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Kliniczne, biomechaniczne i radiologiczne aspekty oceny funkcjonowania stawu biodrowego po operacjach endoprotezoplastyki stawu biodrowego

Rozprawa na stopień doktora nauk medycznych i nauk o zdrowiu

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Wykaz publikacji stanowiących pracę doktorską

1. Budzińska MB, Maciąg BM, Żarnovsky K, Kordyaczny T, Kowalczyk IM, Adamska O, Stolarczyk A. How to analyze postoperative radiographs after total hip replacement. Jpn J Radiol. 2023 Jan;41(1):14-18. doi: 10.1007/s11604-022-01332-8. Epub 2022 Sep 5. PMID: 36063354; PMCID: PMC9813239.
2. Stolarczyk, A.; Stolarczyk, M.; Stępiński, P.; Dorocińska, M.K.;Świercz, M.; Szymczak, J.; Żarnovsky K.; Żuchniewicz, A.; Maciąg, B.M., The Direct Anterior Approach to Primary Total Hip Replacement: Radiological Analysis in Comparison to Other Approaches. J. Clin. Med.2021, 10, 2246. https://doi.org/10.3390/jcm10112246
3. Stępiński, P.; Stolarczyk, A.; Maciąg, B.; Modzelewski, K.;Szymczak, J.; Michalczyk,W.; Zdun, J.; Grzegorzewski, S. Spinopelvic Alignment and Its Use in Total Hip Replacement Preoperative Planning—Decision Making Guide and Literature Review. J. Clin. Med. 2021, 10, 3528. https://doi.org/10.3390/jcm10163528
4. Stolarczyk Artur, Stolarczyk Magda, Oleksy Łukasz, Maciąg Grzegorz, Stępiński Piotr, Szymczak Jakub, Świercz Maciej, Żarnovsky Krystian, Mostowy Marcin, Maciąg Bartosz, Analysis of biomechanical gait parameters in patients after total hip replacement operated via anterolateral approach depending on size of the femoral head implant: retrospective matched-cohort study, Archives of Orthopaedic and Trauma Surgery, 2021, 10.1007/s00402-021-04264-6JJOR
5. Bartosz Michał Maciąg, Krystian Żarnovsky, Olga Adamska, Grzegorz Jan Maciąg, Paweł Czuchaj, Marcin Łapiński, Maciej Świercz, Hanna Tsitko, Artur Stolarczyk. Posture stability and risk of fall test in the objective assessment of balance in patients with ectopic bone tissue after total hip replacement, Chir. Narzadow Ruchu Ortop. Pol., 2022; 87(4): 160-164 DOI:10.31139/chnriop.2022.87.4.4
6. Żarnovsky K, Jegierski D, Budzińska M, Maciąg G, Adamska O, Stolarczyk A. Hip hemiprosthesis due to femoral neck fracture in the elderly population - are we doing it right? Reumatologia. 2022;60(5):340-346. doi: 10.5114/reum.2022.120758. Epub 2022 Nov 4. PMID: 36381207; PMCID: PMC9661412.

Spis treści

Spis rycin

Wykaz stosowanych skrótów

AA	Antewersja panewki (ang. Acetabular Anteversion)
AI	Inklinacji panewki (ang. Acetabular Inclination)
ALA	Dostęp przednio-boczny (ang. Anterolateral Approach)
AO	Offset panewkowy (ang. Acetabular Offset)
COR	Centrum rotacji (ang. Center of Rotation)
CT	Tomografia Komputerowa (ang. Computed Tomography)
DAA	Dostęp bezpośredni przedni (ang. Direct Anterior Approach)
FI	Inklinacja kości udowej (ang. Femoral Inclination)
FO	Offset udowy (ang. Femoral Offset)
LL	Lordoza lędźwiowa (ang. Lumbar lordosis)
LLD	Różnica długości kończyn dolnych (ang. Leg Length Discrepancy)
MRI	Badanie Rezonansu Magnetycznego (ang. Magnetic Resonance Imaging)
PFA	Kąt miedniczno-udowy (ang. Pelvic Femoral Angle)
PI	Kąt padania miednicy (ang. Pelvic Incidence)
PLA	Dostęp tylno-boczny (ang. Postero-lateral Approach)
PT	Nachylenie miednicy (ang. Pelvic Tilt)
ROM	Zakres ruchu (ang. Range of motion)
SS	Pochylenie odcinka krzyżowego kręgosłupa (ang. Sacral Slope)
SSA	Kąt kręgosłupowo-krzyżowy (Spino Sacral Angle)
THA	Endoprotezoplastyka całkowita stawu biodrowego (ang. Total Hip Arthroplasty)
VAS	Wizualna Skala Analogowa (ang. Visual Analogue Scale)
WOMAC	Indeks Choroby Zwyrodnieniowej Uniwersytetów Western Ontario i McMaster (ang. The Western Ontario and McMaster Universities Arthritis Index)

Streszczenie w języku polskim

Kliniczne, biomechaniczne i radiologiczne aspekty oceny funkcjonowania stawu biodrowego po operacjach endoprotezoplastyki stawu biodrowego

Choroba zwyrodnieniowa stawu biodrowego jest jednym z najczęstszych problemów dotykających różne grupy społeczne, z globalną liczbą ponad 500 milionów osób, głównie po 55. roku życia. Główną cechą choroby jest degradacja chrząstki stawowej oraz otaczających ją tkanek miękkich, prowadząca do sklerotyzacji warstwy podchrzęstnej, tworzenia narośli kostnych (osteofitów), przerostu błony maziowej i ogólnej degeneracji stawu. Pacjenci doświadczają bólu, ograniczenia ruchu stawu, skrócenia kończyny i zaburzeń chodu. Leczenie koksartrozy stanowi wyzwanie dla systemów ochrony zdrowia na całym świecie, szczególnie gdy około 10% mężczyzn i 13% kobiet powyżej 60 roku życia cierpi na tę chorobę, a liczba ta wzrasta wraz z wiekiem. Prognozy wskazują na wzrost liczby chorych w krajach rozwiniętych z powodu otyłości, braku aktywności fizycznej i rosnących oczekiwań pacjentów. Początkowo leczenie jest zwykle zachowawcze, obejmując doustne leki przeciwbólowe, rehabilitację i iniekcje stawowe. W zaawansowanych przypadkach, gdzie dochodzi do całkowitej degeneracji chrząstki, konieczna może być endoprotezoplastyka całkowita stawu biodrowego (THA), choć mimo rozwoju alternatywnych metod leczenia, THA pozostaje złotym standardem.

W niniejszym cyklu publikacji wchodzącym w skład pracy doktorskiej omówiono czynniki radiologiczne, biomechaniczne i kliniczne wpływające na wynik leczenia operacyjnego. Przedstawiono wpływ zastosowania małoinwazyjnych dostępów operacyjnych na wynik radiologiczny osadzenia elementów endoprotezy. Ponadto przeanalizowano wpływ ustawienia kręgosłupa i miednicy na techniki ustawienia panewki stawu biodrowego. Wykazano różnice biomechanikę chodu pomiędzy pacjentami, u których zastosowano odmienne rozmiary głów endoprotezy. Oszacowano ryzyko upadków u osób, u których rozwinęły się skostnienia pozaszkieletowe oraz oceniono możliwość odtworzenia prawidłowych uwarunkować biomechanicznych u osób poddawanych endoprotezoplastyce połowiczej stawu biodrowego z zastosowaniem standardowych implantów.

W badaniu "The Direct Anterior Approach to Primary Total Hip Replacement: Radiological Analysis in Comparison to Other Approaches", które jest częścią pracy doktorskiej, autorzy dokonali przeglądu publikacji analizujących parametry osadzenia

implantów endoprotezy w zależności od zastosowanego dostępu operacyjnego, takiego jak DAA, PLA oraz ALA. Analiza koncentrowała się na wpływie dostępu operacyjnego na położenie panewki stawu biodrowego, osiowość osadzenia trzpienia endoprotezy oraz różnicę długości kończyn. Włączono do analizy 9 prac, a wyniki wskazują na różnice pomiędzy dostępem DAA a innymi dostępami w zakresie parametrów osadzenia implantów endoprotezy. Osiem prac wykazało różnice w osadzeniu trzpienia endoprotezy, choć nie wszystkie były statystycznie istotne. W przypadku inklinacji panewki, analiza 9 prac wykazała istotną różnicę między DAA a ALA, jednakże nie wszystkie badania wykazały istotne statystycznie różnice. Antewersja panewki również różniła się istotnie pomiędzy DAA a innymi dostępami, wskazując na potencjalny wpływ zastosowanego dostępu operacyjnego na wynik zabiegu. Jednakże różnica w długości kończyn nie była istotna statystycznie w analizie trzech prac. Podsumowując, zastosowanie dostępu DAA może wpływać na osadzenie elementów endoprotezy, zwłaszcza w kontekście parametrów takich jak antewersja i inklinacja panewki. Chirurdzy powinni mieć na uwadze potencjalne różnice w osadzeniu implantów w zależności od wybranego dostępu operacyjnego.

W pracy "Spinopelvic Alignment and Its Use in Total Hip Replacement Preoperative Planning—Decision Making Guide and Literature Review", części rozprawy doktorskiej, autorzy przeprowadzili pierwszy na świecie systematyczny przegląd literatury oraz opracowali wytyczne dotyczące umiejscawiania endoprotezy w zależności od sztywności odcinka L-S kręgosłupa oraz wtórnych ustawień miednicy. Aby dokładnie określić właściwe umiejscowienie endoprotezy, konieczne jest ocenienie ruchomości miednicy poprzez kilka parametrów mierzonych na bocznym radiogramie miednicy z uwzględnieniem połowy trzonu kości udowej oraz odcinka L-S. Obejmuje to m.in. Pomiar nachylenia krzyża (SS), nachylenie miednicy (PT), nachylenie miednicy do miednicy (PI), kąt między kością krzyżową a kością udową (PFA), lordozę lędźwiową (LL), nachylenie kości udowej (FI) oraz kąt między blaszką graniczną S1 a linia prostopadłą do podłoża (SSA).

W badaniu "Analysis of biomechanical gait parameters in patients after total hip replacement operated via anterolateral approach depending on size of the femoral head implant: retrospective matched-cohort study", będącym częścią rozprawy doktorskiej, autorzy przeprowadzili analizę parametrów chodu pomiędzy dwoma grupami pacjentów operowanych w Klinice Ortopedii i Rehabilitacji Warszawskiego Uniwersytetu

Medycznego a grupą kontrolną zdrowych ochotników. Jedna grupa pacjentów miała endoprotezy z głową o średnicy 36mm, a druga - o średnicy 28 lub 32mm, dobrana pod względem wieku, płci i operowanej strony. Każdy uczestnik był poddany analizie radiologicznej stawów biodrowych, ocenie wyniku funkcjonalnego w skali WOMAC oraz VAS, oraz analizie parametrów chodu. Wykazano, że pacjenci z małymi głowami implantów mieli dłuższy czas podparcia i opadanie miednicy w porównaniu ze zdrowymi, oraz krótszy czas przenoszenia, mniejszą długość kroku, niższą prędkość kroku i kadencję. Natomiast pacjenci z dużymi głowami mieli parametry chodu bardziej zbliżone do zdrowych, jednakże nadal występowały różnice, choć zmniejszone dolegliwości bólowe i wysokie zadowolenie pacjentów. Wybór odpowiedniego implantu zdaje się być kluczową decyzją na etapie planowania przedoperacyjnego, a wyniki pracy mogą wpłynąć na postępowanie rehabilitacyjne po THA, zwracając uwagę na wypracowanie prawidłowego modelu chodu.

W badaniu "Posture stability and risk of fall test in the objective assessment of balance in patients with ectopic bone tissue after total hip replacement", części rozprawy doktorskiej, zidentyfikowano heterotopowe skostnienia u 46 z 312 pacjentów po całkowitej aloplastyce stawu biodrowego. Dopasowano grupę kontrolną złożoną z 39 pacjentów, którzy nie mieli skostnień pozaszkieletowych. Pacjenci przeszli ocenę radiologiczną i biomechaniczną, a także wypełnili kwestionariusze WOMAC i Oxford, służące do oceny funkcji biodra.

W badaniu "Hip hemiprosthesis due to femoral neck fracture in the elderly population - are we doing it right?", części tej rozprawy doktorskiej, autorzy analizowali skuteczność odtworzenia parametrów z użyciem standardowych trzpieni endoprotez w zależności od kąta szyjkowo-trzonowego. Analiza obejmowała 100 kolejnych pacjentów poddanych endoprotezoplastyce połowiczej stawu biodrowego z powodu złamania szyjki kości udowej. Wykazano związek między kątem szyjkowo-trzonowym a zmianą FO oraz istotną różnicę w zmianie tego kąta a zmianą FO. Stosowanie standardowych trzpieni endoprotezy, zaprojektowanych do odtworzenia kąta szyjkowo-trzonowego około 130 stopni, może prowadzić do niepoprawnego odtworzenia FO, co wymaga przemyślanej decyzji przed zabiegiem.

