup placement in concert with other tools, such as prosthetic and bony impingement simulations.

In conclusion, we have developed a computational model that can quantify impingement and verified its accuracy in a case-controlled investigation by simulating impingement in symptomatic and asymptomatic patients. However, iliopsoas tendonitis is also a complex issue and not simply related to acetabular component exposure. This tool has the potential to be used preoperatively, to guide decisions about optimal cup placement, and postoperatively, to aid in the diagnosis of iliopsoas tendonitis and determine an appropriate treatment pathway.

Take home message

- Iliopsoas tendonitis is a relatively common complication after total hip arthroplasty, and is most frequently attributed to impingement between the iliopsoas and acetabular cup.
- We have developed a simulation that can detect impingement between the iliopsoas and cup, and validated it in a case-controlled investigation.
- This simulation has the potential to be used in preoperative planning to optimize cup positioning.

References

1. **Learmonth ID**, **Young C**, **Rorabeck C**. The operation of the century: total hip replacement. *Lancet*. 2007;370(9597):1508–1519.
2. **Beswick AD**, **Wylde V**, **Gooberman-Hill R**, **Blom A**, **Dieppe P**. What proportion of patients report long-term pain after total hip or knee replacement for osteoarthritis? A systematic review of prospective studies in unselected patients. *BMJ Open*. 2012;2(1):e000435.
3. **Scott CEH**, **Bugler KE**, **Clement ND**, **MacDonald D**, **Howie CR**, **Biant LC**. Patient expectations of arthroplasty of the hip and knee. *J Bone Joint Surg Br*. 2012;94(7):974–981.
4. **Zhu J**, **Li Y**, **Chen K**, **et al**. Iliopsoas tendonitis following total hip replacement in highly dysplastic hips: A retrospective study. *J Orthop Surg Res*. 2019;14(1):145.
5. **Capogna BM**, **Shenoy K**, **Youm T**, **Stuchin SA**. Tendon disorders after total hip arthroplasty: evaluation and management. *J Arthroplasty*. 2017;32(10):3249–3255.
6. **Dora C**, **Houweling M**, **Koch P**, **Sierra RJ**. Iliopsoas impingement after total hip replacement: the results of non-operative management, tenotomy or acetabular revision. *J Bone Joint Surg Br*. 2007;89-B(8):1031–1035.
7. **Ala Eddine T**, **Remy F**, **Chantelot C**, **Giraud F**, **Migaud H**, **Duquennoy A.** Anterior iliopsoas impingement after total hip arthroplasty: Diagnosis and conservative treatment in 9 cases. Rev Chir Orthopédique Réparatrice Appar Mot 2002;87:815–819.
8. **Brew CJ**, **Stockley I**, **Grainger AJ**, **Stone MH**. Iliopsoas tendonitis caused by overhang of a collared femoral prosthesis. *J Arthroplasty*. 2011;26(3):504.
9. **Bartelt RB**, **Yuan BJ**, **Trousdale RT**, **Sierra RJ**. The prevalence of groin pain after metal-on-metal total hip arthroplasty and total hip resurfacing. *Clin Orthop Relat Res*. 2010;468(9):2346–2356.
10. **Cobb JP**, **Davda K**, **Ahmad A**, **Harris SJ**, **Masjedi M**, **Hart AJ**. Why large-head metal-on-metal hip replacements are painful: the anatomical basis of psoas impingement on the femoral head-neck junction. *J Bone Joint Surg Br*. 2011;93(7):881–885.
11. **Bin Nasser A**, **Beaulé PE**, **O'Neill M**, **Kim PR**, **Fazekas A**. Incidence of groin pain after metal-on-metal hip resurfacing. *Clin Orthop Relat Res*. 2010;468(2):392–399.
12. **Lavigne M**, **Laffosse JM**, **Ganapathi M**, **Girard J**, **Vendittoli P**. Residual groin pain at a minimum of two years after metal-on-metal THA with a twenty-eight-millimeter femoral head, THA with a large-diameter femoral head, and hip resurfacing. *J Bone Joint Surg Am*. 2011;93 Suppl 2:93–98.
13. **Browne JA**, **Polga DJ**, **Sierra RJ**, **Trousdale RT**, **Cabanela ME**. Failure of larger-diameter metal-on-metal total hip arthroplasty resulting from anterior iliopsoas impingement. *J Arthroplasty*. 2011;26(6):978.
14. **Bricteux S**, **Beguin L**, **Fessy MH**. Iliopsoas impingement in 12 patients with a total hip arthroplasty. *Rev Chir Orthop Reparatrice Appar Mot*. 2001;87(8):820–825.
15. **Trousdale RT**, **Cabanela ME**, **Berry DJ**. Anterior iliopsoas impingement after total hip arthroplasty. *J Arthroplasty*. 1995;10(4):546–549.
16. **Odri GA**, **Padiolleau GB**, **Gouin FT**. Oversized cups as a major risk factor of postoperative pain after total hip arthroplasty. *J Arthroplasty*. 2014;29(4):753–756.
17. **O'Sullivan M**, **Tai CC**, **Richards S**, **Skyrme AD**, **Walter WL**, **Walter WK**. Iliopsoas tendonitis a complication after total hip arthroplasty. *J Arthroplasty*. 2007;22(2):166–170.
18. **Buller LT**, **Menken LG**, **Hawkins EJ**, **et al**. Iliopsoas impingement after direct anterior approach total hip arthroplasty: epidemiology, risk factors, and treatment options. *J Arthroplasty*. 2021;36(5):1772–1778.
19. **Nam D**, **Nunley RM**, **Sauber TJ**, **Johnson SR**, **Brooks PJ**, **Barrack RL**. Incidence and location of pain in young, active patients following hip arthroplasty. *J Arthroplasty*. 2015;30(11):1971–1975.
20. **Henderson RA**, **Lachiewicz PF**. Groin pain after replacement of the hip: aetiology, evaluation and treatment. *J Bone Joint Surg Br*. 2012;94-B(2):145–151.
21. **Buller LT**, **Menken LG**, **Hawkins EJ**, **et al**. Iliopsoas impingement after direct anterior approach total hip arthroplasty: Epidemiology, risk factors, and treatment options. *J Arthroplasty*. 2021;36(5):1772–1778.
22. **Meermans G**, **Konan S**, **Das R**, **Volpin A**, **Haddad FS**. The direct anterior approach in total hip arthroplasty: a systematic review of the literature. *Bone Joint J*. 2017;99-B(6):732–740.
23. **Ries M**, **Faizan A**, **Zhang J**, **Scholl L**. Effects of acetabular cup orientation and implant design on psoas impingement in total hip arthroplasty. *ReconRev*. 2019;9.
24. **Nakano N**, **Yip G**, **Khanduja V**. Current concepts in the diagnosis and management of extra-articular hip impingement syndromes. *Int Orthop*. 2017;41(7):1321–1328.
25. **Cyteval C**, **Sarrabère MP**, **Cottin A**, **et al**. Iliopsoas impingement on the acetabular component: radiologic and computed tomography findings of a rare hip prosthesis complication in eight cases. *J Comput Assist Tomogr*. 2003;27(2):183–188.
26. **Brownlie CA**, **Evans R**, **Morrison D**, **Hayes A**, **Song S**, **Kuster MS**. Improved accuracy of CT based measurements for anterior prominence of acetabular prosthesis using a novel protocol based on anatomical landmarks. *Orthop Traumatol Surg Res*. 2020;106(3):563–568.
27. **Chalmers BP**, **Sculco PK**, **Sierra RJ**, **Trousdale RT**, **Berry DJ**. Iliopsoas impingement after primary total hip arthroplasty: operative and nonoperative treatment outcomes. *J Bone Joint Surg Am*. 2017;99-A(7):557–564.
28. **Sugano N**, **Noble PC**, **Kamaric E**. A comparison of alternative methods of measuring femoral anteversion. *J Comput Assist Tomogr*. 1998;22(4):610–614.
29. **Kim JS**, **Park TS**, **Park SB**, **Kim JS**, **Kim IY**, **Kim SI**. Measurement of femoral neck anteversion in 3D. Part 2: 3D modelling method. *Med Biol Eng Comput*. 2000;38(6):610–616.
30. **Fabricant PD**, **Bedi A**, **De La Torre K**, **Kelly BT**. Clinical outcomes after arthroscopic psoas lengthening: the effect of femoral version. *Arthroscopy*. 2012;28(7):965–971.
31. **Jacobsen JS**, **Hölmich P**, **Thorborg K**, **et al**. Muscle-tendon-related pain in 100 patients with hip dysplasia: prevalence and associations with self-reported hip disability and muscle strength. *J Hip Preserv Surg*. 2018;5(1):39–46.
32. **Hardwick-Morris M**, **Twiggs J**, **Kacker K**, **Miles B**, **Balakumar J**. Functional femoral anteversion: Axial rotation of the femur and its implications for stem version targets in total hip arthroplasty. *Arthroplast Today*. 2022;18:16–23.
33. **Uemura K**, **Takao M**, **Otake Y**, **et al**. Can anatomic measurements of stem anteversion angle be considered as the functional anteversion angle? *J Arthroplasty*. 2018;33(2):595–600.

