DIRECT ANTERIOR APPROACH IN TOTAL HIP ARTHROPLASTY: A NARRATIVE REVIEW

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ABSTRACT

Objective: Worldwide, a growing number of Total Hip Arthroplasty (THA) procedures are being performed each year. However, despite this significant global demand, the ideal surgical approach remains controversial. Globally there has been a significant increase in the use of direct anterior approach THA. Therefore, the objective of this paper was to synthesise the vast body of new, evolving information into one non-biased narrative review, to provide an overarching review of various aspects of this approach, including controversial issues such as, benefits, functional outcomes, complications, costs, and surgical technique.

Data source: The following keywords were entered into various scientific databases including, Mbase, Google scholar and PubMed. Only articles published in journals between 2017 and 2021 were extracted and included in this review. We found 148 articles published during this period and we used the 82 most relevant articles to collate this narrative review.

Data selection/ extraction: Three fellowship trained arthroplasty orthopaedic surgeons, (JRTP, LM and JC) went through all the papers and selected the 82 most relevant papers for inclusion in this review.

Conclusion: There has been significant interest and renewed vaguer in publication rates by authors worldwide evaluating the use of the DAA in THA. Most recent studies show that there is increasing evidence that the DAA is a safe, reliable, and reproducible surgical approach to THA. Direct anterior approach provides, in the most part, superior early short term functional outcomes in comparison with other THA approaches. It has however also been shown that a steep learning curve exists when using this approach. While complication rates are similar to those seen in other approaches, the types of complications however remain slightly different with an increase incidence of intraoperative peri-prosthetic femoral fractures, wound complications and femoral stem aseptic loosening being significantly greater in the direct anterior approach.

Key words: Direct Anterior Approach (DAA), Outcomes, Total Hip Arthroplasty (THA), Narrative review, Complications

INTRODUCTION

Patella tendon ruptures are rare injuries of the extensor mechanism. The common mechanism of injury is eccentric contraction of the quadriceps against a flexed knee. Pre-existing tendinopathy in patients with systemic conditions such as systemic lupus erythematosus, diabetes mellitus or patients using systemic corticosteroids are at increased risk of ruptures, particularly bilateral ruptures.

Acute patella tendon ruptures require prompt surgical intervention to restore function. Evolution of sutures and suturing techniques such as the double Krackow technique allow fashioning of repairs that allow early mobilisation, reducing the incidence of patellofemoral pain and patella cartilage chondrosis, which develop in fixations requiring immobilisation of the limb. This mobilisation however must be graded during postoperative rehabilitation with respect to magnitude and timing of loads applied to the limb. In

the absence of graded rehabilitation, the repair can be significantly displaced with development of gaps between the ends of the repair, preventing healing and resulting in clinical failure and transition into a state of chronic patella tendon rupture(1).

Chronic ruptures can also develop if there is failure to identify acute disruption and manage them appropriately. Surgical management of chronic patella tendon ruptures is complicated by development of adhesions, retraction of the patella and significantly, deterioration of the quality of the patella tendon tissue (2). The poor quality of the patella tendon tissue makes the solitary repair of the patella tendon disruption tenuous. The questionable strength of this repair necessitates some form of augmentation of the patella tendon repair to allow restoration of function of the extensor mechanism (Worldwide, approximately one million Total Hip Arthroplasty (THA) procedures are performed each year (1). The number of THA performed in the developing world is expected to increase and subsequently double the demand for THA globally by 2030 (1). In 2018, 500,000 THAs have been performed in the USA alone. Despite this, the best approach to THA remains controversial (2).

The most common surgical approaches remain the posterior (PA) and Lateral Approach (LA), while less than 5% of surgeons in the UK, Sweden and New Zealand routinely use the Direct Anterior Approach (DAA),(3). An analysis of large databases, however, showed that the use of DAA increased from 4% in 2001 – 2011 to 17% in 2012-2014 (4). In 2018, almost 40% of members of the American Academy of Hip and Knee Surgeons reported that they were routinely performing the DAA, making it the second most common hip approach amongst this group after the Posterior Approach (PA) (47%) (5).

The anterior approach was first described by Hueter in 1870, while Smith-Petersen is credited with introducing it into the USA and promoting it in the English-speaking world (6). The approach became unfashionable due to concerns over inadequate exposure and the simultaneous prodigious success of the Charnley low friction arthroplasty which highlighted the expediency and merit of the direct lateral and posterolateral approaches (6).

However, today, the resurgence in the popularity and interest in the DAA is profound. There is not only an increase in the number of DAA THAs performed, but the volume of academic literature dedicated to DAA THA has increased exponentially since 2008 (7). A PubMed search identified more than 42 papers specifically examining DAA THA in 2017 alone (7).Orthopaedic Residency Programs and Adult Reconstruction Fellowships have increasingly exposed and trained residents and fellows in the DAA over the last decade(7). Shofoluwe *et al* (8) evaluated surgeon-specific websites and found that more than 20% of AAHKS members promoted the DAA. Significantly, their websites reported potential advantages of the DAA, most notably more rapid recovery and less pain, almost nine times more often than warning of potential associated adverse events. Similarly, Mohan *et al*. (9) examined the top 50 websites from 3 major search engines and reported that the majority claimed the DAA was comparatively "superior" to other hip approaches while only 35% reported any potential complications.

The Direct Anterior Approach (DAA)

Surgical access to the hip joint via the DAA is both internervous and intermuscular, through a surgical interval between the sartorius and the tensor fascia latae muscles thus preserving the abductor muscles and short external rotators around the hip. This limits iatrogenic muscle and soft tissue damage making the approach minimally invasive (10). Agten *et al*. (12) reported that post-operative MRI could identify the type of surgical approach by the pattern of soft tissue injury. The anterolateral and DAA showed less soft tissue damage than both the PA and DL approach. Significant compromise of the external rotator muscles in PA and gluteus medius and minimus in the DL approach was obviously not found in the DAA cases (12).