Streszczenie w języku angielskim

Clinical, biomechanical and radiological aspects of assessing the functioning of the hip joint after total hip replacement surgery

Degenerative hip joint disease is one of the most common problems affecting various social groups, with a global count of over 500 million people, mainly over the age of 55. The main feature of the disease is the degradation of the joint cartilage and surrounding soft tissues, leading to sclerosis of the subchondral layer, formation of bone spurs (osteophytes), synovial membrane hypertrophy, and overall joint degeneration. Patients experience pain, joint movement restriction, limb shortening, and gait disturbances. Managing hip osteoarthritis poses a challenge for healthcare systems worldwide, especially when about 10% of men and 13% of women over the age of 60 suffer from this condition, and the numbers increase with age. Projections indicate a rise in the number of cases in developed countries due to obesity, lack of physical activity, and rising patient expectations. Initially, treatment is usually conservative, including oral analgesics, rehabilitation, and joint injections. In advanced cases, where complete cartilage degeneration occurs, total hip arthroplasty (THA) may be necessary, although despite the development of alternative treatment methods, THA remains the gold standard.

In this series of publications included in the doctoral dissertation, radiological, biomechanical, and clinical factors influencing the outcome of surgical treatment are discussed. The impact of using minimally invasive surgical approaches on the radiological result of components placement is presented. Additionally, the influence of spinal and pelvic alignment on hip acetabulum positioning techniques is analyzed. Differences in gait biomechanics between patients with different prosthetic head sizes are demonstrated. The risk of falls in individuals who developed heterotopic ossification is estimated, and the possibility of restoring normal biomechanical conditions in individuals undergoing hemiarthroplasty of the hip joint using standard implants is assessed.

In the study "The Direct Anterior Approach to Primary Total Hip Replacement: Radiological Analysis in Comparison to Other Approaches," which is part of the doctoral thesis, the authors reviewed publications analyzing the parameters of implant fixation depending on the surgical approach used, such as DAA, PLA, and ALA. The analysis

focused on the influence of the surgical approach on the position of the acetabular cup, the axiality of the stem implant, and limb length discrepancy. Nine studies were included in the analysis, and the results indicate differences between the DAA approach and other approaches regarding implant fixation parameters. Eight studies showed differences in stem implantation, although not all were statistically significant. Regarding acetabular inclination, the analysis of 9 studies showed a significant difference between DAA and ALA, although not all studies demonstrated statistically significant differences. Acetabular anteversion also differed significantly between DAA and other approaches, indicating a potential impact of the surgical approach on surgical outcomes. However, limb length discrepancy was not statistically significant in the analysis of three studies. In summary, the use of the DAA approach may affect the fixation of implant components, especially concerning parameters such as anteversion and inclination of the acetabular cup. Surgeons should be aware of potential differences in implant fixation depending on the chosen surgical approach.

In the work "Spinopelvic Alignment and Its Use in Total Hip Replacement Preoperative Planning—Decision Making Guide and Literature Review," a part of the doctoral dissertation, the authors conducted the world's first systematic literature review and developed guidelines for placing hip implants depending on the stiffness of the lumbar-sacral spine segment and secondary pelvic settings. To precisely determine the proper implant placement, it is necessary to assess pelvic mobility through several parameters measured on lateral pelvic radiographs, considering half of the femoral shaft and the lumbar-sacral segment. This includes measuring sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), pelvic femoral angle (PFA), lumbar lordosis (LL), femoral inclination (FI), and angle between the S1 endplate and a line perpendicular to the ground (SSA).

The authors of the work "Spinopelvic Alignment and Its Use in Total Hip Replacement Preoperative Planning—Decision Making Guide and Literature Review" proposed guidelines based on available literature regarding the appropriate placement of the acetabular cup during THR depending on the above classification. To properly assess spinal mobility, the above-described angle values should be measured on radiographs in standing and sitting positions with 90 degrees of hip flexion.

In the study "Analysis of biomechanical gait parameters in patients after total hip replacement operated via anterolateral approach depending on size of the femoral head implant: retrospective matched-cohort study," which is part of the doctoral thesis, the authors analyzed gait parameters between two groups of patients operated on at the Orthopedics and Rehabilitation Clinic of the Medical University of Warsaw and a control group of healthy volunteers. One group of patients had implants with a 36mm head diameter, and the other had a 28 or 32mm diameter, matched by age, sex, and operated side. Each participant underwent radiological analysis of hip joints, functional assessment using WOMAC and VAS scales, and gait parameter analysis. It was shown that patients with small head implants had longer stance time and pelvic drop compared to healthy individuals, and shorter swing time, shorter step length, slower walking speed, and cadence. However, patients with large heads had gait parameters more similar to healthy individuals, albeit with reduced pain and high patient satisfaction. Choosing the appropriate implant seems to be a crucial decision in the preoperative planning stage, and the results of the study may influence post-THA rehabilitation, focusing on developing a proper gait model.

In the study "Posture stability and risk of fall test in the objective assessment of balance in patients with ectopic bone tissue after total hip replacement," part of the doctoral dissertation, heterotopic ossifications were identified in 46 out of 312 patients after total hip arthroplasty. A control group of 39 patients without extra-skeletal ossifications was matched. Patients underwent radiological and biomechanical evaluation and completed WOMAC and Oxford questionnaires for hip function assessment.

In the study "Hip hemiprosthesis due to femoral neck fracture in the elderly population - are we doing it right?" a part of this doctoral thesis, the authors analyzed the effectiveness of reproducing parameters using standard stem prostheses depending on the neck-shaft angle. The analysis included 100 consecutive patients undergoing hemiarthroplasty due to femoral neck fracture. A correlation was demonstrated between the neck-shaft angle and change in FO, and a significant difference in the change in this angle and change in FO. The use of standard stem implants, designed to replicate a neck-shaft angle of about 130 degrees, may lead to incorrect FO reproduction, requiring thoughtful decision-making before surgery.

Wstęp

Pierwotna endoprotezoplastyka stawu biodrowego

Choroba zwyrodnieniowa stawu biodrowego jest jedną z najczęstszych dysfunkcji dotykających wszystkie grupy społeczne. Szacuje się, że dotyczy globalnie ponad 500 milionów ludzi, a największą reprezentacją są osoby w grupie wiekowej po 55 roku życia. (1,2) Istotą choroby jest degeneracja chrząstki stawowej oraz okalających staw tkanek miękkich. W wyniku procesu zapalnego dochodzi do sklerotyzacji warstwy podchrzęstnej, wytworzenia narośli kostnych (osteofitów), przerostu błony maziowej i uogólnionej degeneracji stawu. Pacjenci skarżą się na dolegliwości bólowe, ograniczenie zakresu ruchu w stawie (ang. „Range of motion" – ROM), skrócenie długości kończyny, zaburzony model chodu. (3)

Leczenie koksartrozy stanowi wielkie wyzwanie dla systemów ochrony zdrowia na całym świecie. Szacuje się, że około 10% mężczyzn oraz 13% kobiet po 60 r.ż cierpi na objawową chorobę zwyrodnieniową stawu biodrowego, a liczba ta zwiększa się wraz z wiekiem. Przewiduje się, że w Stanach Zjednoczonych Ameryki oraz krajach Europy liczba chorych wymagających leczenia koksartrozy będzie rosła ze względu na epidemię otyłości, siedzący tryb życia i coraz większe wymagania pacjentów. (4,5)

Początkowo chorzy leczeni są zachowawczo. Do możliwych terapii należy leczenie doustne lekami przeciwbólowymi, rehabilitacją oraz iniekcjami dostawowymi.

Mimo rozwoju sposobów leczenia nieoperacyjnego złotym standardem w zaawansowanych zmianach zwyrodnieniowych, gdzie dochodzi do całkowitej degeneracji chrząstki, a co za tym idzie pełnej ekspozycji tkanki kostnej i jej bólowych zakończeń nerwowych, pozostaje endoprotezoplastyka całkowita stawu biodrowego (ang. „Total Hip Arthroplasty" – THA).

Zabieg endoprotezoplastyki całkowitej stawu biodrowego polega na chirurgicznym wycięciu uszkodzonych chorobowo fragmentów kostnych i chrzęstnych i zastąpieniu ich implantami. Do rekonstrukcji stawu biodrowego standardowo stosowane są implanty składające się z 4 części – panewki, wkładki, głowy oraz trzpienia endoprotezy. Podczas zabiegu niezwykle istotne jest odwzorowanie anatomicznych uwarunkowań biomechanicznych indywidualnych dla każdego chorego. Nieprawidłowe osadzenie elementów endoprotezy może przyspieszać obluzowanie implantów, ograniczać pooperacyjny zakres ruchomości chorego oraz upośledzać model chodu i powodować tym samym dolegliwości bólowe.

Endoprotezoplastyka stawu biodrowego jest stosowana również u osób ze złamaniami szyjki kości udowej. W przypadku chorych w wieku podeszłym oraz bez zmian zwyrodnieniowych zabiegiem z wyboru jest endoprotezoplastyka połowicza, inaczej bipolarna, podczas której nie jest osadzany implant panewki a specjalna czasza endoprotezy mocowana jest do głowy i pozwala na ruchy rotacyjne w panewce.

Przez lata THA osiągnęło status zabiegu operacyjnego o najwyższej skuteczności. W niedawnej publikacji w Lancet została nawet uznana za operację stulecia. Szacuje się, że liczba zadowolonych pacjentów sięga 90-96%. (6)

Mimo ciągłego doskonalenia techniki operacyjnej oraz implantów wciąż pozostaje około 10% niezadowolonych chorych. Do przyczyn niepowodzenia zalicza się niepełną restorację ROM, odczuwalne różnice w długości kończyn, dolegliwości bólowe, obluzowania endoprotezy oraz konieczność zabiegu rewizyjnego. Kluczem do osiągnięcia optymalnego wyniku leczenia jest odpowiednie planowanie i egzekucja prawidłowego osadzenia implantów endoprotezy. (7)

Mimo to, ze względu na coraz to rosnącą liczbę młodszych oraz starszych pacjentów wymagania co do wyniku klinicznego stale rosną. Młodsi pacjenci wymagają nieograniczonego zakresu ruchu oraz długą wytrzymałość implantu. Podczas, gdy dla pacjentów w starszym wieku kluczowym wynikiem leczenia jest redukcja dolegliwości bólowych i jak najmniejsza liczba powikłań.

Ocena radiologiczna zabiegu operacyjnego

W codziennej praktyce podstawą diagnostyki radiologicznej jest klasyczny radiogram przeglądowy miednicy w obciążeniu kończyn. Badanie pozwala na ocenę w projekcji przednio-tylnej (antero-posterior) oceny ścieńczenia i/lub ubytków chrząstki oraz relacji kości tworzących staw biodrowy, co odwzorowuje natywną biomechanikę stawu. (8)

Dodatkowymi możliwymi badaniami obrazowymi są tomografia komputerowa (ang. „Computed tomography: - CT) oraz rezonans magnetyczny (ang. „Magnetic resonance imaging" – MRI). CT mimo dokładniejszej analizy relacji kostnych w trzech wymiarach ma niewielki wpływ na diagnostykę oraz planowanie leczenia standardowej choroby zwyrodnieniowej, a niesie za sobą ryzyko zwiększonej ekspozycji radiacyjnej oraz jest badaniem mniej dostępnym niż klasyczny radiogram. (9)

MRI jest zarezerwowane głownie dla diagnostyki pooperacyjnej, gdzie poszukuje się przyczyn niepowodzenia leczenia takich jak obluzowanie elementów endoprotezy, konfliktu elementów implantu z tkankami miękkimi. Ponadto ze względu na duży koszt badania oraz niski wpływ na decyzje terapeutyczne w diagnostyce koksartrozy jest badaniem niezwykle rzadko wykonywanym. (10)

Kluczowe dla dobrego wyniku jest zastosowanie odpowiedniej techniki operacyjnej. Pozwala to na prawidłowe osadzenie implantów, w taki sposób by jak najlepiej odtworzyć anatomiczne, pierwotne stosunki struktur stawu biodrowego.

Przez lata określono parametry osadzenia implantów w trzech płaszczyznach pozwalające na prawidłowe rozkłady sił podczas chodu, zmniejszające ryzyko niestabilności oraz nie ograniczające zakresu ruchu.

Przed laty Lewinek i wsp. opublikowali pracę, która przez wiele lat była uznawana za źródło wytycznych określających prawidłowe położenie panewki endoprotezy, w celu uzyskania pełnej stabilności implantów. Po wielu latach okazało się, że mimo stosowania zaleceń z powyższej pracy donoszono o niestabilności stawów biodrowych po zabiegach endoprotezoplastyki. Mimo to, wartości kątowe inklinacji oraz antewersji panewki pozostały złotymi standardami, do których należy dążyć podczas implantacji endoprotezy. (11,12)

W publikacji „How to analyze postoperative radiographs after total hip replacement", która wchodzi w skład pracy doktorskiej dokonano analizy parametrów, które opisują prawidłowe osadzenie implantów endoprotezy stawu biodrowego. Jest to pierwsza tego typu praca na świecie podsumowująca sposoby mierzenia tych wartości.