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Funding statement:
- The authors received no financial or material support for the research, authorship, and/or publication of this article.

ICMJE COI statement:
- M. Hardwick-Morris and J. Twiggs are employees of 360 Med Care and Enovis, who supported this research. B. Miles declares consulting fees and stock/stock options from 360 Med Care, which are related; stock/stock options, royalties, and an employee of Enovis, which are related; grants or contracts from NSW Health Medical Device Fund, Australian Tax Office, AusIndustry, and Johnson & Johnson; royalties from Corin; consulting fees from Johnson & Johnson, all of which are unrelated. J. Twiggs and B. Miles also declares several patents. R. M. A. Al-Dirini and M. Taylor's research institutions receive funding and research support from 360 Med Care. J. Balakumar reports stock options in 360 Med Care (related to this study); royalties or licenses from Medacta; consulting fees from Medacta and Stryker; and speaker payments from Medacta, Stryker, and Johnson & Johnson (all unrelated to this study). W. L. Walter declares stock options in 360 Med Care (related to this study); and reports royalties from MatOrtho; speaker payments from Smith & Nephew, Johnson & Johnson, and MatOrtho; stock or stock options in Navbit (all unrelated to this study); and a leadership or fiduciary role on the HSS Journal.

Acknowledgements:
- The authors would like to acknowledge 360 Med Care and Enovis for their support of this research and Yuan Chai for his assistance with data curation.

Ethical review statement:
- This study was approved by the Bellberry Human Research Ethics Committee (study number 201203710).

Open access funding
- The authors confirm that the open access fee for this study was self-funded.