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HIP

Defining the optimal position of the lipped liner in combination with cup orientation and stem version

A KINEMATIC MODEL ANALYSIS

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Aims

The aim of this study was to identify the optimal lip position for total hip arthroplasties (THAs) using a lipped liner. There is a lack of consensus on the optimal position, with substantial variability in surgeon practice.

Methods

A model of a THA was developed using a 20° lipped liner. Kinematic analyses included a physiological range of motion (ROM) analysis and a provocative dislocation manoeuvre analysis. ROM prior to impingement was calculated and, in impingement scenarios, the travel distance prior to dislocation was assessed. The combinations analyzed included nine cup positions (inclination 30-40-50°, anteversion 5-15-25°), three stem positions (anteversion 0-15-30°), and five lip orientations (right hip 7 to 11 o'clock).

Results

The position of the lip changes the ROM prior to impingement, with certain combinations leading to impingement within the physiological ROM. Inferior lip positions (7 to 8 o'clock) performed best with cup inclinations of 30° and 40°. Superior lip positions performed best with cup inclination of 50°. When impingement occurs in the plane of the lip, the lip increases the travel distance prior to dislocation. Inferior lip positions led to the largest increase in jump distance in a posterior dislocation provocation manoeuvre.

Conclusion

The lip orientation that provides optimal physiological ROM depends on the orientation of the cup and stem. For a THA with stem anteversion 15°, cup inclination 40°, and cup anteversion 15°, the optimal lip position was posterior-inferior (8 o'clock). Maximizing jump distance prior to dislocation while preventing impingement in the opposite direction is possible with appropriate lip positioning.

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Introduction

One of the benefits of using highly cross-linked polyethylene (XLPE) liners during hip arthroplasty is the ability to use elevated rim or lipped liners. These asymmetrical liners increase the travel distance of the femoral head before dislocation and therefore can provide better stability.[1] Impingement is a concern with lipped liners, and there has been considerable debate and opinion on whether the benefits of improved stability are outweighed by impingement,[2] the potential of polyethylene wear,[3] and increased torque leading to early loosening.[4] There has been increasing interest in this area, leading to several publications that now show significant improvements in survivorship of the lipped or elevated rim liners compared to that of flat liners, with no increasing risk of loosening.[5-8] The benefits of the lipped

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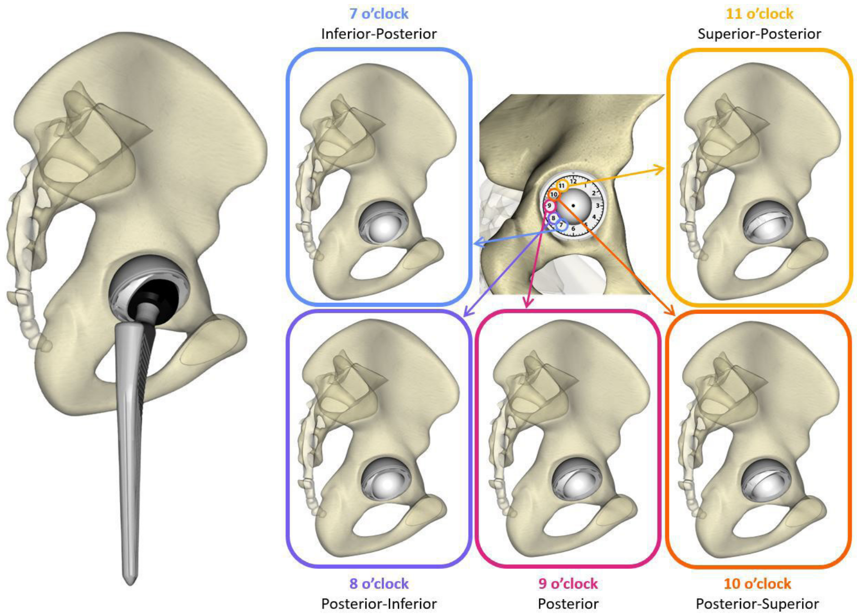

Fig. 1

Computer model of the implanted hip and lip orientations included in the study.

liners are reported to be more pronounced when using the posterior approach compared to the direct lateral, and there is a paucity in the literature at present on their effect in anterior approach total hip arthroplasties (THAs).[8] The significant reduction in dislocation rate may foster an increase in the use of lipped liners. Despite the mounting evidence on the advantages of using lipped liners, controversy remains on the optimal position of the lip. Retrieval studies have shown increased impingement when the elevated rim is placed in the posterior-superior position.[2] The effect of the position of the lip can have a marked effect on the range of motion (ROM) prior to dislocation, as revealed by in vivo and ex vivo studies.[9-11] Therefore, an incorrect position of the lip, due to either cup malpositioning or suboptimal selection of the lip orientation within the cup, might produce impingement and, possibly, dislocation.