Centrum rotacji stawu biodrowego (ang. „Center of rotation" - COR) opisuje oś obrotu głowy kości udowej w panewce stawu.

W publikacji Lum i wsp. opisano, że podczas implantacji endoprotezy limit przesunięcia COR to 3 mm dogłowowo oraz 5 mm przyśrodkowo. Przesunięcie większe powoduje zmianę rozkładu wektorów sił w endoprotezie oraz otaczających tkanek miękkich, w tym stabilizatorów miednicy oraz rotatorów i odwodzicieli. Może to powodować przyspieszone obluzowanie implantu, ograniczenie ROM, dolegliwości bólowe, niestabilność stawu biodrowego czy upośledzony model chodu. (13)

Offset udowy (ang. "Femoral offset" – FO) opisywany jest jako odległość pomiędzy COR głowy kości udowej a linią poprowadzoną w przedłużeniu osi trzonu kości udowej. W publikacji opisano, że zwiększenie wartości FO powyżej 5 mm może powodować przyspieszenie zużycia polietylenowej wkładki endoprotezy. Zmniejszenie natomiast o 5 lub więcej mm może powodować zmniejszone spoczynkowe napięcie tkanek, a co za tym idzie dolegliwości bólowe, a nawet prowadzić do niestabilności stawu. (14)

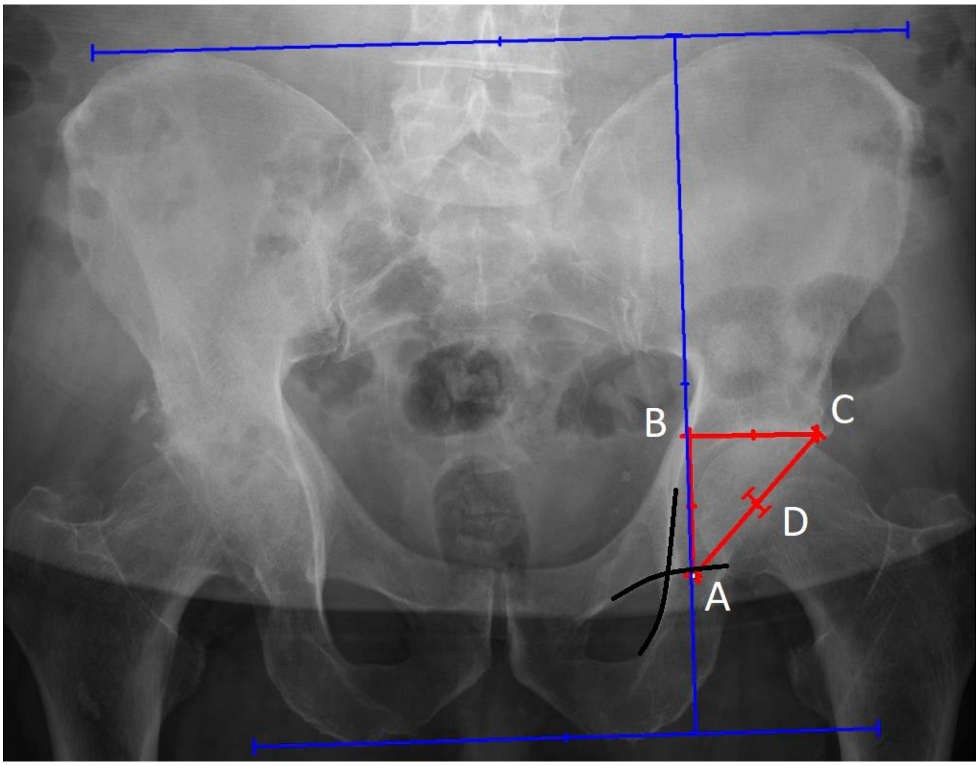
Offset panewkowy (ang. "Acetabular offset" – AO) opisywany jest jako odległość pomiędzy COR głowy kości udowej a ścianą przyśrodkową powierzchni czworobocznej miednicy, która określana jest jako łezka Koehlera. Niepoprawne odtworzenie AO wpływa na napięcie mięśni pośladkowych oraz wektor ramienia siły, w którym dochodzi do ich skurczu. (15)

Inklinacja panewki (ang. "Acetabular inclination" - AI) określana również jako kąt odwiedzenia biodra. Opisywana jest jako kąt zawarty pomiędzy linią styczną do guzów kulszowych oraz linii poprowadzonej wzdłuż brzegu panewki endoprotezy. Wartość tego kąta wpływa na ROM oraz zużycie wkładu polietylenowego. Gdy kąt ten jest zbyt niski zgięcie oraz odwiedzenie stawu biodrowego może być mechanicznie ograniczone. W przypadku zbyt rozwartego kąta ograniczeniu ulega przywiedzenie oraz rotacja, a także zwiększone są siły działające na wkładkę powodując jej zbyt szybkie wycieranie. (16)

Antewersja panewki (ang. "Acetabular anteversion" – AA) opisywana jest jako kąt zawarty pomiędzy osią podłużną panewki a poprzeczną elipsy ją tworzącą. Jest to parametr trudny do zmierzenia w standardowym badaniu radiologicznym, które pozwala jedynie oszacować wartość tego kąta. Dedykowanym badaniem do oceny AA jest tomografia komputerowa. Zbyt duża oraz zbyt mała antewersja zwiększa ryzyko niestabilności endoprotezy. Jednakże w literaturze brak jest konsensusu jaka wartość tego kąta jest odpowiednia oraz coraz większą uwagę zwraca się na wpływ sztywności odcinka lędźwiowo-krzyżowego na dynamiczną antewersję panewki. Ocena antewersji panewki ma również znaczenie w diagnostyce obluzowania elementu panewkowego endoprotezy, gdyż udowodniono, że już zmiana tego kąta w badaniach obrazowych o 1.59 stopnia jest wczesnym objawem obluzowania. (17)

Różnica długości kończyn dolnych (ang, "Leg length discrepancy" – LLD) jest jednym z najczęstszych błędów podczas THA. Dużo częściej występuje nadmierne wydłużenie kończyny niż jej skrócenie. Udowodniono, że wydłużenie powyżej 6 mm a skrócenie powyżej 10mm są wartościami odczuwalnymi przez chorych. Wydłużenie kończyny wiąże się z wtórnymi zmianami ustawienia miednicy orz kręgosłupa lędźwiowego, co może powodować dolegliwości bólowe w tym odcinku oraz upośledzać model chodu. (18)

Istnieje kilka Technik określania różnicy w długości kończyn. Jedną z najpopularniejszych jest wyznaczenie linii prostopadłej pomiędzy łzą Koehlera a szczytem krętarza mniejszego.



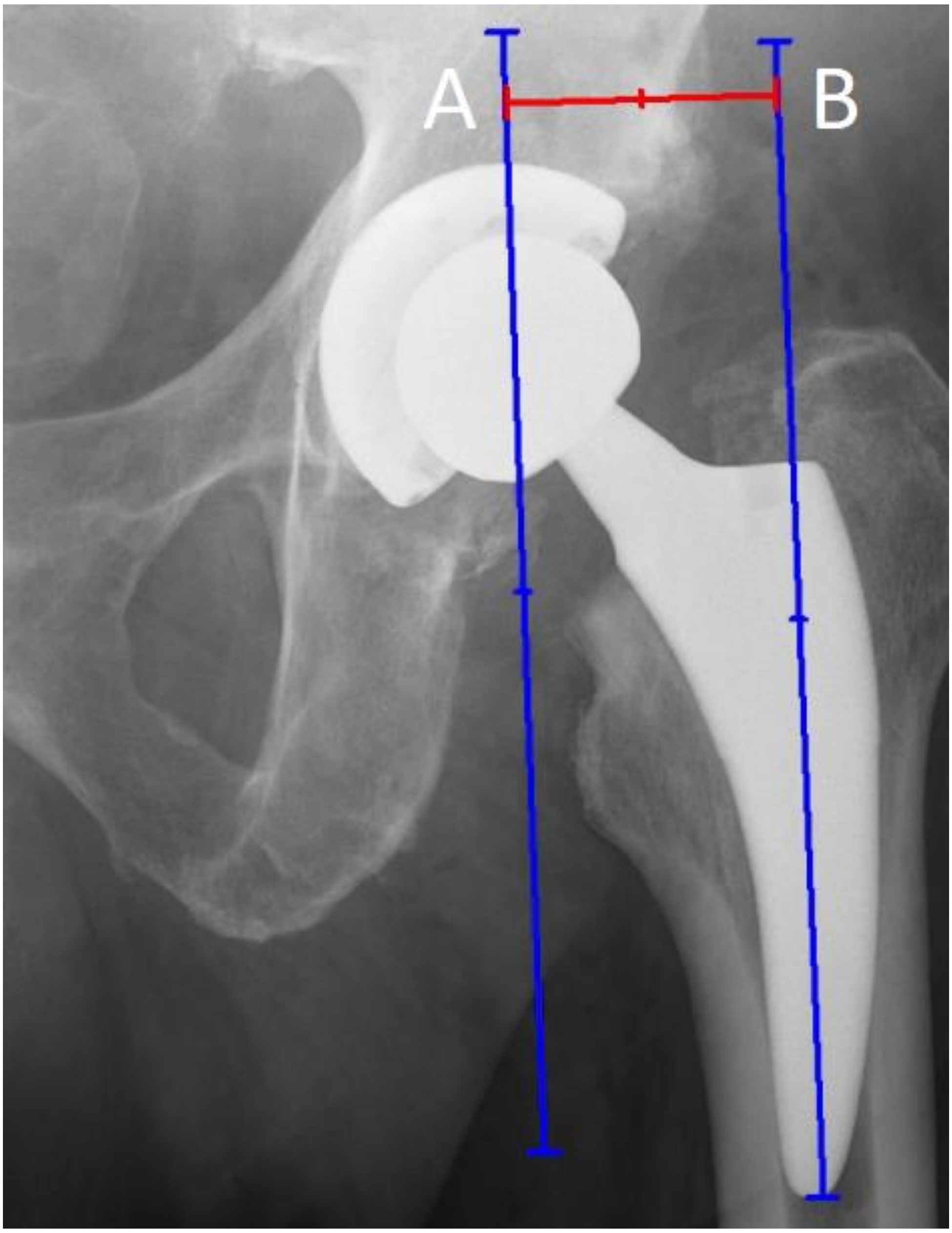
Rycina 1. Określanie COR.

A. *Punkt zlokalizowany 5mm bocznie od miejsca przecięcia łuku Shentona oraz łzy Koehlera*

B. *Punkt zlokalizowany na szczycie warstwy podchrzęstnej panewki stawu biodrowego w linii przebiegającej przez punkt A oraz prostopadle do podłoża*

C. *Punkt zlokalizowany w linii równoległej do podłoża przebiegającej przez punkt B oraz położony na bocznej części warstwy podchrzęstnej panewki stawu biodrowego*

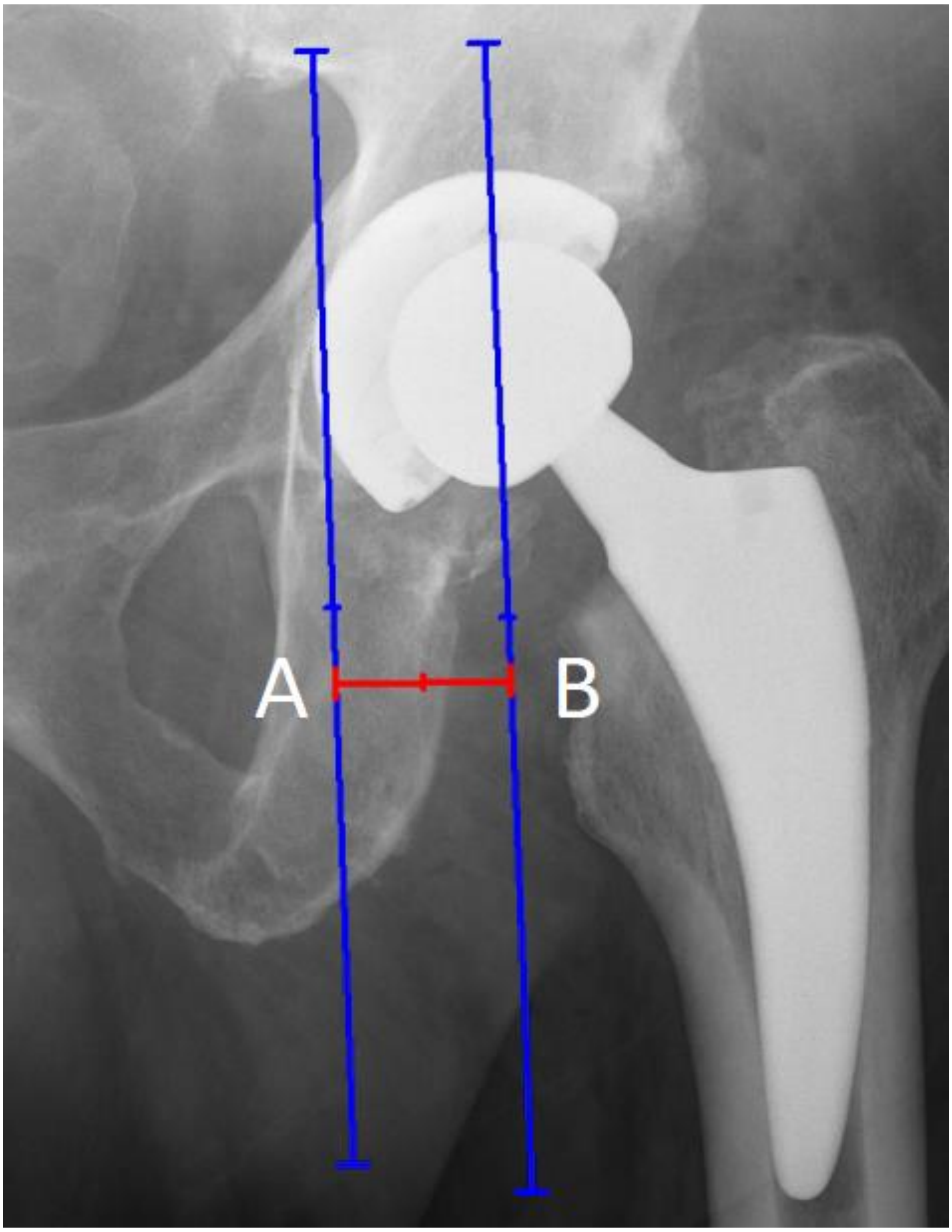
D. *Punkt zlokalizowany w połowie dystansu między punktami A i C*



Rycina 2. Pomiar FO.