Meneghini *et al*. (11), however, challenged this assertion by showing more injury to tensor fascia lata and rectus femoris in the DAA than in the Posterior Approach (PA) in a cadaveric study. MRI of the hips done at 6 months in a comparative study of DAA and LA showed more significant fatty atrophy of the gluteus muscles in the LA group (12). However, differences in muscle damage had no bearing on functional outcome at 3 and 9 months post-operatively as results were equivalent. While other surgical approaches demand muscle splitting and tendon detachment to gain adequate exposure, the comparatively limited soft tissue releases and associated muscle damage with the DAA offer the potential benefit of improved hip function, less pain and shorter Length of Hospital Stay (LOS). Additionally, lower rates of hip dislocation, readmissions and fewer unplanned re-operations have also been suggested.

DAA: Indications and contra-indications

The DAA is suitable for all THAs, however, more difficult exposure is experienced in previous hip surgery, protrusio acetabuli, hip contractures, severe femoral neck shortening and femoral deformity (10). Traditionally, especially early in the learning curve, optimal patient selection for DAA includes patients with end-stage OA, minimal muscle mass, valgus femoral neck-shaft angle and lack of abdominal pannus to avoid surgical incision complications.

A 2019 electronic survey of the members of the American Association of Hip and Knee Surgeons (AAHKS) reported that 56.2% of respondents performed the DAA. However, 65% and 53% of these surgeons would preferentially use the PA for cases with complex anatomy and increased BMI (5). Those members of AAHKS who had not adopted the DAA cited concerns over poorer outcomes, limited clinical benefit and the learning curve for continued use of other hip approaches (5).

Benefits of DAA

(i) Functional outcomes: The DAA seems to show a clear early clinical and functional advantage, yet any extra benefit appears to level out with time (2,13). In a systematic analysis of 42 papers evaluating the DAA, Meermans *et al*. (2) found that functional outcome scores were superior for the DAA for the first 6 weeks post-operatively. However, PROMs were equivalent between the DAA and PA thereafter.

In a prospective randomized study, Parvizi *et al.* (14) showed significantly superior functional outcomes in patients undergoing DAA compared to the Direct Lateral (DL) or modified Hardinge approach. At both 6 weeks and 6 months post-operatively, the DAA had better time-to-get-up-and-go (TUG) times and gait speeds than DL. In addition, the DAA allowed a more Rapid Return to Work (RTW) and to driving (14). Analgesic requirements, blood transfusions and LOS were, however, comparable.

In a prospective study comparing the outcomes at 3 months of 12,774 primary THA, Peters *et al*. (15) showed that the DAA and PL approach had better, albeit small, self-reported physical functioning than the direct lateral and anterolateral approach at 3 months post-operatively.

Sauder *et al*. (16) highlighted that clinical and functional advantages were not long-term when reporting no demonstrable difference in both functional and self-reported clinical outcomes or pain scores between the DAA and the PL approaches at 1, 3 or 5 years post-operatively. Similarly, Sibia *et al*. (17) reported that the DAA had superior HHS at 3 and 6 months post-operatively, but there were no clinical and functional differences at 1 year (17). In this series, the DAA hips were more likely to have longer operative times, shorter LOS and be discharged directly home than the PA approach hips.

The Forgotten Joint Score (FJS-12) has both a high test-retest consistency and an enhanced discriminatory ability due to its lack of ceiling effect. In a comparison of 1469 patients, Singh *et al*. (18) reported that the Forgotten Joint Score (FJS-12) and satisfaction rates were superior in the DAA than in the PA at 12 weeks, but were equivalent at 1.75 years post-operatively. However, the 2 cohorts were dissimilar and the authors concluded that a surgeon's experience and THA volume were more influential on improved early results than the surgical approach.

(ii) Length of Hospital Stay (LOS): LOS is used as a surrogate marker of surgical efficiency (19). Patients mobilize more rapidly and efficiently after DAA, with less use of assistive devices and the LOS is generally shorter than after both PA and LA (6). Kamath *et al* (20) showed that DAA had a shorter LOS than traditional approaches. Patients were also 20% more likely to be discharged home than a specialist care facility and the financial costs were 50% less in DAA (20). Free *et al*. (21) reported that the LOS was 20% shorter than in LA and PA. The proportion of patients successfully discharged directly home was also significantly greater in DAA surgery (21). However, a recent systematic review opposed this view when demonstrating no difference in LOS (2).

(iii) Physical activity: A RCT conducted to compare the DAA with the PA, showed superior stair climbing and unlimited walking distance at 6 weeks and 3 months post-operatively in DAA patients (22). However, at 6 and 12 months no difference existed (22). Similarly, Nakata *et al*. (23) showed faster walking speeds at 3 weeks and the ability to do a single leg stance for at least 5 seconds a week earlier in DAA patients. In a comparison of mini-posterior approach with DAA, Taunton *et al*. (24) reported that the DAA group took more steps per day and spent a greater percentage of the day engaged in voluntary activities at 2 weeks post-operatively. Walking aids are generally discontinued 1 week earlier in DAA patients than in other hip approaches (24).

Enhanced attainment of early functional milestones with the DAA, like unlimited walking distance and ability to climb stairs, is not uniformly

reported in the literature (6). Engdal *et al*. (25) used an activity tracking device (accelerometer) to show that no difference existed between the 3 common surgical approaches and activity in the first post-operative week. All patients spent about 3.5 hours upright every day and managed more than 2000 steps every 24 hours. There are reports that show no differences in gait analysis between the DAA, PA and anterolateral approach (2).

(iv) Pain: Lower pain and decreased narcotic consumption after DAA has been described (2,19). This benefit over other major surgical approaches is negligible at 6 weeks (19). However, Ilchman *et al*. (26) reported superior pain scores and less limping in comparison to LA for at least 1 year post-operatively. Interestingly, no data exists reporting inferior pain scores in patients after DAA (14).