The aim of this study was to use a computer model to evaluate the effect of different lip orientations on stability parameters relevant to a THA implanted using a posterior approach. Specifically, the following questions were addressed: 1) Can the lip be oriented to maximize hip physiological ROM before impingement?; 2) What lip orientation maximizes jump distance during provocative dislocation manoeuvres in both anterior and posterior directions?; and 3) Does optimal lip orientation depend on cup and stem orientations?

Methods

Computer model. A computer model of an implanted hip was developed in LifeMOD (Smith+Nephew, USA). The implant model included an R3 acetabular component (48 mm outer diameter), a 20° lipped liner, a 32 mm femoral head of medium length (+ 4 mm), and a POLARSTEM◊ Standard stem size 6 (all Smith+Nephew). Five liner lip orientations were evaluated: inferior-posterior (7 o'clock for a right hip), posterior-inferior (8 o'clock), posterior (9 o'clock), posterior-superior (10 o'clock), and superior-posterior (11 o'clock) (Figure 1).

Implant range of motion. Implant ROM was calculated for each liner orientation as the set of impingement-free implant angles, consistent with the implant impingement diagram displayed in the THA planning software RI.HIP MODELER (Smith+Nephew). Only implant-to-implant impingement was considered. The position of the stem relative to the cup was described with two angles, corresponding to the rotations about two perpendicular axes within the cup opening plane.

Kinematic analyses. Two separate kinematic analyses were performed. First, hip physiological motions based on reference data from Widmer and Zurfluh[12] were evaluated to assess if they would lead to implant impingement: 40° of extension to 130° of flexion, 40° of external rotation to 80° of internal rotation, and 50° of adduction to 50° of abduction (Figure 2). Secondly, two provocative dislocation motions used in clinical assessment were evaluated:[13] flexion to 90° followed by internal rotation until impingement (FLEX + IR), and external rotation until impingement (ER) (Figure 3a). The FLEX + IR and ER provocative tests are clinically relevant motions representative of posterior (e.g. rising from a low chair) and anterior (e.g. pivot manoeuvre) dislocation scenarios, respectively. Acceptable ROMs for the provocative tests were 30° of internal rotation for FLEX + IR according to Widmer[14] and 40° for ER according to Widmer and Zurfluh.[12]

Implant kinematics for these two sets of motions were compared to implant ROM profile (i.e. impingement-free angles) to assess if/when impingement occurred.

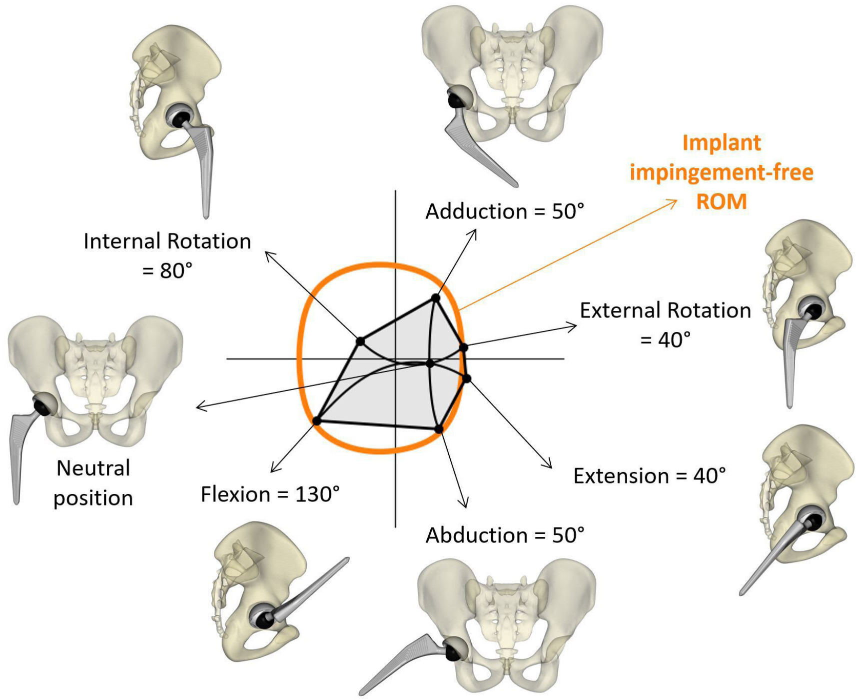

Fig. 2

Hip physiological motions as defined by Widmer and Zurfluh,[12] overlaid with the implant impingement-free range of motion (ROM) to determine impingement occurrence.