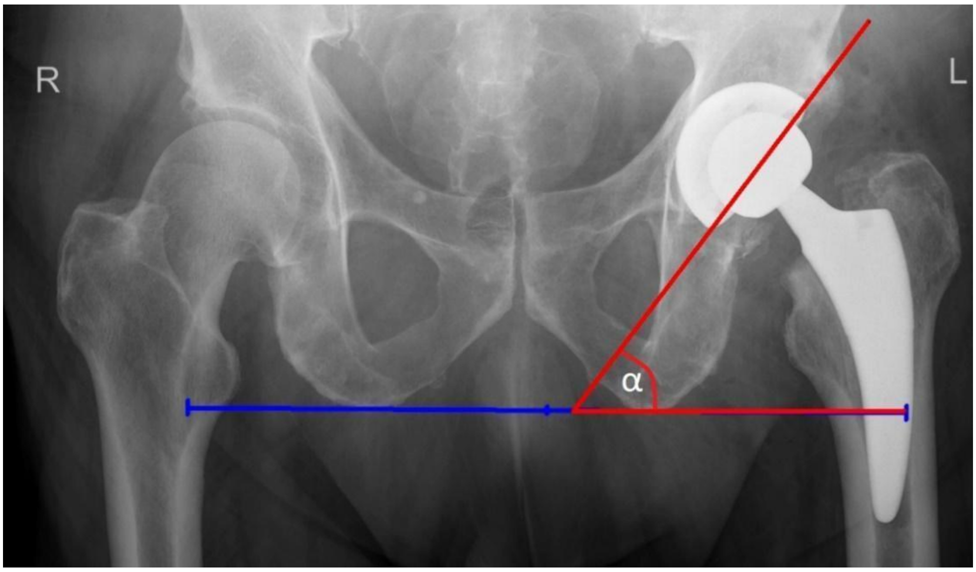
A. *Linia przechodząca przez COR, prostopadle do podłoża*

B. *Linia przechodząca w osi kości udowej*



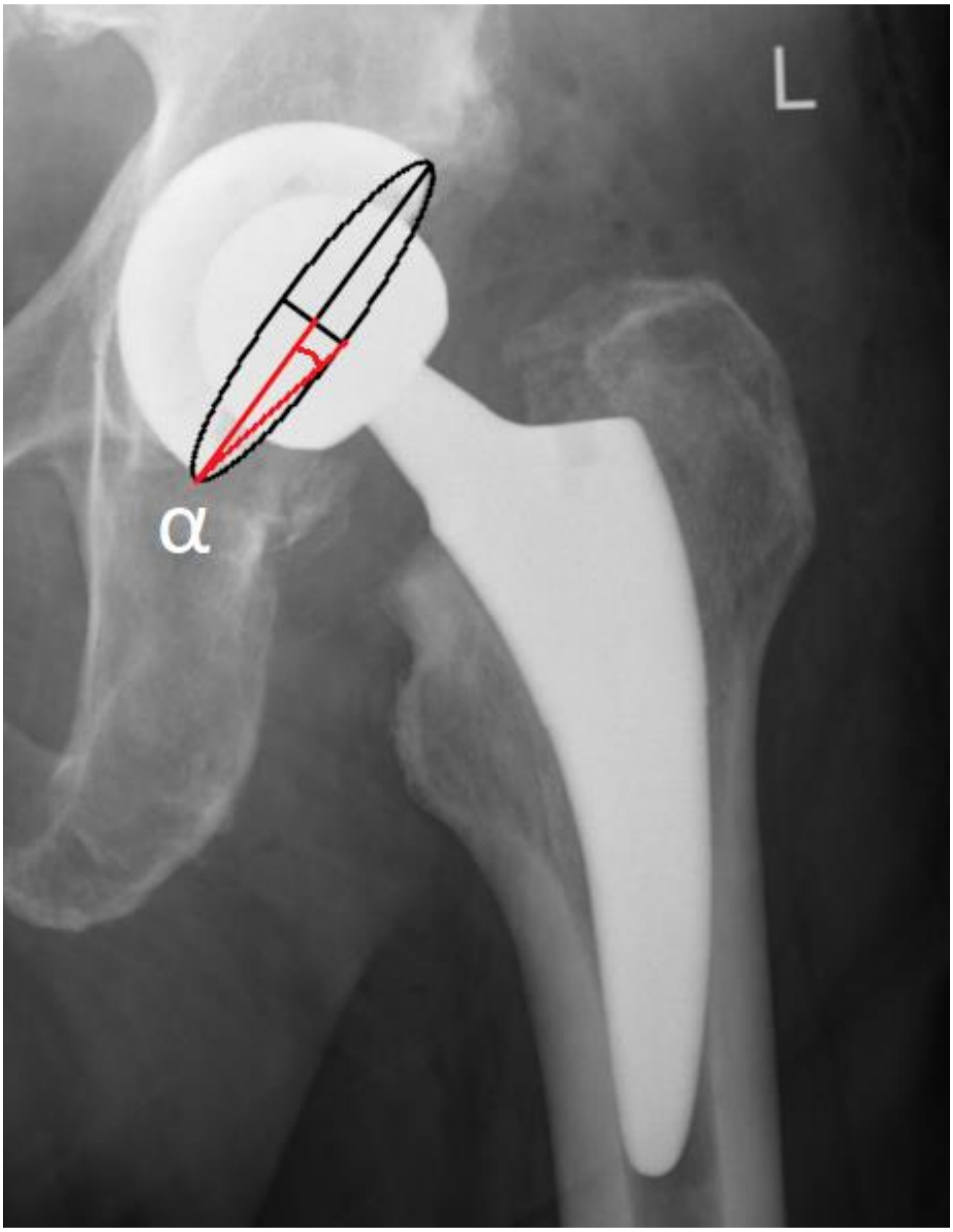
Rycina 3. Pomiar AO.

A. *Linia przechodząca przez przyśrodkową*
B. *Linia przechodząca przez COR prostopadła do podłoża*



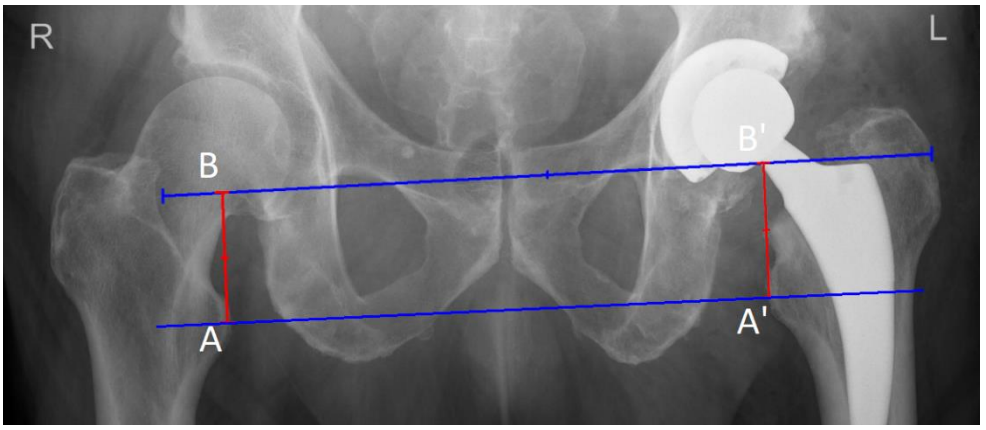
Rycina 4.

Kąt α – kąt zawarty pomiędzy linią międzykulszową oraz linią przebiegająca stycznie do brzegów panewki.



Rycina 5 Pomiar antewersji panewki stawu biodrowego.

Kąt α – zawarty pomiędzy długą przekątną elipsy panewki a linią łączącą z krótką przekątną



Rycina 6 Pomiar różnicy długości kończyn.

A. *Oraz A' Punkty w najwydatniejszym punkcie krętarzy mniejszych*
B. *Oraz B' Punkty zlokalizowane na najniższych punktach łez Koehlera*
C. *Różnica odległości pomiędzy punktami AB oraz A'B' to różnica długości kończyn*

Technika operacyjna a wynik kliniczny

Do wykonania zabiegu operacyjnego konieczne jest zastosowanie jednego z kilku możliwych dostępów operacyjnych. Obecnie najczęściej stosowanymi na świecie są dostępy bezpośredni przedni (ang. „Direct anterior approach" - DAA), przednio-boczny (ang. „Antero-lateral approach" – ALA) oraz tylno-boczny (ang. „postero-lateral approach" – PLA). W zależności od dostępu operator preparuje konkretne tkanki miękkie oraz wykonuje implantację endoprotezy w specyficznym ułożeniu ciała.

W ostatnich latach dostęp DAA cieszył się ogromną popularnością wśród pacjentów, gdyż wiąże się z teoretycznie najmniejszą traumatyzacją dla tkanek miękkich. Podczas tego dostępu operacyjnego wykorzystuje się naturalny interwał międzymięśniowy pomiędzy naprężaczem powięzi szerokiej a mięśniem krawieckim. W wielu przeglądach systematycznych i meta-analizach wykazano, że istotnie dostęp ten w porównaniu do innych dostępów wykazuje szybszy powrót do aktywności oraz poprawy funkcji stawu. Jednakże istotne różnice utrzymują się jedynie przez około 3 miesiące, a w późniejszym okresie wynik kliniczny jest porównywalny. (19, 20) Ponadto w niedawnych publikacjach zwrócono uwagę na istotnie zwiększoną liczbę wczesnych rewizji endoprotez wykonywanych z dostępu DAA. (21) Podejrzewano ograniczenie widoczności oraz mała przestrzeń do manewrowania narzędziami chirurgicznymi jako przyczynę związaną z nieprawidłowym osadzeniem elementów endoprotezy. W literaturze brak do tej pory było prac przeglądowych, które analizowałyby osadzenie elementów endoprotezy pod kątem radiologicznym pomiędzy DAA a innymi klasycznymi dostępami operacyjnymi.

W badaniu “The Direct Anterior Approach to Primary Total Hip Replacement: Radiological Analysis in Comparison to Other Approaches”, które wchodzi w skład rozprawy doktorskiej autorzy przeprowadzili przegląd publikacji analizujących powyższe parametry pomiędzy dostępem DAA a PLA oraz ALA. W publikacji przeanalizowano wpływ dostępu operacyjnego na sposób osadzenia implantów endoprotezy.

Przeprowadzono przegląd literatury dotyczący DAA w porównaniu z dostępami przednio-bocznym oraz tylno-bocznym i wpływu użycia tego dostępu na położenie panewki stawu biodrowego (inklinacja, offset udowy, panewkowy oraz antewersja) oraz osadzenie w granicach bezpieczeństwa Lewinnek’a, osiowość osadzenia trzpienia endoprotezy, różnica długości kończyn. Do ostatecznej analizy włączono 9 prac.

Oś osadzenia trzpienia endoprotezy

Analiza 7 prac włączonych do analizy tego aspektu osadzenia trzpienia endoprotezy wykazała, że w porównaniu dostępu DAA oraz ALA, ten pierwszy charakteryzował się mniej szpotawym osadzeniem trzpienia endoprotezy (1.23 stopnia vs. 2.37 stopnia). Mimo to w analizowanych publikacjach różnica ta nie osiągała wartości istotności statystycznej.