Persistent pain and residual symptoms may occur in 40% of patients after THA (27). The perception of continuing pain after DAA is different in comparison with other surgical approaches. In a retrospective analysis Nam *et al*. (27) reported that DAA patients experienced significantly less severe groin pain and trochanteric pain than PA patients. There is no difference in the experience of posterior thigh, back or buttock pain between DAA and the PA (27).

(v) Dislocations: Dislocation is a considerable and unwelcome complication after THA. It is the most common cause of revision THA in the USA (28). The additional hospital expenses of unstable THA is 300% more than primary surgery (28). The preservation of muscles and tendons in DAA enhances the dynamic stabilization of the hip joint and decreases the risk of dislocation of THA (28). The rate of dislocation after DAA is 0 to 1.5% (22). Berry *et al*. (30) reported that the incidence of dislocation in 6,623 THAs with the anterolateral, lateral and posterior approach was 4.8%. A cumulative risk of dislocation was reported with time and the risk increased constantly by 1% every 5 years. Tamaki *et al.* (29) reviewed 871 consecutive DAA THAs and reported that 75% of dislocation in DAA is within the first 3 weeks and that the risk actually decreases substantially with time. Sariali *et al*. (31) reported a dislocation rate of 1.5% in 1764 cases of DAA, however, only 0.11% actually required revision THA.

(vi) Intra-operative fluoroscopy: Intra-operative fluoroscopy has been shown to decrease component abduction and version outliers (6). DAA may more easily facilitate the use of intra-operative fluoroscopy. This may limit technical inaccuracies of component placement and sizing and potentially enhance hip biomechanics (6). Ji *et al*. (32) achieved less variation superior positioning in acetabular cup placement in DAA with intra-operative fluoroscopy than in the posterior approach with imaging.

(vii) Readmissions: The overall readmission rate in the first 30- to 90-days after THA is 2.2 - 7.8% (33). In an observational study of 259,980 THAs, the overall 30-day readmission rate for THA was 5.5%, with 2.9% being surgery-related problems and 0.8% needing urgent return to theatre (34). Sali *et al*. (35) reported that the 30- and 90-day readmission rates for 335 patients who underwent DAA was 1.8% and 2.7% respectively. The most common reason for un-planned readmissions was wound related problems. Age older than 60 years and morbid obesity were patient related risk factors for early readmissions (35).

(viii) *Inflammatory markers:* De Anta-Diaz *et al*. (36) compared 49 patients that underwent THA through a DAA approach and 51 through a Lateral Approach (LA) and showed that the acute phase reactants and cytokines including IL-6, IL-8 and Tumour Necrosis Factor (TNF) were lower post-operatively up to day 4 in the DAA group. It is proposed that peri-operative values of Creatine Kinase (CK), C-reactive Protein (CRP) and Interleukin-6 (IL-6) are lower in DAA inhibiting the pain response. This results in better post-operative pain management. In a randomized prospective trial, Nistor *et al* (37) showed that post-operative myoglobin levels were lower post-operatively in DAA than in the LA. This translated to lower pain scores, less post-operative analgesia and morphine requirements in hospital after surgery.

Disadvantages of DAA

(i) *Learning curve*: The introduction of the DAA into clinical practice may increase the risk of complications and early failure. Muller *et al*. (38) reported that most complications occurred within the first 20 DAA cases. The 5-year survival rate was only 79% in these cases as opposed to 97% in the proceeding procedures. In an analysis of the Australian Orthopaedic Association National Joint Registry (AOANJRR), Pirruccio *et al*. (39) reported that 50 DAA cases needed to be performed before the subsequent revision rate was equivalent to that of a surgeon who had performed 100 cases.

The support of an experienced surgeon and the additional benefit of intra-operative fluoroscopy may diminish the impact of the learning curve navigation, robot-assisted (6). In a prospective, randomized study, Pirruccio *et al*. (39) successfully proved that the impact of the learning curve may be lessened with a well-regulated and disciplined training strategy when comparing a single surgeon's first 100 DAA cases with their last 100 PA THAs. The DAA was associated with an increased surgical time of 7-minutes but shorter LOS by 0.7 days. Equivalent blood loss, complication and mortality rates were reported. Kong *et al*. (40) showed that after 50 cases and with the use of intra-operative fluoroscopy improvements in surgical time and LOS were achieved. The complication rate decreased from 44% in the first 50 cases to 16% in the next 50 procedures.

(ii) *Limited surgical exposure:* A potential dis-advantage of the DAA is limited extensibility. Intra-operative exposure may thus be both difficult and inadequate (6). Both the transverse and descending branches of the Lateral Femoral Circumflex Artery (LFCA) and accompanying motor branches of both the Vastus Lateralis (VL) and intermedius (VM) may be injured with distal extension. Denervation of these two muscles may be a sequelae of any injury most notably with passing cables for calcar fracture fixation (40).

(iii) *Complications:* The DAA has been associated with an increased incidence of wound complications (41), femoral nerve palsy (42), intra-operative femoral fractures (43) and early femoral failure and subsequently an increased need for early revision THA (44).

In a population-based, retrospective study evaluating 5,986 patients, Pincus *et al*. (45) reported that the rate of major complications in DAA THA was 2%. The incidence of severe adverse events in DAA was statistically significantly greater p = 0.005 than in patients who had LA or PA.

Tay *et al*. (46) reviewed 2,437 THAs performed by a variety of hip approaches and noted that although the complication rates were similar, different approaches presented with certain complications more prominently. In this study, periprosthetic fractures, most notably in the calcar region, were more commonly associated with the DAA. Comparatively, dislocations were seen more regularly in patients who had undergone PA THA (46).