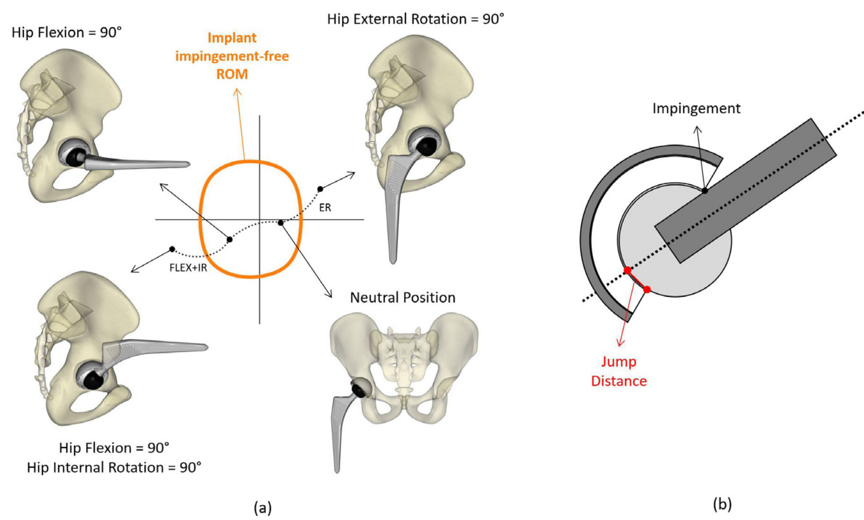

Fig. 3

a) Provocative dislocation manoeuvres as defined by Klemt et al,[13] overlaid with the implant range of motion (ROM) to determine impingement occurrence. b) Jump distance at impingement calculated as the distance between the intersection of the stem neck axis on the liner and the liner edge. ER, external rotation until impingement; FLEX + IR, flexion to 90° followed by internal rotation until impingement.

Implant positions within the implant impingement-free ROM profile do not lead to impingement, whereas implant positions on or outside the ROM profile indicate that impingement occurred.

Output measures. For impinging physiological motions (first set of motions), the amount of rotation prevented by impingement was quantified. For example, if a certain configuration allowed 35° of external rotation, the prevented rotation was 5°, given that the physiological range in external rotation was set to 40°.

For provocative manoeuvres (second set of motions), jump distance at impingement required to dislocate the head was quantified. Jump distance was calculated as the distance between the intersection of the stem neck axis onto the liner internal face and the liner edge (Figure 3). Although jump distance is often calculated