Inklinacja panewki

Analiza 9 prac włączonych do analizy wykazała, istotną statystycznie różnicę pomiędzy powyższym parametrem w porównaniu dostępu DAA oraz ALA (42.68 vs 46.29 stopni). Jednakże, w publikacji Brun’a i wsp. autorzy podawali istotnie statystycznie większą wartość kąta inklinacji w grupie DAA (średnia różnica 2.5 stopnia, $p=0.023$). W porównaniu dostępu DAA do PA, nie wykazano istotnych różnic w wartości inklinacji panewki w żadnym z analizowanych badań.

Antewersja panewki

Analiza 6 prac wykazała, że dostęp DAA charakteryzuje się większą wartością powyższego parametru w porównaniu do każdego stosowanego dostępu. W porównaniu z dostępem PA (średnia różnica 3.82 stopnia, $p<0.05$), PLA (średnia różnica 4.85 stopnia, $p<0.05$) oraz ALA (średnia różnica 3.6, $p< 0.0001$).

Różnica długości kończyn

Jedynie 3 prace analizowały różnicę w długości kończyn po zabiegu operacyjnym. W żadnej z analizowanych prac różnica długości kończyn nie wykazywała istotnej różnicy.

Konkludując, należy zauważyć, że zastosowanie dostępu DAA może mieć istotny wpływ na osadzenie elementów endoprotezy. W powyższej analizie wykazano, że takie parametry jak antewersja oraz inklinacja panewki zależą od zastosowanego dostępu. Mimo braku istotnych statystycznie wyników różnic pozostałych parametrów osadzenia implantów endoprotezy w zależności od zastosowanego dostępu operacyjnego, chirurdzy muszą mieć na uwadze, że zmiana kierunku wprowadzania implantów może wpływać na ich przestrzenne ułożenie, a co za tym idzie na wynik zabiegu.

Analiza biomechaniczna

Staw biodrowy oraz kręgosłup funkcjonują od najmłodszych lat jako biomechaniczny łańcuch z wyrafinowanymi zależnościami między sobą. Siły i ruch przenoszone są pomiędzy stawem biodrowym a kręgosłupem poprzez miednicę i stawy krzyżowo-biodrowe. W związku z tym zaburzenie funkcji w wyniku choroby któregokolwiek odcinka kręgosłupa wpływa wtórnie na ustawienie miednicy i stawu biodrowego i odwrotnie. (22) W ciągu życia oraz w wyniku działania czynników ryzyka dochodzi do rozwoju choroby zwyrodnieniowej stawów międzykręgowych kręgosłupa, zwłaszcza w odcinku L-S oraz dehydratacji krążków. W związku z tym często pacjenci charakteryzują się zmniejszoną lordozą w odcinku L-S oraz zwiększoną kifozą w odcinku piersiowym, przykurczami w stawach biodrowych czy kolanowych i wtórnymi ustawieniami miednicy. Im dłużej trwają te zmiany i im bardziej zaawansowana jest choroba tym mniej mobilne stają się odcinki kręgosłupa, stawy krzyżowo-biodrowe oraz stawy biodrowe. (23) W badaniu Malkani i wsp. wykazano, że ryzyko zwichnięcia endoprotezy stawu biodrowego u chorych ze sztywnością kręgosłupa L-S oraz stawów krzyżowo-biodrowych było większe niż u chorych bez wtórnych zmian ustawienia miednicy. (24) W związku z tym zwrócono uwagę w światowej literaturze na konieczność modyfikowania sposobu wykonywania endoprotezoplastyki całkowitej stawu biodrowego u chorych z wtórnymi zmianami ustawienia miednicy. Jednakże wciąż pozostawało niejasne jak określić, którzy pacjenci należą do grupy ryzyka.

„Spinopelvic alignment" uznawane jest obecnie za koncept, który ma odmienić endoprotezoplastykę całkowitą stawu biodrowego. Dzięki powiązaniu mechaniki miednicy i stawu biodrowego z odcinkiem L-S chirurdzy na świecie mogą z większym zrozumieniem dobierać indywidualnie osadzenie elementów endoprotezy, by zapewnić pacjentowi jak największy bezpieczny ROM, a co za tym idzie ograniczyć liczbę powikłań i konieczności wykonywania zabiegów rewizyjnych. Określenie w jaki sposób zindywidualizować osadzenie endoprotezy dla konkretnego pacjenta jest niezwykle trudne i wymaga bardzo dokładnego szerokiego planowania przedoperacyjnego.

W publikacji "Spinopelvic Alignment and Its Use in Total Hip Replacement Preoperative Planning—Decision Making Guide and Literature Review", która wchodzi w skład rozprawy doktorskiej autorzy dokonali pierwszego na świecie przeglądu systematycznego oraz określili wytyczne osadzania elementów endoprotezy w zależności od sztywności odcinka L-S kręgosłupa oraz wtórnych ustawień miednicy. Do określenia prawidłowego osadzenia endoprotezy należy ocenić mobilność miednicy za pomocą kilku parametrów mierzonych na bocznym radiogramie miednicy z objęciem połowy trzonu kości udowej oraz odcinka L-S:

A. Sacral Slope (SS) — by zmierzyć wartość tego kata należy przeprowadzić linię styczną do górnej blaszki granicznej kręgu S1 oraz do wektora działania siły grawitacji. Prawidłowa wartość kata zawartego między tymi stycznymi wynosi 32-49 stopni

B. Pelvic Tilt (PT) — by zmierzyć wartość tego kata należy wyznaczyć linię prostopadłą łączącą styczną do górnej blaszki kręgu S1 oraz środka głowy kości udowej. Prawidłowa wartość wynosi pomiędzy 7 a 19 stopni.

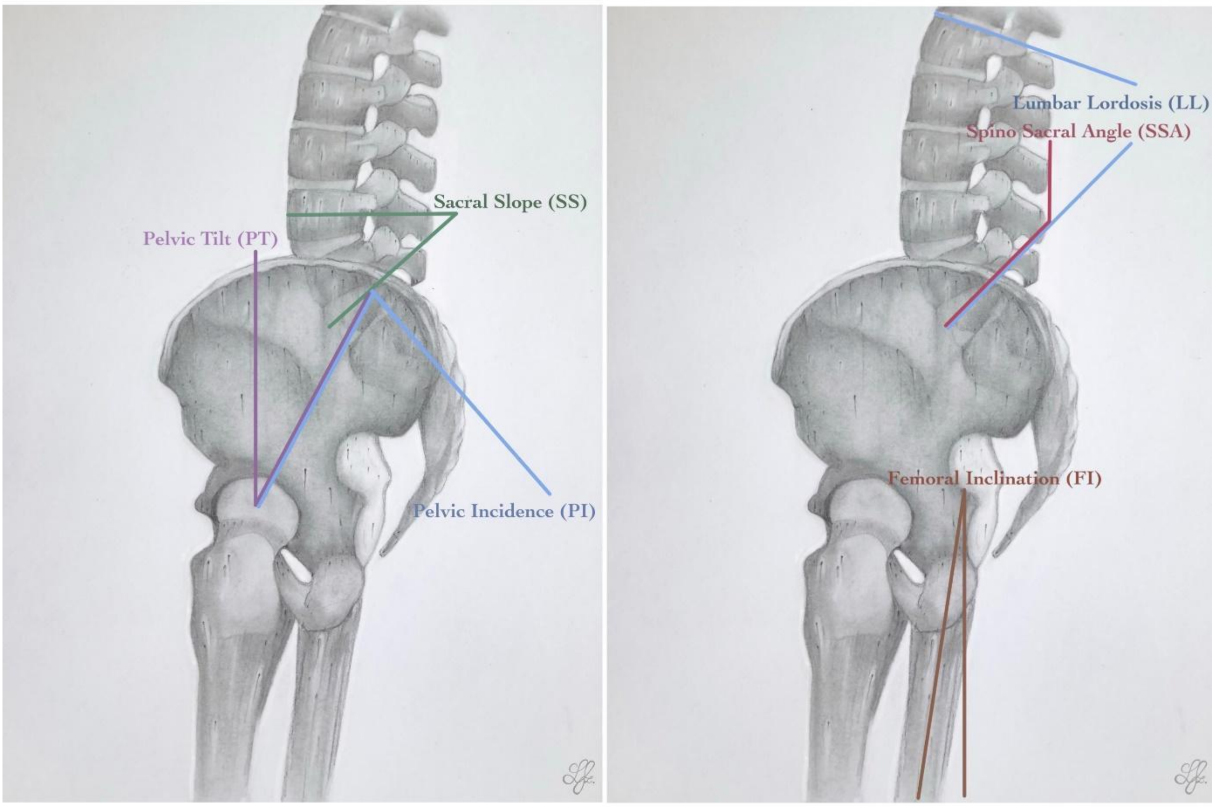
C. Pelvic Incidence (PI) — by zmierzyć wartość tego kata należy wyznaczyć linię łączącą najwyższy punktu blaszki granicznej S1 oraz oś głowy kości udowej. Prawidłowa wartość wynosić powinna pomiędzy 38 i 56 stopni.

D. Pelvic Femoral Angle (PFA) — by zmierzyć wartość tego kąta należy przeprowadzić linię przez środek kości krzyżowej oraz w osi długiej kości udowej. Prawidłowa wartość zawarta jest pomiędzy 1 a 17 stopni.

E. Lumbar Lordosis (LL) — kąt zawarty pomiędzy styczną do górnej blaszki granicznej kręgu L1 oraz stycznej do górnej blaszki granicznej kręgu S1. Prawidłowa wartość zawarta jest pomiędzy 40 i 58 stopni.

F. Femoral Inclination (FI) — kąt zawarty pomiędzy linią prostopadłą do połdoża a osią długą kości udowej. Prawidłowa wartość zawiera się pomiędzy 0 a 18 stopni.

H. Spino Sacral Angle (SSA) — kąt zawarty pomiędzy blaszką graniczną S1 oraz linią prostopadłą do podłoża. Prawidłowa wartość zawiera się pomiędzy 119 a 133 stopnie.



Rycina 7 .Przykładowe pomiary wykonane na radiogramie miednicy w projekcji bocznej (b) Spino Sacral Angle, Lumbar Lordosis and femoral Inclination (b) Sacral Slope, Pelvic Incidence and Pelvic Tilt

Na podstawie powyższych pomiarów można podzielić ruchomość kompleksu kręgosłupowo-miednicznego na trzy typy.

Tabela 1. Typy mobilności połączenia miedniczno-krzyżowego

Spinopelvic motion	Zmiana pochylenia miednicy [°]	Zmiana nachylenia biodra [°]	Lordoza lędźwiowa [°]	Kąt miedniczno-udowy [°]
Prawidłowe	20-35	55-70	20	45
Hipermobilny	>35	<55	>20	<45
Sztywny	<20	>70	<20	>45

Autorzy pracy “ Spinopelvic Alignment and Its Use in Total Hip Replacement Preoperative Planning—Decision Making Guide and Literature Review” zaproponowali na podstawie dostępnej literatury wytyczne dotyczące odpowiedniego położenia panewki podczas THR w zależności od powyższej klasyfikacji. By odpowiednio ocenić mobilność kręgosłupa należy zmierzyć powyżej opisane wartości kątów na radiogramie w pozycji stojącej oraz siedzącej w 90 stopniach zgięcia w stawach biodrowych.

Tabela 2. Rekomendacje osadzania elementów endoprotezy w zależności od mobilności połączenia miedniczno-krzyżowego

Spinopelvic alignment	Rekomendacja przedoperacyjna
Retorwersja miednicy	Większa antewersja i inklinacji panewki – w granicach strefy bezpieczeństwa
Antewersja miednicy	Mniejsza antewersja i inklinacji panewki – w granicach strefy bezpieczeństwa
Stan po stabilizacji kręgosłupa lędźwiowego z miednicą z tendecją do antewersji	Większa qntewersja panewki – do 30 stopni
Stan po stabilizacji kręgosłupa lędźwiowego z miednicą z tendecją do retrowersji	Mniejsza antewersja panewki – do 5 stopni
Hipermobilność złącza miedniczno-krzyżowego	Większa antewersja panewki – do 25 stopni
Sztywność połączenia miedniczno-krzyżowego	Większa inklinacja panewki – w granicach strefy bezpieczeństwa

Dotychczas udowodniono związek pochylenia miednicy z antewersją panewki endoprotezy. Zmiana antewersji o jeden stopień powoduje zmianę tiltu o 0.7 stopnia [36]. Podobnie inklinacją panewki zwiększa się o 0.3 stopnia przy zwiększeniu pochylenia o 1 stopień. Jednakże zależność ta wydaje się być nielinearna i dużo bardziej skomplikowana.