It is unknown whether the increased risk of periprosthetic fractures are related to the DAA approach itself or limitations of the surgical instruments (46). The use of a traction table and manipulation of the leg to gain optimal surgical exposure may generate substantial forces, especially increased hoop stresses, during femoral elevation and broaching which may result in greater trochanteric fractures, femoral perforation or calcar fractures more commonly (43).

Femoral Nerve Palsy (FNP) after THA is 14.8 times greater with the DAA (42). Motor function recovery is generally only noticeable after 6 months and full resolution is seen in 75% of patients after 33 months (42). The Lateral Femoral Cutaneous Nerve (LFCN) is at risk in DAA and injury results in numbness, paraes-thesia's and even dysesthesias in the cutaneous distribution of the anterolateral thigh (47). Neuropraxia related to LFCN occurs in 14% to 81% of cases and pain may be experienced 6 to 8 years later in 11% of these patients (47).

Superficial wound dehiscence complicates 1-2% of DAA (48). Both the skin quality around the anterior hip and the location of the surgical incision is contributory. The DAA surgical skin incision may be in, or overlapping, the inguinal and waist creases. This moist environment may precipitate the incision being exposed to infectious organisms. Wound healing may be inhibited by the shear forces generated by hip movement forcibly separating the skin edges. Diabetic and obese patients are most at risk of post-operative wound complications after DAA (48).

In a retrospective analysis of 6,086 consecutive patients undergoing primary THA in a single institution, Aggarwal *et al*. (49) reported that PJI was 2.2 times more likely with the DAA approach than with non-anterior approaches. Conversely, in a comparison of 1,182 DAA THAs with 18,853 posterolateral the rate of PJI was reported as 0.25% and 0.31% respectively. While surgical approach had no impact on PJI, an increased risk was attributed to younger age, not discharging patients directly home post-operatively and increased LOS (50).

(iv) Revision of DAA THA: The burden of revision THA is 52% greater than TKA (51). Patients undergoing revision THA are older, more ill and the treatment costs are greater than revision TKA. Revision surgery for periprosthetic fracture and PJI result in most significant costs and LOS (51).

A multicentre retrospective review of 478 consecutive early revision THA showed that 50% of femoral failures were attributed to the DAA (44). The study highlighted that after controlling for both implant-specific and patient specific factors DAA was,

itself, a significant risk factor for early femoral failure and subsequent revision. This may be as a result of limited intra-operative visualization of the femur, learning curve or an earlier return to increased activities leading to greater stress across implant-bones interfaces.

Eto *et al*. (52) showed that the time to revision THA was significantly shorter in DAA surgery than in non-anterior approaches. Aseptic loosening and subsequent femoral stem revision was also considerably more common in the patients that underwent DAA (53). Angerame *et al*. (54) evaluated 103 revisions in 6,894 primary THAs and reported that there was no difference in the revision rate or time to revision in DAA compared with the PA. Revision for femoral stem loosening was, however, much more likely in DAA while a greater likelihood of revision for instability was seen in the PA (54).

Very little data exists examining the long-term survivorship of DAA THA. In a consecutive series of 150 cases via the DAA, Muller *et al*. (38) showed an increased risk of implant failure in the first 20 cases upon adoption of the DAA. However, an overall survivorship of 97.7% was reported after a minimum of 5 years post-operatively.

DAA and traction table

The DAA may be performed on a standard operating room table or on a specialized traction table (55). The potential benefit of preferentially using a standard table includes the ability to prepare both limbs in the surgical field thereby potentially limiting post-operative Leg Length Inequality (LLI), allowing the surgeon better control and feel of the limb thus mitigating the risk of intraoperative femoral fracture by reducing the forces through the femur (55). Alternatively, traction table use limits the need for assistants and more easily facilitates the use of intra-operative imaging (55). However, traction tables are not ordinarily available and are priced from USD 100,000. Current comparative literature is scare and use is generally dictated by surgeon preference (2).

In a systematic review of 44 studies and more than 26,000 patients, Sarraj *et al* (55) reported that the short term functional improvements and complication profile is similar between standard- and traction-table DAA. However, there was less blood loss, quicker operative times and decreased incidence of intra-operative fractures with the standard table DAA technique (55).

DAA and obesity

The association of wound complications in obese patients undergoing DAA is controversial. The complex interplay between immune dysfunction in obesity, the anterior incision and overhanging abdominal pannus may instigate wound problems. Purcell *et al.* (57) reported a 7.1 times increased risk of deep infections and need for revision surgery in patients with a BMI > 35kg/m^2. The rate of all complications in patients with BMI <35 kg/m^2 was 1.27% as opposed to 4.41% in BMI >35 kg/m^2 (57). Russo *et al*. (56) showed that there were increased surgical times, narcotic use and LOS in obese patients after DAA. The likelihood of major and minor complications in patients with a BMI >30 kg/m^2 was increased 8.8- and 3.6-fold respectively.

Purcell *et al*. (57) compared the effect of the posterior approach and DAA on the incidence of superficial and deep infections in obese and non-obese patients. The impact of DAA and posterior approach on deep infections in non-obese patients was equivocal, however, an increased rate of deep infections in obese patients after DAA was reported. The DAA had a greater incidence of superficial wound complications in both obese and non-obese patients.

Antoniadis *et al*. (58) showed that despite a 4 times increased risk of re-operation for infection and wound dehiscence, DAA was still a reliable alternative in obese patients with good functional and radiographic outcomes.

Costs of DAA

Each year, health care costs for primary THA exceeds US$15 billion in the USA alone (59). Costs of THA are projected to increase exponentially in the future (59). The DAA may improve cost-efficiency.

Petis *et al*. (60) used a prospective, micro-costing comparative analysis to show that by decreasing the LOS, the cost of DAA was significantly less than both the LA and PA. Miller *et al*. (59) reported that the DAA may save US$6,200 per patient in comparison to other surgical approaches. A saving of US$223 million annually would ensue for every 10% of THAs done preferentially by the DAA (59). These savings were facilitated by the DAA by ensuring a decrease in the consumption of post-acute care (lower pain, less narcotic use and superior hip functioning) and limiting hospital readmissions within 90 days of index surgery.