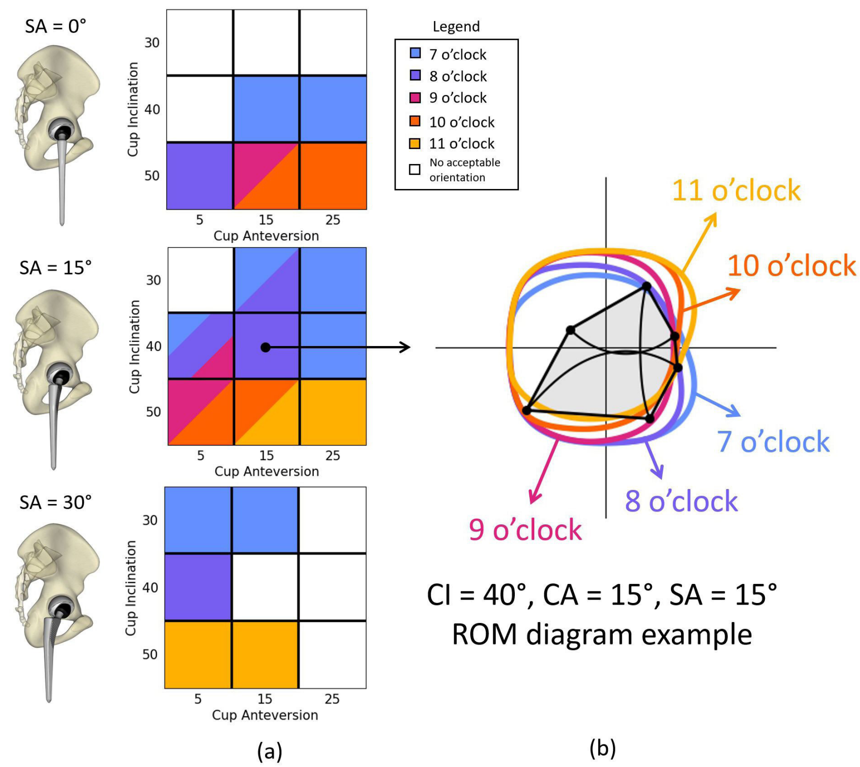

Fig. 4

a) White squares indicate unacceptable cup placements (i.e. all lip orientations limited hip physiological rotations by more than 10°). Coloured squares indicate acceptable combinations, and each square's colour represents the best-performing lip orientation (i.e. providing minimum impingement) according to the legend. Squares with multiple colours indicate that multiple lip orientations were equivalent in terms of impingement during the simulated hip physiological motions. b) Sample results. Hip motions overlaid with implant impingement-free range of motion (ROM) profiles. Refer to Figure 2 for a description of the hip motion extremes represented with the black polygon. The black polygon extremes change position when placement parameters change, whereas the ROM profiles do not change position within the diagram. CA, cup anteversion; CI, cup inclination; SA, stem anteversion.

using the direction of the head-to-liner contact force,[15] it was calculated here using an approximation based on the stem neck axis orientation, since contact force during these motions was not estimated. Since measurements from instrumented implants demonstrated that contact force direction during activities of daily living is closely aligned with the stem neck axis due to the contribution of muscle forces that generate a compressive force on the joint, use of the stem neck axis for jump distance calculation seems a reasonable approximation.[16]

Implant placement combinations. Hip motions were evaluated for a set of implant placements combining the following parameters: cup inclination (30°, 40°, 50°); cup anteversion (5°, 15°, 25°); and stem anteversion (0°, 15°, 30°). Cup placement was implemented according to the radiological definition.[17]

For each implant placement combination, impingement during hip motions and jump distance at impingement were compared between the five lip orientation cases. Lip orientations that prevented hip rotation by more than 10° for at least one hip physiological motion were considered not acceptable. Within the acceptable cases, the lip orientation that provided maximal ROM was determined for each implant placement combination based on two criteria: 1) lower number of hip motions impinging; and 2) lower prevented rotation, if the same number of impinging motions was observed.

Finally, the same analyses were performed for a flat liner to provide a comparative benchmark.

Results

Physiological range of motion analysis. The five liner orientations produced five different ROM profiles (see coloured profiles in Figure 4). Compared to a posterior lip orientation (9 o'clock), the 7 and 8 o'clock lip orientations (more inferior) increased implant ROM in the bottom quadrants of the impingement diagram and decreased ROM in the top quadrants. In contrast, the 10 and 11 o'clock lip orientations (more superior) increased ROM in top quadrants and decreased ROM in the bottom quadrants. The physiological hip motions corresponding to the quadrants of the impingement diagram can be seen in Figure 2.

Acceptable and best liner rotations for each implant placement were determined based on the rotation prevented for each hip motion (Table I). For example, with a stem anteversion of 15°, all but one cup placement presented at least one acceptable lip orientation. These are depicted in Figure 4 and expanded upon in

Table I. Acceptable (indicated by the “x” symbol) and optimal (indicated by “x” symbols in bold font) lip orientations for each implant placement combination. Rows containing multiple "x" symbols in bold font indicate that multiple lip orientations are equivalent in terms of impingement during the simulated hip physiological motions.

Implant placement			Lip orientations					
Stem anteversion	Cup inclination	Cup anteversion	7 o’clock	8 o’clock	9 o’clock	10 o’clock	11 o’clock	Flat liner
0	30	5						
		15						
		25						
	40	5						
		15	**x**	x	x			
		25	**x**	x	x	x		x
	50	5	x	**x**	x	x		x
		15	x	x	**x**	**x**		x
		25	x	x	x	**x**	x	x
15	30	5						
		15	**x**	**x**	x			x
		25	**x**					x
	40	5	**x**	**x**	**x**	x		x
		15	x	**x**	x	x		x
		25	**x**					x
	50	5	x	x	**x**	**x**	x	x
		15		x	x	**x**	**x**	x
		25					**x**	x
30	30	5	**x**	x				
		15	**x**					x
		25						x
	40	5	**x**	x	x	x	x	x
		15						x
		25						x
	50	5			x	x	**x**	x
		15					**x**	x
		25						x

Table I. A total of 18 acceptable cases (prevented hip rotation lower than 10° for at least one lip orientation) were observed within the 27 implant placement combinations.