Rozumiejąc biomechanikę stawu biodrowego i konieczność dążenia do odtworzenia jej prawidłowej mechaniki chirurdzy od lat poszukują najlepszej kombinacji implantów, pozwalających na odtworzenie prawidłowego modelu chodu. Jednym z podnoszonych aspektów dotyczących wyboru implantu stawu biodrowego jest określenie średnicy głowy endoprotezy. Powstało wiele badań i analiz krajowych rejestrów endoprotezoplastyk, w których określano średnicę głowy zapewniającą jak najdłuższe przeżycie implantu oraz najlepszy wynik kliniczny. (25-27)Wykazano, że średnice głów powyżej x mm, wiążą się ze zwiększonym tarciem i wartościami wektorów sił działających na jednostkę powierzchni wkładki polietylenowej. Wykazano, że mimo stosowania głów, których średnice są zbliżone do średnicy natywnej głowy kości udowej wiązały się z dużo szybszym ścieraniem polietylenu, a co za tym idzie koniecznością wcześniejszej rewizji endoprotezy oraz mogły powodować konlifktowanie ze ścięgnem mięśnia biodrowo-lędźwiowego. Jednakże, większa średnica głowy istotnie wiąże się z mniejszym ryzykiem zwichnięcia stawu biodrowego z powodu większego ramienia siły potrzebnego do wyważenia jej z panewki. Związany jest z tym również lepszy zakres ruchomości stawu. Obecnie najpowszechniej stosowanymi średnicami głów są te o wielkości 32 lub 36 mm. Jednakże dotychczas publikacje skupiały się na porównaniu przeżycia oraz zakresu ruchu pomiędzy tymi głowami.

W badaniu „Analysis of biomechanical gait parameters in patients after total hip replacement operated via anterolateral approach depending on size of the femoral head implant: retrospective matched-cohort study", które wchodzi w skład rozprawy doktorskiej autorzy przeanalizowali parametry chodu pomiędzy dwoma grupami pacjentów operowanych w Klinice Ortopedii i Rehabilitacji Warszawskiego Uniwersytetu Medycznego oraz kontrolną grupą zdrowych ochotników. Jedną z grup stanowili pacjenci, u których endoprotezoplastyka została wykonana z użyciem implantów z głową o średnicy 36mm. Do tej grupy została dobrana homogenna pod względem wieku, płci, operowanej strony grupa pacjentów, których zabieg został przeprowadzony z użyciem implantów o średnicy głowy 28 lub 32mm oraz wyniki porównano z parametrami chodu typowymi dla osób bez choroby zwyrodnieniowej.

Każdy uczestnik badania przeszedł analizę radiologiczną stawów biodrowych, ocenę wyniku funkcjonalnego w skali WOMAC oraz VAS, oraz analizę parametrów chodu.

Wykazano, że w analizie chodu pacjenci, u których zastosowano małe głowy w porównaniu z grupą zdrowych uczestników występował dłuższy czas podporu zarówno dla operowanej (72.3% vs. 61.0%, $p = 0.012$) i nieoperowanej kończyny (70.8% vs.61.0%, $p = 0.023$), czas podporu na dwóch kończynach (20.3% vs. 13.0%, $p = 0.001$) oraz opadanie miednicy po stronie przeciwnej do operowanej (9.0° vs. 7.0°, $p = 0.034$) oraz nieoperowanej 8.5° vs. 7.0°, $p = 0.036$).

Wykazano istotnie krótszy czas fazy przenoszenia zarówno w operowanej (27.7% vs. 39.0%, p = 0.007 jak i nieoperowanej kończynie (29.2% vs. 39.0%, p = 0.005);, długość kroku w operowanej (0.31 m vs. 0.73 m, p = 0.001) i nieoperowanej (0.44 m vs. 0.73 m, p = 0.021);, niższą średnią prędkość kroku (0.52 m/s vs.1.39 m/s, p = 0.007) oraz kadencje chodu (75.4 kroki/min vs. 113.8 kroki/min, p = 0.004) w porównaniu ze zdrowymi uczestnikami.

Wykazano, że w analizie chodu pacjenci, u których zastosowano duże głowy w porównaniu z grupą zdrowych uczestników cechowali się dużo bardziej zbliżonymi do nich parametrami chodu takimi jak czas podporu zarówno dla operowanej (64.1% vs. 61.0%, p = 0.065) i nieoperowanej kończyny (64.0% vs. 61.0%, p = 0.064), czas przenoszenia dla operowanej (35.9% vs. 39.0%, p = 0.059) i nieoperowanej kończyny (36.0% vs. 39.0%, p = 0.06), czas podporu na dwóch kończynach (16.4% vs. 13.0%, p = 0.057). p = 0.001). Jednakże opadanie miednicy było istotnie większe w tej grupie w porównaniu do osób zdrowych zarówno dla operowanej (8.5° vs. 7.0°, p = 0.023) i nieoperowanej kończyny (8.0° vs. 7.0°, p = 0.046).

Istotnie mniejsze od wartości u osób zdrowych występowały długość kroku w operowanej (0.5 mvs. 0.73 m, p = 0.022)) i nieoperowanej (0.6 m vs. 0.73 m, p = 0.041;, niższą średnią prędkość kroku 0.7 m/s vs.1.39 m/s, p = 0.025)   oraz kadencje chodu (87.3 kroki/min vs. 113.8 kroki/min, p = 0.032).

Wyniki powyższej analizy jednoznacznie wskazują na fakt, ze zastosowanie głów o średnicy 36 mm zdecydowanie odtwarzało parametry chodu bliższe modelowi osób zdrowych. Mimo to nadal występują znaczące różnice mimo zdecydowanego zmniejszenia dolegliwości bólowych i wysokiego stopnia zadowolenia chorych. Wybór odpowiedniego implantu zdaje się być jedną z kluczowych decyzji na etapie planowania przedoperacyjnego. Ponadto wyniki tej pracy mogą zmienić postępowanie rehabilitacyjne po THA, zwracając większą uwagę na wypracowanie prawidłowego modelu chodu – jak najbliższego natywnemu stawu biodrowemu.

Jak wspomniano wyżej odtworzenie prawidłowych warunków anatomicznych podczas endoprotezoplastyki stawu biodrowego jest kluczem do odpowiedniej jego funkcji i braku dolegliwości bólowych. Podczas endoprotezoplastyki połowiczej stawu biodrowego dochodzi do implantacji endoprotezy bez elementu panewkowego. Wiąże się z tym brak możliwości zmiany offsetu panewkowego – AO. W związku z tym dla odpowiedniego napięcia i funkcji mięśni pośladkowych niezwykle istotne jest osadzenie elementów endoprotezy jak najbliżej odtwarzając LLD oraz FO. Dotychczas w literaturze nie zwracano uwagi na odtwarzanie powyższych parametrów z użyciem standardowych trzpieni endoprotez.

W badaniu "Hip hemiprosthesis due to femoral neck fracture in the elderly population - are we doing it right?", które wchodzi w skład tej rozprawy doktorskiej autorzy przenalizowali skuteczność odtworzenia powyższych parametrów z użyciem standardowych trzpieni endoprotez w zależności od kąta szyjkowo-trzonowego.

Do analizy włączono 100 kolejnych pacjentów poddanych zabiegowi endoprotezoplastyki połowiczej stawu biodrowego z powodu złamania szyjki kości udowej w trybie przyspieszonym. Wszyscy pacjenci byli operowani z użyciem standardowych trzpieni stosowanych w THA. Zmierzono przed- oraz pooperacyjnie FO oraz kąt szyjkowo-trzonowy.

Wykazano, że zachodził związek pomiędzy kątem szyjkowo-trzonowym a zmianą FO ($r = 0.568$, $p < 0.0001$). Istniała statystycznie istotna różnica pomiędzy zmianą tego kata a zmianą FO (24:52 vs. 14:7, $p = 0.005$). Oznacza to, że u pacjentów z biodrami szpotawymi (kątem udowo-szyjkowym poniżej 120 stopni) pooperacyjna zmiana FO wynosiła więcej niż 5 mm, a jedynie połowa pacjentów miała prawidłowo odtworzony FO, czyli różnicę zawierającą się w wartości bezwzględnej 5mm.

Przyczyną tak niepoprawnego odtworzenia FO było stosowanie standardowych trzpieni endoprotezy, które zaprojektowane są do odtworzenia kąta szyjkowo-trzonowego o wartości około 130 stopni. Podczas stosowania ich u chorych z istotnie mniejszą i większą wartością tego parametru operator naraża się na istotne zmniejszenie lub zwiększenie FO, co w przypadku endoprotezoplastyk połowiczych nie może być skorygowane położeniem panewki endoprotezy. W związku z tym kluczową decyzją jest wybranie odpowiedniego typu trzpienia przed zabiegiem, co pozwoli na prawidłowe odtworzenie FO.

Skostnienia pozaszkieletowe

Powikłania po THA są stosunkowo rzadkie i występują u około 2% operowanych chorych. Jednym z nich są skostnienia pozaszkieletowe, które wg literatury mogą występować pomiędzy 8 a 60% pacjentów po THA. (28) Wykazano, że mogą powodować dolegliwości bólowe, obrzęk i wzmożone ocieplenie okolicy stawu, oraz ograniczenie ROM. (29) Powyższe czynniki wydaje się, że powinny mieć wpływ na utrzymanie równowagi oraz balansu ciała podczas chodu, a co za tym idzie większe ryzyko upadków. Wykazano, że ryzyko upadków po 65 roku życia wzrasta i w tej grupie wiekowej około 30% populacji ulega upadkowi co najmniej raz do roku. (30) Upadki u osób po endoprotezoplastykach stawów i związane z nimi złamania okołoprotezowe są wyjątkowymi rodzajami złamań, gdyż ich leczenie jest zdecydowanie bardziej wymagające technicznie oraz wyniki są znacznie gorsze. (31) Dotychczas w literaturze nie oceniono jak skostnienia szkieletowe wpływają na utrzymanie równowagi i balansu ciała.

W badaniu „Posture stability and risk of fall test in the objective assessment of balance in patients with ectopic bone tissue after total hip replacement", które wchodzi w skład rozprawy doktorskiej zaobserwowano, że u 46 z 312 pacjentów poddanych całkowitej aloplastyce stawu biodrowego w Klinice Ortopedii i Rehabilitacji Warszawskiego Uniwersytetu Medycznego rozwinęły się heterotopowe skostnienia. Dla tych pacjentów wygenerowano wskaźnik skłonności oparty na wieku, płci oraz BMI i wybrano dopasowaną grupę kontrolną składającą się z 39 pacjentów, którzy nie wykazali skostnień pozaszkieletowych w czasie obserwacji. Każdy pacjent był operowany z tego samego dostępu operacyjnego oraz z użyciem tego samego implantu. Pacjenci z obu kohort przeszli pooperacyjną ocenę radiologiczną i biomechaniczną oraz wypełnili przed- i pooperacyjnie kwestionariusze WOMAC i Oxford, służące do oceny funkcji biodra.

Wystąpiły statystycznie istotne różnice między kohortami w teście stabilności postawy (4,9±1,1 vs 2,0±1,0 $p<0,05$), wskaźniku stabilności przednio-tylnej (3,6±1,2 vs 1,6±0,9, $p<0,05$), wskaźniku stabilności przyśrodkowo-bocznej (3,0±1,3 vs 1,0±0,7, $p<0,05$) oraz test ryzyka upadku (9,8±1,0 vs 7,8±1,0, $p<0,05$). Nie zaobserwowano statystycznie istotnych różnic w kwestionariuszach WOMAC i Oxford.

Badanie wykazało, że heterotopowe skostnienia pojawiające się w mięśniach odwodzących biodra mogą mieć wpływ na równowagę i ryzyko upadków u pacjentów po całkowitej aloplastyce stawu biodrowego. W populacji osób starszych po całkowitej aloplastyce stawu biodrowego może to skutkować bardzo poważnymi konsekwencjami, takimi jak złamanie okołoprotezowe lub uraz głowy. Dotychczas jest to pierwsze badanie porównujące ryzyko upadków u pacjentów z i bez skostnień pozaszekieletowych po THA.

Założenia i cel pracy

`Endoprotezoplastyka stawu biodrowego jest jedną z najczęstszych oraz najbardziej efektywnych procedur zabiegowych w całej medycynie. W związku ze zmianami społeczeństwa na całym świecie zapotrzebowanie będzie stale rosło. Ponadto w światowych rejestrach wskazuje się na fakt, że dochodzi do zmiany profilu pacjentów poddawanych endoprotezoplastykom. Są to z jednej strony chorzy coraz starsi i bardziej obciążeni, którzy dzięki postępowi medycyny i odpowiedniemu leczeniu chorób przewlekłych cechują się coraz dłuższą długością życia i wymagają życia bez dolegliwości bólowych. Z drugiej strony operacjom poddawani są coraz młodsi chorzy z powodu siedzącego trybu życia, szerokiego rozprzestrzenienia chorób cywilizacyjnych oraz większej liczby urazów. W związku z tym istnieje potrzeba wykonywania tych zabiegów w prawidłowy sposób, by przedłużyć przeżywalność endoprotez oraz zapewnić chorym jak najlepszy wynik kliniczny. Mimo relatywnie małego procentu chorych niezadowolonych oraz możliwych powikłań w związku z rozpowszechnieniem THA liczby bezwzględne są nadal wysokie i prawdopodobnie będą rosnąć. Szacuje się, że leczenie powikłań po zabiegach endoprotezoplastyk może stanowić wyzwanie dla systemu opieki zdrowotnej wielu krajów. W cyklu publikacji stanowiących rozprawę doktorską przedstawiono wyniki prac dotyczących radiologicznego planowania i wyniku endoprotezoplastyki stawu biodrowego z zastosowaniem różnych technik operacyjnych oraz najnowszych koncepcji osadzania elementów endoprotezy, zwrócono uwagę na wyniki biomechaniczne parametru chodu w zależności od stosowanego implantu. Ponadto opisano parametry chodu u pacjentów, którzy rozwinęli skostnienia pozaszkieletowe.