However, Joseph *et al*. (61) argued that the impression on cost savings with shorter LOS is negligible and that decreased hospital costs resulted in less financial burden on healthcare economics.

REFERENCES

1. Zagra, L. Advances in hip arthroplasty surgery What is justified? *EFORT Open Rev.* 2017; **2**(5): 171-178.
2. Meermans, G., Konan, S., Das, R., Volpin, A. and Haddad, F.S. The direct anterior approach in total hip arthroplasty. *Bone Joint J* [Internet]. 2017 Jun [cited 2020 Apr 5];**99-B**(6):732–740. Available from: http://online.boneandjoint.org.uk/doi /10 .1302/0301-620X.99B6.38053.
3. Yue, C., Kang, P. and Pei, F. Comparison of direct anterior and lateral approaches in total hip arthroplasty. *Medicine* (Baltimore) [Internet]. 2015 Dec [cited 2020 Apr 5];**94**(50):e2126. Available from: http://www.ncbi.nlm.nih.gov/ pubmed/26683920.
4. Maratt, J.D., Gagnier, J.J., Butler, P.D., Hallstrom, B.R., Urquhart, A.G. and Roberts, K.C. No difference in dislocation seen in anterior vs posterior approach total hip arthroplasty. *J Arthroplasty [Internet]*. 2016 Sep [cited 2020 Apr 6];**31**(9):127–30. Available from: http://www. ncbi.nlm.nih.gov/pubmed/27067754.
5. Abdel, M.P. and Berry, D.J. Current practice trends in primary hip and knee arthroplasties among members of the American Association of Hip and Knee Surgeons: A long-term update. 2019 [cited 2020 Apr 7]; Available from: *J Arthroplasty.* https://doi.org/10.1016/j.arth. 2019.
6. Kyriakopoulos, G., Poultsides, L. and Christofilopoulos, P. Total hip arthroplasty through an anterior approach: The pros and cons. *EFORT open Rev* [Internet]. 2018 Nov [cited 2020 Apr 7];**3**(11):574–83. Available from: http:// www.ncbi.nlm.nih.gov/pubmed/30595843.
7. Martin, J.R., Nikolaus, O.B. and Springer, B.D. Direct anterior total hip arthroplasty: solicitation and industry. *Ann Jt [Internet]*. 2018 Jun [cited 2020 Apr 28];**3**:54–54. Available from: http://aoj. amegroups.com/article/view/4406/5016.
8. Shofoluwe, A.I., Naveen, N.B., Inabathula, A., Ziemba-Davis, M., Meneghini, R.M., Callaghan, J.J., *et al*. Internet promotion of direct anterior approach total hip arthroplasty by Members of the American Association of Hip and Knee Surgeons. *J Arthroplasty [Internet].* 2018 Jan [cited 2020 Apr 5];**33**(1):167-170.e1. Available from: https://linkinghub.elsevier.com/retrieve/ pii/S0883540317307386.
9. Mohan, R., Yi, P.H. and Hansen, E.N. Evaluating online information regarding the direct anterior approach for total hip arthroplasty. *J Arthroplasty* [Internet]. 2015 May [cited 2020 Apr 5];**30** (5):803–7. Available from: http://www.ncbi.nlm. nih.gov/ pubmed/ 25697892
10. Bender, B., Nogler, M. and Hozack, W.J. Direct anterior approach for total hip arthroplasty. *Orthop Clin NA* [Internet]. [cited 2020 Apr 6];**40**:321–328. Available from: https://0-www-clinicalkey-com.innopac. wits.ac.za/ service/ content/pdf/watermarked/1-s2.0-S003058980 9000042.pdf? locale=en_US&searchIndex.
11. Meneghini, R.M., Pagnano, M.W., Trousdale, R.T. and Hozack, W.J. Muscle damage during mis total hip arthroplasty. *Clin Orthop Relat Res* [Internet]. 2006 Dec [cited 2020 Apr 7];**453**:293–298. Available from: http://www.ncbi.nlm.nih. gov/pubmed /17006366.
12. Agten, C.A., Sutter, R., Dora, C. and Pfirrmann, C.W.A.M R imaging of soft tissue alterations after total hip arthroplasty: comparison of classic surgical approaches. *Eur Radiol* [Internet]. 2016 Jun 24 [cited 2020 May 9]; **27**(3):1312–21. Available from: https://europepmc.org/article/ med/27342822.
13. Poehling-Monaghan, K.L., Taunton, M.J., Kamath, A.F., Trousdale, R.T., Sierra, R.J. and Pagnano, M.W. No correlation between serum markers and early functional outcome after contemporary THA. *Clin Orthop Relat Res* [Internet]. 1999 [cited 2020 Apr 5];**475**. Available from: https://0-www-ncbi-nlm-nih-gov.innopac. wits.ac.za/pmc/articles/PMC5213923/pdf/1199 9_2016_Article_4904.pdf.
14. Parvizi, J., Restrepo, C. and Maltenfort, M.G. Total hip arthroplasty performed through direct anterior approach provides superior early outcome. *Orthop Clin North Am* [Internet]. 2016 Jul [cited 2020 Apr 6];**47**(3):497–504. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27 241374.
15. Peters, R.M., van Beers, L.W.A.H., van Steenbergen, L.N., Wolkenfelt, J., Ettema, H.B., ten Have, B.L.E.F., *et al*. Similar Superior patient-reported outcome measures for anterior and posterolateral approaches after total hip arthroplasty. *J Arthroplasty* [Internet]. 2018 Jun [cited 2020 Apr 1];**33**(6):1786–93. Available from: http://www.ncbi.nlm.nih.gov/pubmed/29 502965.