Inferior (7 and 8 o’clock) lip positions performed best (minimum impingement during physiological ROM) in 11 combinations, mostly with 30° to 40° of cup inclination. The posterior (9 o’clock) lip position performed best in three combinations only with 5° or 15° of cup anteversion. Finally, the superior lip positions (10 and 11 o’clock) performed best in seven cases, only with 50° of cup inclination. The flat liner produced a total of 20 acceptable cases within the 27 implant combinations (Table I).

Provocative dislocation manoeuvre analysis. Results for provocative dislocation manoeuvres are only presented for implant placement cases with stem anteversion of 15°, as relative results for different lip orientation are equivalent when stem anteversion changes.

Altering cup anteversion and inclination has an effect on ROM in posterior and anterior dislocation manoeuvre scenarios. Specifically, ROM for the FLEX + IR provocative manoeuvre changed with cup position (without changing the lip orientation). With a cup position of 30° CI and 5° CA, FLEX + IR ROM was 90° of flexion and 23° of internal rotation (lip at 8 o’clock). With a cup position of 50° CI and 25° CA, the FLEX + IR ROM increased to 90° flexion and 53° internal rotation (lip 8 o’clock). Increasing CI and increasing CA both increase the FLEX + IR ROM. The opposite trend can be seen for the ER (anterior dislocation provocation manoeuvre) ROM. This pattern is further explored in Table II and Figure 5. For the majority of posterior lip positions analyzed (7 o’clock to 10 o’clock), minimal differences (≤ 1°) were observed on FLEX + IR ROM, as the lip is away from the area of impingement. For the same reason, the flat liner presented FLEX + IR ROM practically equivalent to lipped liners. With 15° of stem anteversion, 30° of IR after 90° of flexion was achieved for each cup placement except for the combination with lowest cup angles (CI = 30° and CA = 5°). The 11 o’clock orientation was an exception, which presented a mean decrease of 11° in internal rotation to impingement (Figure 5 and Table I). Posterior lip positions did, however, have an effect on the opposite direction leading to reduced ER ROM prior to impingement compared to the flat liner case. All implant placement combinations except one (96%) achieved the goal of 40° of ER with a flat liner, whereas the acceptable range was

Table II. Rotation at impingement during the FLEX + IR and ER provocative manoeuvres for each lip orientation. Only results with 15° of stem anteversion are included because their relative trend is equivalent for the other two stem anteversion values.

Rotation at impingement, °	Implant placement			Lip orientations					
	SA	CI	CA	7 o'clock	8 o'clock	9 o'clock	10 o'clock	11 o'clock	Flat liner
FLEX + IR	15	30	5	23*	23*	22	22	14†	21
			15	33*	33*	32	32	21†	31
			25	42*	42*	42*	42*	29†	41
		40	5	33*	33*	32	32	24†	31
			15	43*	43*	42	42	31†	41
			25	52*	52*	52*	52*	39†	51
		50	5	43*	43*	42	42	34†	41
			15	53*	53*	52	52	41†	51
			25	62*	62*	62*	62*	49†	61
ER	15	30	5	68	61†	61†	79	≥ 90*	≥ 90
			15	52	43	39†	44	78*	87
			25	37*	26	21†	22	35	61
		40	5	60	54†	56	69	≥ 90*	≥ 90
			15	46	39	38†	45	69*	75
			25	32	24	22†	26	42*	56
		50	5	52	48†	50	62	79*	80
			15	40	34†	35	43	62*	66
			25	27	21	20†	26	43*	50

*Provided the largest rotation at impingement given a specific implant placement.
†Provided the lowest rotation at impingement given a specific implant placement.
CA, cup anteversion; CI, cup inclination; ER, external rotation until impingement; FLEX + IR, flexion to 90° followed by internal rotation until impingement; SA, stem anteversion.

obtained in 54%, 41%, and 74% of cases with posterior-inferior, posterior, and posterior-superior lip orientations, respectively.