A. Pierwsza praca miała na celu zebranie informacji oraz opisanie sposobu wykonywania pomiarów parametrów stosowanych do określania położenia przestrzennego elementów endoprotezy stawu biodrowego.
B. Celem drugiej pracy było określenie różnic w parametrach osadzenia elementów endoprotezy przy użyciu dostępu bezpośredniego przedniego oraz innych powszechnych dostępów operacyjnych.
C. Trzecie badanie miało na celu opisanie parametrów wchodzące w skład koncepcji „spinopelvic alignment" oraz stworzenie wytycznych osadzania elementów endoprotezy w zależności od mobilności kręgosłupa lędźwiowo-krzyżowego

D. Celem czwartej pracy była analiza parametrów chodu z zastosowaniem standardowych 28-32mm oraz dużych głów endoprotezy stawu biodrowego oraz porównanie wyników do grupy uczestników bez choroby zwyrodnieniowej.
E. Piąta publikacja miała na celu określenie ryzyka upadku u chorych po endoprotezoplastyce całkowitej stawu biodrowego, u których doszło do rozwinięcia skostnień pozaszekieletowych
F. Celem ostatniej, szóstej publikacji było określenie odtworzenia relacji kostnych podczas endoprotezoplastyki połowiczej stawu biodrowego z użyciem standardowych implantów.

Kopie opublikowanych prac

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REVIEW

How to analyze postoperative radiographs after total hip replacement

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Abstract

Total hip replacement is one of the most widely performed surgeries. It is stated as the most efficient method of treating end-stage osteoarthritis of the hip joint. What is more, it significantly improves the quality of patients' lives, relieves them from pain and restores decreased range of motion, provided that is conducted properly. Aim of this article is to indicate which constituents of prosthetic placement can be easily measured on postoperative radiographs and point out how to interpret obtained results. Multiple mechanical factors, such as center of rotation, femoral offset, acetabular offset, acetabular inclination, acetabular anteversion and leg length discrepancy can be measured on postoperative radiographs. To provide a successful surgery and to acquire both radiological and clinical satisfying results, proper prosthetic placement is crucial. Malpositioning of each element, in varying degrees may lead to dislocation or reoperation.

Keywords Total hip replacement · Radiological evaluation · Radiographs

Introduction

Total hip replacement (THR) is one of the most widely performed surgeries. There were 98.649 hip replacement procedures performed in 2019 in the United Kingdom [1]. Not only is it cost-effective treatment, but what is more important it is a very successful one, which relieves patients from pain, improves their quality of life and restores decreased range of motion. Unfortunately, there still exists a group of patients, which does not derive any advantage from THR. It is most often caused by the impact of mechanical aspects of THR on clinical outcome.

In everyday clinical practice, radiographs are the most widely used tool for imaging. It is the most widespread and commonplace method. Classical radiography is associated with a lower dose of radiation in comparison to computed tomography. Its advantage over other imaging methods results also from the lowest price. Computed tomography can be used for postoperative assessment as well. It is certainly more accurate than radiographs, but it has its limitations, such as radiation dose and limited availability [2]. There is also one method of imaging—magnetic resonance imaging, which is far less accessible and more expensive than previously mentioned imaging modalities. However, there are situations in which magnetic resonance imaging is helpful to obtain a diagnosis. They include tendinopathy, implants loosening, persistent postoperative pain or other conditions that are hard or even impossible to detect using computed tomography and classical radiography.

In connection with this, in the majority of cases, radiographs are perfectly adequate. What is more, the application of this imaging technique is not associated with the artifacts caused by metal implants, in contrast to the use computed tomography or magnetic resonance.

Aim of this article is to indicate which constituents can be measured on postoperative radiographs and point out how to interpret obtained results.

Multiple mechanical and biomechanical factors, such as center of rotation (COR), femoral offset, acetabular offset, acetabular inclination (AI), acetabular anteversion and leg length discrepancy can be measured on radiographs. Each one of them, in varying degrees, can affect the outcome of the surgery.

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Materials and methods

The literature was reviewed. Articles related to the subject, published in the years 1978–2021 were researched. Therefore publications including keywords such as total hip replacement, center of rotation, femoral offset, acetabular offset, cup anteversion, cup inclination and leg length discrepancy were searched in the PubMed database. Research was focused on English language papers, available abstracts, studies performed on people and articles. Inclusion of the articles was determined on the basis of titles, then abstracts, eventually entire articles. As terms of exclusion non-English language articles, papers ahead of print and only titles or abstract available were chosen. All studies presenting procedures conducted on animals were also excluded. If there occurred any signs of unreliability or relation to the topic were insignificant, the articles were eliminated during further evaluation. Afterwards, every selected article was verified another time. Any duplicates or obsolete information were removed. Research and error risk assessments were performed by one author. All information was selected and verified individually. Analysis and synthesis of studies were prepared independently.

All methods of measurements apply to radiographs taken in the supine position at a source-to-film distance of 100–115 cm with the X-ray beam directed to the midpoint of the pubic symphysis and perpendicular to the patient.

The described radiographic technique is a non-weight-bearing view. It is connected with the lesser radiation dose, allows to obtain a better quality radiographs, but it does not take into account the functional anatomy in contrast to weight-bearing view.

Results

Center of rotation (COR)

One of the goals of THR is to reconstruct the COR. As the study shows, restoring COR is an extremely important factor affecting operation result. It should be restored within 5 mm medial and 3 mm superior to the normal side. If optimal reconstruction is unattainable, the ability to control hip offset meticulously is limited. Shifting COR over 1 cm superiorly or medially causes early radiological signs of loosening. Malposition of COR may lead to abnormal gait, abductors insufficiency, increased risk of impingement and dislocation [3]. What is more, well reconstructed COR reduces the number of failures and revision surgeries [4]. Proper position of COR diminishes the risk of leg length discrepancy.

Ranawat's method is an old but still applicable method used for the definition of the COR [5]. To determine the center of rotation on anteroposterior pelvis radiograph, two horizontal lines must be drawn. One at the level of iliac crests and the second one, at the level of ischial tuberosities. These lines must be connected by a perpendicular line passing through a point, which is located 5 mm lateral to the intersection of Kohler's and Shenton's lines. Point B and point C are situated along the horizontal line at the level of the subchondral roof of the cup. Point B is at an equal distance from both A and C points. COR is located half the length of the AC line [3, 5] (Fig. 1).

Femoral offset

Femoral offset is stated as a distance from the COR of the femoral head to a line bisecting the long axis of the femur [3] (Fig. 2). Restored femoral offset enhances biomechanics, such as abduction strength and range of motion (ROM) by improving flexion and internal rotation of the hip [9, 10].

In addition, femoral offset restored within 5 mm to the normal side, decreases both linear and volumetric polyethylene wear [4]. Failing to restore offset < 5 mm may cause pain aggravation and deterioration of the joint. Reduced offset decreases soft-tissue tightness and predisposes to dislocation. According to the studies, well-positioned femoral offset may be the critical mechanical factor preventing dislocation after THR. However, it is still not stated which values of femoral offset are indications for revision [6–10].

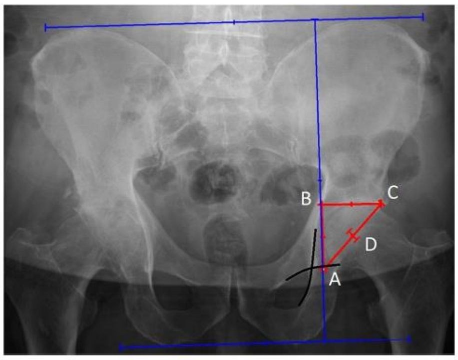

Fig. 1 Determination of the COR. A. point located 5 mm lateral to the intersection of the Kohler's and Shenton's lines; B. point situated along the horizontal line at the level of the subchondral roof of the cup; at equal distance from both A and C points; C. point situated along the horizontal line at the level of the subchondral roof of the cup; D. point located half the length of the AC line

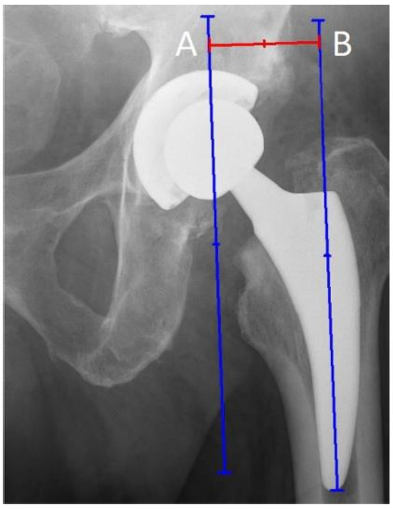

Fig. 2 Femoral offset measurement. A. line passing through the COR; B. line bisecting the long axis of the femur

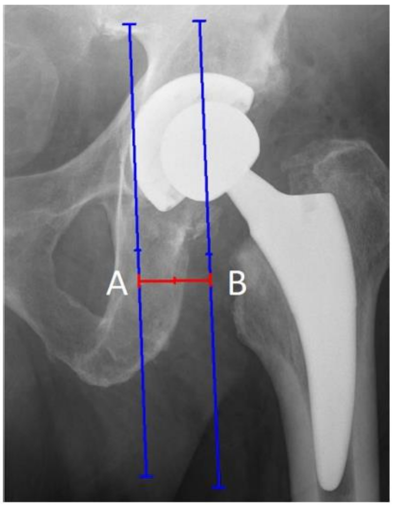

Fig. 3 Acetabular offset measurement. A. line passing through the medial wall of the quadrilateral plate; B. line passing through the COR

Acetabular offset

Hip offset is not only femoral offset. There is another component part-acetabular offset, which should not be omitted because its value varies from person to person. Acetabular offset is the distance from COR to the medial wall of the quadrilateral plate [11, 12]. It is measured as a vertical distance between the center of rotation and teardrop on the same side (Fig. 3). The unreconstituted acetabular offset reduces the lever arm of body weight. As a result, gluteus medius and minimus muscles get a more vertical line of action [11].

Acetabular inclination (AI)

Acetabular inclination is also known as an abduction angle. Radiographic AI is measured on anteroposterior radiographs. It is an angle between transischial line and a line conducted through the cup margins [10] (Fig. 4). AI affects range motion and wear of the acetabular component. When the abduction angle is lesser than 45°, flexion and abduction decreases. On the other hand, AI over 45° reduces adduction and rotation. There is also higher wear of acetabular polyethylene when the AI is over 45° [13, 14]. It cannot be univocally stated, without additional studies, what is a safe range for AI [15, 16].

Acetabular anteversion

Computed tomography facilitates accurate determination of acetabular cup position, especially anteversion, but it is not widely used in clinical practice because of its high cost, limited availability and additional radiation exposure [17, 18]. Because of that, plain radiographs are in common use. Plenty of methods can be used to measure anteversion, and there is no validated and most efficient one [14]. This is due to the fact that pelvic tilt has a greater impact on measuring anteversion on anteroposterior radiographs

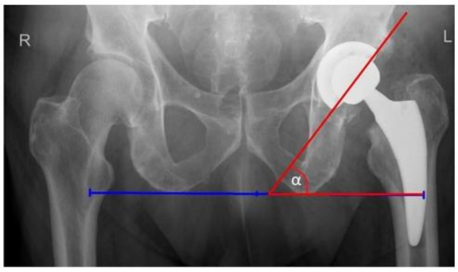

Fig. 4 Acetabular inclination measurement. α—an angle between transischial line and a line conducted through the cup margin

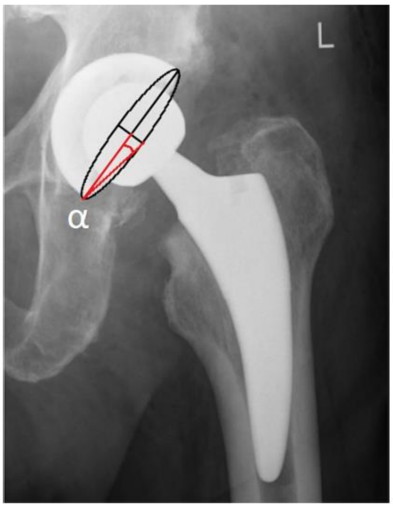

Fig. 5 Liaw's acetabular anteversion measurement. α—an angle between the principal axis of the ellipse and the vector connecting the endpoints of the main and the minor axes

rather than determining abduction angle on anteroposterior radiographs. Nevertheless, as studies show, there is a method that enables measurements that do not differ from measurements carried out using computed tomography. It is a method created by Liaw [19, 20].