16. Sauder, N., Vestergaard, V., Siddiqui, S., Galea, V.P., Bragdon, C.R., Malchau, H., *et al*. The AAHKS Clinical Research Award: No evidence for superior patient-reported outcome scores after total hip arthroplasty with the direct anterior approach at 1.5 months postoperatively, and through a 5-year follow-up. *J Arthroplasty* [Internet]. 2020 Feb 12 [cited 2020 Apr 9]; Available from: http://www.ncbi.nlm.nih.gov/pubmed/32169382.

17. Sibia, U.S., Turner, T.R., MacDonald, J.H. and King, P.J. The impact of surgical technique on patient reported outcome measures and early complications after total hip arthroplasty. *J Arthroplasty* [Internet]. 2017 Apr [cited 2020 Apr 25];**32**(4):1171–75. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0883540316307598.

18. Singh, V., Zak, S., Schwarzkopf, R. and Davidovitch, R. Forgotten joint score in THA: Comparing the direct anterior approach to posterior approach. *J Arthroplasty* [Internet]. 2020 Apr 27 [cited 2020 Apr 29]; Available from: https://www.sciencedirect.com/science/article/pii/S0883540320304629.

19. Barry, J.J., Masonis, J.L. and Mason, JB. Recovery and outcomes of direct anterior approach total hip arthroplasty. *Ann Jt*. 2018; **3**:51..

20. Kamath, A.F., Chitnis, A.S., Holy, C., Lerner, J., Curtin, B., Lochow, S., *et al*. Medical resource utilization and costs for total hip arthroplasty: benchmarking an anterior approach technique in the Medicare population. *J Med Econ* [Internet]. 2018 Feb 3 [cited 2020 Apr 8];**21**(2):218–224. Available from: http://www.ncbi.nlm.nih.gov/pubmed/29034792.

21. Free, M.D., Owen, D.H., Agius, P.A., Pascoe, E.M. and Harvie, P. Primary arthroplasty direct anterior approach total hip arthroplasty: an adjunct to an enhanced recovery pathway outcomes and learning curve effects in surgeons transitioning from other surgical approaches. 2018 [cited 2020 Apr 8]; Available from: *J Arthroplasty* [Internet]. **33**(11); 3490-95 November2018,https://doi.org/10.1016/j.arth.2018.06.033

22. Barrett, W.P., Turner, S.E. and Leopold, J.P. Prospective randomized study of direct anterior vs postero-lateral approach for total hip arthroplasty. *J Arthroplasty* [Internet]. 2013 Oct 1 [cited 2020 Apr 8];**28**(9):1634–1638. Available from: https://www.sciencedirect.com/science/article/pii/S0883540313001617.

23. Nakata, K., Nishikawa, M., Yamamoto, K., Hirota, S. and Yoshikawa, H. A clinical comparative study of the direct anterior with mini-posterior approach. *J Arthroplasty* [Internet]. 2009 Aug [cited 2020 Apr 8];**24**(5):698–704. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18555653.

24. Taunton, M.J., Mason, J.B., Odum, S.M. and Springer, B.D. Direct anterior total hip arthroplasty yields more rapid voluntary cessation of all walking aids: a prospective, randomized clinical trial. *J Arthroplasty* [Internet]. 2014 [cited 2020 Apr 5];**29**:169–172. Available from: http://dx.doi.org/10.1016/j.arth.2014.03.051.

25. Engdal, M., Foss, O.A., Taraldsen, K., Husby, V.S. and Winther, S.B. Daily physical activity in total hip arthroplasty patients undergoing different surgical approaches. *Am J Phys Med Rehabil* [Internet]. 2017 Jul [cited 2020 Apr 8];**96**(7): 473–478. Available from: http://www.ncbi.nlm.nih.gov/pubmed/ 28628534.

26. Ilchmann, T., Gersbach, S., Zwicky, L. and Clauss, M. Standard transgluteal versus minimal invasive anterior approach in hip arthroplasty: a prospective, consecutive cohort study. *Orthop Rev* (Pavia) [Internet]. 2013 [cited 2020 Apr 9];**5**(4):e31. Available from: http://www.ncbi.nlm.nih. gov/pubmed/24416 475.

27. Nam, D., Nunley, R.M., Clohisy, J.C., Lombardi, A.V., Berend, K.R. and Barrack, R.L. Does patient-reported perception of pain differ based on surgical approach in total hip arthroplasty? *Bone Joint J* [Internet]. 2019 Jun [cited 2020 Apr 14];**101-B**(6_Supple_B):31–36. Available from: http://www.ncbi.nlm.nih.gov/pubmed/31146567.

28. Rowan, F.E., Salvatore, A.J., Lange, J.K. and Westrich, G.H.Dual-mobility vs fixed-bearing total hip arthroplasty in patients under 55 years of age: A single-institution, matched-cohort analysis. *J Arthroplasty* [Internet]. 2017 Oct [cited 2020 Apr 1];32(10):**3076**–81. Available from: http://www. ncbi.nlm.nih.gov/pubmed/28606460.

29. Tamaki, T., Oinuma, K., Miura, Y., Higashi, H., Kaneyama, R. and Shiratsuchi, H. Epidemiology of dislocation following direct anterior total hip arthroplasty: a minimum 5-year follow-up study. *J Arthroplasty* [Internet]. 2016 Dec [cited 2020 Apr 9];**31**(12):2886–88. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27378635.