Jump distance analysis. Jump distance at impingement for FLEX + IR was consistently larger for the inferiorly oriented lips (7 and 8 o'clock), with an average increase of 65% with regard to the superiorly oriented lips (10 and 11 o'clock) (Figure 5 and Table III). Jump distance for ER was largest for either 8 or 9 o'clock, and it was consistently lowest for the 11 o'clock orientation (mean 69% lower compared to the largest case). The flat liner presented lowest jump distance in each case, as expected, and was approximately half of the largest jump distance (approximately 5 mm vs approximately 10 mm) (Table III).

Discussion

Our study demonstrates that the optimal lip position can be chosen to maximize physiological ROM and jump distance. We were able to identify safe positions for the lipped liner that would protect from impingement during physiological ROM. In addition, the beneficial effect of the lipped liner on posterior stability was demonstrated by quantifying the increase in jump distance prior to posterior dislocation, which is most relevant for posterior approach THA. For anterior dislocation, the results highlighted the presence of a tradeoff between ROM and jump distance. The optimal lip positions for common component orientations were defined.

Widmer and Zurfluh[12] were the first to apply the concept of combined component orientation to a mathematical model, which allowed assessment of the impingement-free ROM during physiological movements and led to a safe zone that took stem version as well as cup orientation into account. This concept was further expanded upon by Widmer[14] to include different neck-shaft angles, head-neck ratios, and head size. In the present study we have built a model to include five different positions of the lip of a lipped XLPE liner in combination with changing cup anteversion, inclination, and stem anteversion. We have limited the analyzed cup/stem orientation combinations to 27 clinically relevant positions and the shaft-neck angle (CCD 135) and head size to a single option (32 mm). We opted for these combinations to produce a dataset volume that can be interpreted by the reader with a focus on the five different lip positions analyzed. To our knowledge, this is the first attempt at incorporating lipped liner position to a computational model with a view to define a lipped liner safe zone. The same 27 placement combinations were analyzed with a flat liner to provide a comparison to a commonly used component.

Five lip orientations on the posterior side of the cup were evaluated, ranging from an inferior-posterior position (7 o'clock for a right hip) to a superior-posterior position (11 o'clock). Posterior orientations were evaluated to replicate a posterior approach THA. The surgical approach weakens the soft-tissue (capsule and external rotator muscle) constraint on internal rotation and flexion/internal rotation, and therefore increases the risk of posterior dislocation at least in the early postoperative phase. Although anterior dislocation remains a

Table III. Jump distance at impingement during the FLEX + IR and ER provocative manoeuvres for each lip orientation. Only results with 15° of stem anteversion are included because their relative trend is equivalent for the other two stem anteversion values.

Jump distance at impingement, mm	Implant placement			Lip orientations					
	SA	CI	CA	7 o'clock	8 o'clock	9 o'clock	10 o'clock	11 o'clock	Flat liner
FLEX + IR	15	30	5	10*	10*	9	6†	6†	5
			15	10*	10*	9	6†	7	5
			25	10*	10*	9	6†	7	5
		40	5	10*	10*	9	6†	6†	5
			15	10*	10*	9	6†	7	5
			25	10*	10*	9	6†	7	5
		50	5	10*	10*	9	6†	6†	5
			15	10*	10*	9	6†	7	5
			25	10*	10*	9	6†	7	5
ER	15	30	5	10	11*	11*	8†	8†	5
			15	9	10	11*	10	6†	5
			25	8†	10	11*	11*	8†	5
		40	5	10	11*	11*	8	6†	5
			15	9	11*	11*	9	6†	5
			25	9	11*	11*	10	7†	5
		50	5	10	11*	10	8	6†	5
			15	10	11*	11*	9	6†	5
			25	9	11*	11*	10	6†	5

*Largest jump distance at impingement given a specific implant placement.
†Lowest jump distance at impingement given a specific implant placement.
CA, cup anteversion; CI, cup inclination; ER, external rotation until impingement; FLEX + IR, flexion to 90° followed by internal rotation until impingement; SA, stem anteversion.

concern in posterior approach THA and can occur with implant-on-implant impingement during external rotation, the anterior soft-tissue constraint (capsule, iliofemoral ligament) often limits ER range and protects from anterior instability. Therefore, increased ROM in flexion and increased jump distance when impinging in flexion without posterior impingement are the ideal outcomes for a lipped liner posterior approach THA.

Surgeons often assess joint stability intraoperatively by manually moving the leg in flexion and internal rotation to replicate an anterior impingement scenario. In this study, the provocative dislocation FLEX + IR test was used to mimic the clinically relevant test performed intraoperatively. The results of this study demonstrated equivalent internal rotation ROM in flexion for every lip orientation, except for 11 o'clock, which presented lower ROM. In addition, 7 and 8 o'clock lips presented consistently larger jump distance at anterior impingement (mean +65% compared to superiorly oriented lips). Hau et al[10] measured THA ROM intraoperatively for different lip orientations (6 to 12 o'clock) during the same FLEX + IR manoeuvre tested in the current study, and found that maximum ROM depended on cup orientation but was achieved in most cases with an 8 o'clock lip position.

Although, as previously mentioned, posterior dislocation is more relevant to a posterior approach scenario, anterior dislocation is still possible, especially in cases of implant malpositioning. Therefore, this study also analyzed ROM and jump distance in a manoeuvre that led to posterior impingement in external rotation. Our analysis identified the lip orientations that allow physiological external rotation without impingement, therefore avoiding the risk of impingement-induced anterior dislocation. For those cases in which physiological external rotation was not achieved, the reduced ROM comes with the advantage of an increased jump distance, as demonstrated by the comparison with flat liners (Table III). The flat liner case presented a constant jump distance of 5 mm regardless of where impingement occurred, whereas lipped liners reached peaks of 11 mm. The increased jump distance reflects the fact that impingement occurs at a lower ER angle when compared to flat liners. Although impingement occurs at a lower ER angle, the jump distance prior to dislocation is higher. The same tradeoff can be observed when comparing different lip orientations. For example, the 11 o'clock lip presented the largest ROM, but also the lowest jump distance. In addition, the increased ROM in ER possible with flat liners substantially exceeds the physiological range (40°) as per Widmer and Zurfluh,[12] and is therefore unlikely to be of clinical benefit. Despite this, care needs to be taken intraoperatively to prevent impingement in external rotation with lipped liners, as this can adversely load the acetabular component and cause polyethylene damage. Finally, the comparison between lipped and flat liners demonstrated that the FLEX + IR ROM was practically equivalent, since impingement occurs anteriorly where the lip is not present, but jump distance is twice as large for posterior-inferior lips (Tables II and III).

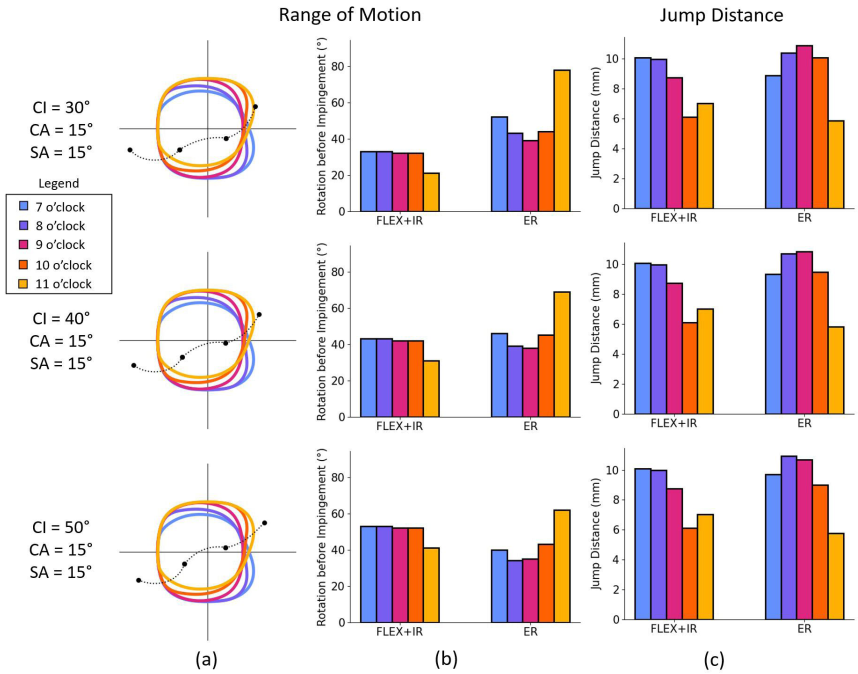

Fig. 5

a) Provocative dislocation manoeuvre kinematics (black dotted lines) overlaid with implant impingement-free range of motion (ROM) profiles for three exemplary cup alignments (cup inclination (CI), cup anteversion (CA), and stem anteversion (SA)). See legend for correspondence between ROM colour and lip orientation. Refer to Figure 4 for a description of the manoeuvre extremes. The black dotted lines change position and shape when placement parameters change, whereas the ROM profiles do not change position within the diagram. b) Rotations before impingement for each manoeuvre for the same exemplary cup alignments in (a). Bars for the FLEX + IR manoeuvre include only the internal rotation portion, since all placement combinations reached 90° of flexion. c) Jump distances at impingement for each hip motion for the same exemplary cup alignments in (a). ER, external rotation until impingement; FLEX + IR, flexion to 90° followed by internal rotation until impingement.