30. Berry, D.J., von Knoch, M., Schleck, C.D. and Harmsen, S.W. The cumulative long-term risk of dislocation after primary charnley total hip arthroplasty. *J Bone Jt Surg-Amer* [Internet]. 2004 Jan [cited 2020 Apr 9];**86A**(1):9–14. Available from: http://www.ncbi.nlm.nih.gov/ pubmed/ 14711939.
31. Sariali, E., Leonard, P. and Mamoudy, P. Dislocation after total hip arthroplasty using hueter anterior approach. *J Arthroplasty* [Internet]. 2008 Feb [cited 2020 Apr 9];**23** (2):266–272. Available from: http://www. ncbi. nlm.nih.gov/pubmed/18280423 https://www. sciencedirect.com/ science/ article /pii/ S235234 411 9301505.
32. Ji, W. and Stewart, N. Fluoroscopy assessment during anterior minimally invasive hip replacement is more accurate than with the posterior approach. Int Orthop [Internet]. 2016 Jan 10 [cited 2020 Apr 25];**40**(1):21–27. Available from: http://www.ncbi.nlm.nih.gov/pubmed/ 25957590.
33. Stone, A.V., Md, Y., Jacobs, C.A., Luo, T.D., Meadows, M.C., Nho, S.J., *et al*. High degree of variability in reporting of clinical and patient-reported outcomes after hip arthroscopy. [cited 2017 Dec 7]; *The Amer J Sports Med.* **46** (12), September 2018 Available from: http://0-journals.sagepub.com.innopac.wits.ac.za/doi/ pdf/10.1177/0363546517724743.
34. Bottle, A., Loeffler, M.D., Orth, T., Aylin, P. and Ali, A.M. Comparison of 3 types of readmission rates for measuring hospital and surgeon performance after primary total hip and knee arthroplasty. 2018 [cited 2020 Apr 26]; *J Arthroplasty.* **33**(7), Available from: https://doi.org/10.1016/j.arth. 2018.02. 064.
35. Sali, E., Marmorat, J-L., Gaudot, F. and Nich, C. Perioperative complications and causes of 30- and 90-day readmission after direct anterior approach primary total hip arthroplasty. 2019 [cited 2020 Apr 5]; Available from: *S J Orthopaed*. **17**; 69-72. 10 Aug https:// doi.org/10.1016/j.jor. 2019.08.006
36. De Anta-Díaz, B., Serralta-Gomis, J., Lizaur-Utrilla, A., Benavidez, E. and López-Prats, F.A. No differences between direct anterior and lateral approach for primary total hip arthroplasty related to muscle damage or functional outcome. *Int Orthop* [Internet]. 2016 Oct 12 [cited 2020 Apr 7];**40**(10):2025–30. Available from: http://www.ncbi.nlm.nih.gov/pubmed/ 26753844.
37. Nistor, D.V., Caterev, S., Bolboacă, S.D., Cosma, D., Lucaciu, D.O.G. and Todor, A. Transitioning to the direct anterior approach in total hip arthroplasty. Is it a true muscle sparing approach when performed by a low volume hip replacement surgeon? *Int Orthop* [Internet]. 2017 Nov 24 [cited 2020 Apr 5];**41**(11):2245–52. Available from: http://www.ncbi.nlm.nih.gov/pubmed/ 28439629.
38. Müller, D.A., Zingg, P.O. and Dora, C. Anterior minimally invasive approach for total hip replacement: five-year survivorship and learning curve. *Hip Int* [Internet]. 2014 May 18 [cited 2020 Apr 7];**24**(3):277–283. Available from:http:// journals.sagepub.com/doi/10.5301/hipint. 5000108.
39. Pirruccio, K., Evangelista, P.J., Haw, J., Goldberg, T. and Sheth, N.P. Safely implementing the direct anterior total hip arthroplasty. *J Am Acad Orthop Surg* [Internet]. 2020 Feb 3 [cited 2020 Apr 7];1. Available from: http://www.ncbi.nlm.nih.gov/ pubmed/ 32015249.
40. Kong, X., Grau, L., Ong, A., Yang, C. and Chai, W. Adopting the direct anterior approach: experience and learning curve in a Chinese patient population. [cited 2020 Apr 5]; *J Orthopaed Traumatology:* official journal of the Italian Society of Orthopaedics and Traumatology, **22**(1); 46, Available from: https://doi.org/ 10.1186/s13018-019-1272-0.
41. Christensen, C.P., Karthikeyan, T. and Jacobs, C.A. Greater Prevalence of wound complications requiring reoperation with direct anterior approach total hip arthroplasty. *J Arthroplasty* [Internet]. 2014 Sep [cited 2020 Apr 7];**29** (9):1839–41. Available from: https:// linking hub. elsevier.com/retrieve/pii/S088354031400 2940.
42. Fleischman, A.N., Rothman, R.H. and Parvizi, J. Femoral nerve palsy following total hip arthroplasty: incidence and course of recovery. *J Arthroplasty* [Internet]. 2018 Apr [cited 2020 Apr 7];**33**(4):1194–99. Available from: http:// www.ncbi.nlm.nih. gov/pubmed/29239773.
43. De Geest, T., Vansintjan, P. and De Loore, G. Direct anterior total hip arthroplasty: complications and early outcome in a series of 300 cases. *Acta Orthop Belg* [Internet]. 2013 Apr [cited 2020 Apr 6];**79**(2):166–173. Available from: http://www. ncbi.nlm.nih.gov/pubmed/23821968.

44. Meneghini, R.M., Elston, A.S., Chen, A.F., Kheir, M.M., Fehring, T.K. and Springer, B.D. Direct anterior approach. *J Bone Jt Surg* [Internet]. 2017 Jan 18 [cited 2020 Apr 7];**99**(2):99–105. Available from: http://www.ncbi.nlm.nih.gov/pubmed/28099299.
45. Pincus, D., Jenkinson, R., Paterson, M., Leroux, T. and Ravi, B. Association between surgical approach and major surgical complications in patients undergoing total hip arthroplasty. *JAMA* [Internet]. 2020 Mar 17 [cited 2020 Apr 7];**323**(11):1070. Available from: http:// www.ncbi.nlm.nih.gov/pubmed/32181847.
46. Tay, K., Tang, A., Fary, C., Patten, S., Steele, R. and De Steiger, R. The effect of surgical approach on early complications of total hip arthoplasty. [cited 2020 Apr 5]; *Open Access Arthroplasty*, September, 2019 Available from: https://doi.org/10.1186/s42836-019-0008-2.
47. Patton, R.S., Runner, R.P., Lyons, R.J. and Bradbury, T.L. Primary arthroplasty clinical outcomes of patients with lateral femoral cutaneous nerve injury after direct anterior total hip arthroplasty. 2018 [cited 2020 Apr 8]; Available from: https://doi.org/10.1016/j.arth.2018.04.032.
48. Jahng, K.H., Bas, M.A., Rodriguez, J.A. and Cooper, H.J. Risk factors for wound complications after direct anterior approach hip arthroplasty. *J Arthroplasty* [Internet]. 2016 Nov [cited 2020 Apr 7];**31**(11):2583–87. Available from: http:// www.ncbi.nlm.nih.gov/pubmed/ 27267230.
49. Aggarwal, V.K., Weintraub, S., Klock, J., Stachel, A., Phillips, M., Schwarzkopf, R., *et al*. 2019 Frank Stinchfield Award: A comparison of prosthetic joint infection rates between direct anterior and non-anterior approach total hip arthroplasty. *Bone Joint J* [Internet]. 2019 Jun [cited 2020 Apr 13];**101-B**(6_Supple_B):2–8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/31146560.
50. Triantafyllopoulos, G.K., Memtsoudis, S.G., Wang, H., Ma, Y., Alexiades, M.M. and Poultsides, L.A. Surgical approach does not affect deep infection rate after primary total hip arthroplasty. *HIP Int* [Internet]. 2019 Nov 30 [cited 2020 Apr 14];**29**(6):597–602. Available from: http:// www.ncbi.nlm.nih.gov/pubmed/30698022.
51. Bozic, K.J., Kamath, A.F., Ong, K., Lau, E., Kurtz, S., Chan, V., *et al.* Comparative epidemiology of revision arthroplasty: failed THA poses greater clinical and economic burdens than failed TKA. *Clin Orthop Relat Res* [Internet]. 2015 Jun [cited 2020 Apr 13];**473**(6):2131–38. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25467789.
52. Eto, S., Hwang, K., Huddleston, J.I., Amanatullah, D.F., Maloney, W.J. and Goodman, S.B. The direct anterior approach is associated with early revision total hip arthroplasty. *J Arthroplasty* [Internet]. 2017 Mar [cited 2020 Apr 10]; **32**(3):1001–5. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27843039.
53. Eto, S., Hwang, K., Huddleston, J.I., Amanatullah, D.F., Maloney, W.J. and Goodman, S.B. Complications-other the direct anterior approach is associated with early revision total hip arthroplasty. 2016 [cited 2020 Apr 10]; Available from: http://dx.doi.org/10.1016/j.arth. 2016.09.012.
54. Angerame, M.R., Fehring, T.K., Masonis, J.L., Mason, J.B., Odum, S.M. and Springer, B.D. Early failure of primary total hip arthroplasty: is surgical approach a risk factor? *J Arthroplasty* [Internet]. 2018 Jun [cited 2020 Apr 10];**33**(6):1780–85. Available from: http:// www.ncbi.nlm.nih.gov/pubmed/29439894.
55. Sarraj, M., Chen, A., Ekhtiari, S. and Rubinger, L. Traction table versus standard table total hip arthroplasty through the direct anterior approach: a systematic review. *HIP Int* [Internet]. 2020 Jan 29 [cited 2020 Apr 3];112070001990098. Available from: http://www.ncbi.nlm.nih.gov/pubmed/31994425.
56. Russo, M.W., Macdonell, J.R., Paulus, M.C., Keller, J.M. and Zawadsky, M.W. Increased complications in obese patients undergoing direct anterior total hip arthroplasty. *J Arthroplasty* [Internet]. 2015 Aug [cited 2018 May 24];**30**(8):1384–87. Available from: http:// www.ncbi.nlm.nih.gov/pubmed/25820116.
57. Purcell, R.L., Parks, N.L., Cody, J.P. and Hamilton, W.G. Comparison of Wound Complications and deep infections with direct anterior and posterior approaches in obese hip arthroplasty patients. *J Arthroplasty* [Internet]. 2018 Jan [cited 2020 Apr 8];**33**(1):220–223. Available from: http://www.ncbi.nlm.nih.gov/ pubmed/28864031.
58. Antoniadis, A., Dimitriou, D., Flury, A., Wiedmer, G., Hasler, J. and Helmy, N. Is direct anterior approach a credible option for severely obese patients undergoing total hip arthroplasty? A matched-control, retrospective, clinical study. *J Arthroplasty* [Internet]. 2018 Apr 11 [cited 2018 May 24]; Available from: http://www. ncbi.nlm.nih.gov/pubmed/29729934.

59. Miller, L.E., Martinson, M.S., Gondusky, J.S., Kamath, A.F., Boettner, F. and Bhattacharyya, S.K. Ninety-day postoperative cost in primary total hip arthroplasty: an economic model comparing surgical approaches. *Clinicoecon Outcomes Res* [Internet]. 2019 [cited 2020 Apr 13];**11**:145–149. Available from: http://www.ncbi.nlm.nih.gov/pubmed/30799943.
60. Petis, S.M., Howard, J.L., Lanting, B.A., Marsh, J.D. and Vasarhelyi, E.M. In-hospital cost analysis of total hip arthroplasty: does surgical approach matter? *J Arthroplasty* [Internet], 31(1); 2016 [cited 2020 Apr 13]; Available from: http://dx.doi.org/10.1016/j.arth.2015.08.034
61. Joseph, N.M., Roberts, J. and Mulligan, M.T. Financial impact of total hip arthroplasty: a comparison of anterior versus posterior surgical approaches. *Arthroplast Today* [Internet]. 2017 [cited 2020 25].