The current study also demonstrated that the lip orientation that maximizes physiological ROM depended on cup and stem placement. The 7 and 8 o'clock orientations (posterior-inferior) achieved maximum ROM in most cases (11 placement combinations), whereas posterior-superior lip orientations (10 and 11 o'clock) performed better only with 50° of cup inclination. Therefore, the results of this study indicate that, if stem anteversion is unknown and the cup inclination target is < 50°, orienting the lip at 7 or 8 o'clock represents the safest option, both in terms of impingement-free ROM and jump distance protecting against posterior dislocation. The effect of a more superior lip orientation (11 o'clock) consisted of increased ROM in external rotation, but also decreased jump distance when impinging in external rotation. The reduced jump distance is a result of the superior lip positions moving the lip outside the plane of impingement and therefore resulting in lower jump distance measurements, as would be expected with a flat liner. Changes in stem anteversion resulted only in a shift of ROM results without affecting the relative performance of different lip orientations. Therefore, although stem version remains critical for hip stability, this placement parameter had a relatively lower effect on the research questions addressed by this study compared to cup inclination.

Myers et al[18] used a computer model to estimate the dislocation resistance provided by different implant constructs, and observed an increased resistance with increasing lip height (9%, 19%, and 47% resistance increases to posterior dislocation for 10°, 15°, and 20° lip heights, respectively). The current study analyzed only 20° lips, but lip height peaks at one location on the liner and gradually decreases and transitions to a flat liner on the opposite side. The different jump distances observed for different lip orientations during the FLEX + IR test suggest that maximum lip height is aligned to the dislocation direction only with a specific lip orientation. Practically, suboptimal lip orientations correspond to decreasing lip height. The non-linear increase in dislocation resistance observed by Myers et al[18] when increasing lip height indicates that an increase of a few millimetres in jump distance (as observed in our results) might provide substantially greater stability.

The present study has some limitations. First, a single implant combination was analyzed. Therefore, the results presented here cannot be generalized to other implant options. However, it is reasonable to assume that changes in cup size, head size, and stem offset would produce similar relative results, as they would increase or decrease ROM and jump distance consistently between lip orientations. Second, only implant-on-implant impingement was considered. Although dislocation can be initiated by a variety of factors including soft-tissue tension, impingement is generally recognized as the primary dislocation mechanism. Impingement scenarios that do not involve contact between implant components are bone-on-bone collision or soft-tissue impingement, which were not included in this study. For example, ROM during the FLEX + IR manoeuvre might be limited by the greater trochanter impinging on the ilium,[19] making differences in implant impingement-free ROM less relevant. Although bone-on-bone impingement might occur earlier than implant-on-implant impingement, the benefit of the increased jump distance with lipped liner use remains relevant. Jump distance relative changes between lip orientations would still apply whether the impingement causing the head to subluxate is caused by implant-to-implant or bone-on-bone impingement. Lastly, the same nine combinations of cup inclination and anteversion values were used for each stem anteversion case (0°, 15°, and 30°). According to the combined version paradigm,[20] cup anteversion should be adjusted based on stem anteversion. It is possible that such an adjustment would produce a larger number of acceptable lip orientations for non-average stem anteversions (0° and 30°).

When using enabling technologies in THA, our analysis can help to identify the optimal lipped liner position based on the planned and confirmed implant position. In THA using manual instrumentation, the exact orientation of the cup cannot be accurately confirmed intraoperatively. In this scenario, we recommend positioning of the liner based on the templated cup alignment and proceeding with careful intraoperative ROM and stability assessment. In cases where the lip causes restriction in ROM and/or impingement, this should be identified and the lip should be repositioned or exchanged for a flat liner.

In conclusion, lip orientations that maximize implant mobility (i.e. ROM) and stability (i.e. jump distance) were identified for different cup and stem placement combinations. A tradeoff between external rotation ROM and increased stability (jump distance) was observed. In cup inclinations < 50°, the posterior-inferior lip orientation (7 and 8 o'clock) allowed physiological ROM without impingement and increased stability against posterior dislocation.

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