Liaw's anteversion is stated as:

$$\text{Anteversion} = \text{arc sic } (\tan \alpha)$$

α is an angle between the principal axis of the ellipse and the vector connecting the endpoints of the main and the minor axes. In plan, ellipse is located on the margin of a cup (Fig. 5).

The positioning of the cup influences the risk of dislocation. There is no consensus among researchers on what really is a safe zone for acetabular anteversion. According to Lewinnek safe zone theory, cup anteversion should be oriented between 5° and 25° to minimize dislocation after THR. But in fact, recent studies show that there is no real safe range, whether for AI or acetabular anteversion [14, 15, 21].

Anteversion values can be exploited to monitor acetabular migration. Change of anteversion on postoperative radiographs over 1.59° is an early sign of cup loosening, which can manifest itself in hip pain [18].

Leg length discrepancy

Leg length discrepancy is one of the most frequent complications after THR. Lengthening occurs more often than shortening of the limb and is more noticeable in patients. According to the study, leg length discrepancy is perceived by patients when the operated limb is lengthened over 6 mm or shortened below 10 mm [22]. However, the greatest problem are inequalities above 10 mm due to their impact on everyday functioning. They can cause abnormal gait, instability, sciatica and back pain. Moreover, lengthening greater than 10 mm occurs with other complications: limping, pelvic obliquity and feeling disenchanted [15, 23].

The leg length discrepancy on anteroposterior radiographs is given as the difference in perpendicular distance between a line passing through the lower edge of the teardrop points to the corresponding tip of the lesser trochanter [10] (Fig. 6).

Conclusions

To provide a successful surgery and to acquire both radiological and clinical satisfying results, all of the mechanics and biomechanics must be restored, if it is not, surgery can aggravate the patient's complaints instead of removing them and the results of performed THR can be unsatisfactory. This may also result in dislocation or the need for reoperation.

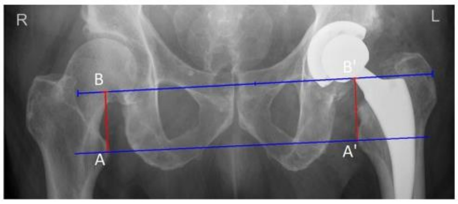

Fig. 6 Leg length discrepancy measurement. A and A' are located at the level of the tips of the lesser trochanters. B and B' are situated at the level of the lower edge of the teardrop points. AB and A'B' lines are distances between a line passing through the lower edge of the teardrop points to the corresponding tip of the lesser trochanter. Difference between AB and A'B' lengths is stated as leg length discrepancy

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. NJR Annual Reports. http://www.njrreports.org.uk/ (Date Last Accessed 31 Dec 2020).
2. Reito A, Puolakka T, Paakkala A. Assessment of inter- and intra-observer reliability in the determination of radiographic version and inclination of the cup in metal-on-metal hip resurfacing. Int Orthop. 2012;36:519–25.
3. Lum ZC, Dorr LD. Restoration of center of rotation and balance of THR. J Orthop. 2018;15(4):992–6.
4. Lecerf G, Fessy MH, Philippot R, et al. Femoral offset: anatomical concept, definition, assessment, implications for preoperative templating and hip arthroplasty. Orthop Traumatol Surg Res. 2009;95:210–9.
5. Ranawat CS, Dorr LD, Inglis AE. Total hip arthroplasty in protrusio acetabuli of rheumatoid arthritis. J Bone Jt Surg Am. 1980;62(7):1059–65.
6. Little NJ, Busch CA, Gallagher JA. Acetabular polyethylene wear and acetabular inclination and femoral offset. Clin Orthop Relat Res. 2009;467(11):2895–900.
7. McGrory BJ, Morrey BF, Cahalan TD. Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. J Bone Jt Surg (Br). 1995;77:865–89.
8. Fordea B, Engelnb K, Bedairc H. Restoring femoral offset is the most important technical factor in preventing total hip arthroplasty dislocation. J Orthop. 2018;15(1):131–3.
9. Xu B, Yang D, Aili R, Cao L. Effect of femoral offset change on pain and function after total hip arthroplasty. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi. 2013;27(7):843–6.
10. Mahmood SS, Amiry BA, Mukka SS. Validity, reliability and reproducibility of plain radiographic measurements after total hip arthroplasty. Skeletal Radiol. 2015;44(3):345–51.
11. Matsushita A, Nakashima Y, Jingushi S, Yamamoto T, Kuraoka A, Iwamoto Y. Effects of the femoral offset and the head size on the safe range of motion in total hip arthroplasty. J Arthroplasty. 2009;24(4):646–51.
12. Bonnin MP, Pooler HA, Basiglini L. Do we medialise the hip centre of rotation in total hip arthroplasty? Influence of acetabular offset and surgical technique. Hip Int. 2012;22(04):371–8.
13. D'Lima DD, Uruhart AG, Buehler KO, Walker RH, Colwell CW Jr. The effect of the orientation of the acetabular and femoral components on the range of motion of the hip at different head-neck ratios. J Bone Jt Surg Am. 2000;82(3):315–21.
14. Lee GC, Lee SH, Kang SW, Park HS, Jo S. Accuracy of planar anteversion measurements using anteroposterior radiographs. BMC Musculoskelet Disord. 2019;20(1):586.
15. Biedermann R, Tonin A, Krismer M. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Jt Surg Br. 2005;87(6):762–9.
16. Abdel MP, von Roth P. What safe zone? The vast majority of dislocated THAs are within the Lewinnek safe zone for acetabular component position. Clin Orthop Relat Res. 2016;474:386–91.
17. Loughead JM, Chesney D, Holland JP, McCaskie AW. Comparison of offset in Birmingham hip resurfacing and hybrid total hip arthroplasty. J Bone Jt Surg Br. 2005;87:163–6.
18. Yeh KL, Wu TY, Ma HH. Ellipse method for measuring Liaw's anteversion of the acetabular component after total hip arthroplasty. BMC Musculoskelet Disord. 2020;21:667.
19. Park YS, Shin WC, Lee SM, Kwak SH, Bae JY, Suh KT. The best method for evaluating anteversion of the acetabular component after total hip arthroplasty on plain radiographs. J Orthop Surg Res. 2018;13(1):66.
20. Alzohiry MA, Abdelnasser MK, Moustafa M. Accuracy of plain antero-posterior radiographic-based methods for measurement of acetabular cup version. Int Orthop. 2018;42:2777–85.
21. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Jt Surg Am. 1978;60(2):217–20.
22. Konyves A, Bannister GC. The importance of leg length discrepancy after total hip arthroplasty. J Bone Jt Surg Br. 2005;87:155–7.
23. Flecher X, Ollivier M, Argenson JN. Lower limb length and offset in total hip arthroplasty. Orthop Traumatol Surg Res. 2016;102(1 Suppl):S9-20.

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Review

The Direct Anterior Approach to Primary Total Hip Replacement: Radiological Analysis in Comparison to Other Approaches

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Abstract: Total hip arthroplasty (THA) is currently considered the most effective treatment for end-stage hip osteoarthritis (OA). The surgery can be performed via a number of different approaches, including direct anterior (DAA; Smith–Petersen; Hueter), anterolateral (ALA; Watson–Jones), direct lateral (LA; Bauer), posterior (PA; Kocher–Langenbeck), and posterolateral (PLA). There is still a dispute over the optimal technique. The aim of this systematic review was to assess how different surgical approaches toward a THA influence the prosthesis elements' positioning. We conducted a literature search of Scopus, ScienceDirect, PubMed, Embase, and The Cochrane Library. We evaluated studies in terms of the first author's name, country, publication year, type of surgical approach being compared to the direct anterior approach, any significant differences at baseline, sample size, and radiographic analysis. A subanalysis of each approach in comparison to the DAA revealed differences in terms of all analyzed implant positioning radiographic parameters. There is still an insufficient number of randomized controlled studies that include radiological analyses comparing THRs (total hip replacements) performed using DAA with other approaches. Implant placement is a crucial step during a THR and surgeons must be aware that the approach they use might impact their judgment on angles and spaces inside the joint and thus alter the implant positioning.

Keywords: THR; approach; hip; anterior

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1. Introduction

Total hip arthroplasty is currently considered the most effective treatment for end-stage hip osteoarthritis (OA) [1]. However, there is a continuous dispute over selecting the optimal technique [2–4], with the most popular being direct anterior, anterolateral, direct lateral, posterior, and posterolateral. The choice of approach determines which tissues, including muscles and tendons, need to be dissected in order to reach the joint, which structures should be avoided, and how difficult it is for a surgeon to correctly position the implants [5,6]. A direct anterior approach (DAA; Smith–Petersen; Hueter) is considered the least traumatic as it utilizes the intermuscular plane between the sartorius, rectus femoris, and tensor fasciae latae muscles, with no need for the dissection of any of them. Even though it was introduced many years ago [7], it is currently gaining in popularity, along with the general tendency toward minimally invasive surgery [8,9]. The key to its recognition are postulated positive effects on prosthesis stability and patient satisfaction. There are several claimed advantages of DAA when compared to some other approaches, including faster rehabilitation and reduced postoperative pain [10–12].

However, significant differences in clinical (functional) outcomes are usually observed for only a few months postoperation and we have found no sufficient scientific evidence of DAA's long-term superiority [10–12]. Inevitably, there are also claimed downsides of this approach, such as a flat learning curve, an associated increase in the rate of complications, and worse functional outcomes when compared to other approaches [10,13,14].

Even though the relative effects of the direct anterior approach have already been covered by several systematic reviews and/or meta-analyses, we have found that none of them included radiographic assessment of prosthesis placements [10,13,14]. Furthermore, while there are no definitive conclusions on the choice of the approach, such a review could play a significant role in the discussion, addressing a common allegation that the DAA learning curve might often have an impact on proper implant alignment. Radiographic prosthesis position evaluation is essentially based on acetabular cup anteversion and inclination. The most notable application of these parameters is attributed to finding the safe zone introduced by Lewinnek et al. [15] to predict which positions promote dislocations. Although the values and the evidence they used were repeatedly contested, the safe zone remains an important guideline for prosthesis placement.

The objective of our study was to collect and review the available data regarding radiographic assessments of prosthesis placement after total hip arthroplasties performed using the direct anterior approach compared to other common approaches.

2. Materials and Methods

This study is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement [16] (Figure 1) and the Cochrane Handbook for Systematic Reviews of Interventions [17]. This study protocol was registered in the International prospective register protocol of systematic reviews PROSPERO (PROSPERO number CRD42019122675).

No institutional review board approval was required for this review because the study included data that had been published previously.

We conducted an English language literature search of Scopus, ScienceDirect, PubMed, Embase, and The Cochrane Library in January 2021 without restriction in terms of the date. The following search terms were used: 'total hip replacement,' 'total hip arthroplasty,' 'THA,' 'THR,' 'anterior,' 'direct anterior,' 'anterior supine intermuscular,' 'Hueter approach,' and 'Smith–Petersen.' Search terms were combined using the Boolean operators 'AND' and 'OR' in accordance with the methodology used by Yue et al. [18].

In this review, the inclusion criteria consisted of randomized clinical trials involving patients over 18 years old (with primary hip osteoarthritis that was treated surgically), studies comparing the direct anterior approach (DAA) with other approaches, and consisting of radiological analysis. We excluded non-English studies, studies for which only abstracts were available, review or non-comparative studies, and research in which bilateral hip replacement or hemiarthroplasty surgeries were analyzed.

Three independent researchers (B.M., K.Ż., M.D.) evaluated the final set of studies in terms of: the first author's name, country, publication year, type of surgical approach being compared to the direct anterior approach, any significant differences at baseline, sample size, and radiographic analysis (femoral stem alignment, mean radiographic cup inclination, mean radiographic cup anteversion, mean radiographic cup abduction, position in Lewinnek's safe zone).

We provide a narrative synthesis of the findings from the included studies, which was structured around the type of intervention, the targeted population characteristics, the outcome, and the intervention content. The primary outcomes were the femoral stem alignment, mean radiographic cup inclination, mean radiographic cup anteversion, and mean radiographic cup abduction. Secondary outcomes were the leg length following the surgery and the position in Lewinnek's safe zone. Furthermore, subgroup analysis regarding the type of approach toward the THR was performed. We considered studies comparing DAA to one of the following: LA (lateral approach; Bauer), PA (posterior approach; Kocher–Langenbeck), or PLA (posterolateral approach). To provide a structured summary of the questions asked in this narrative review, a table depicting the study characteristics in accordance with the PICOS strategy was prepared (Table 1).

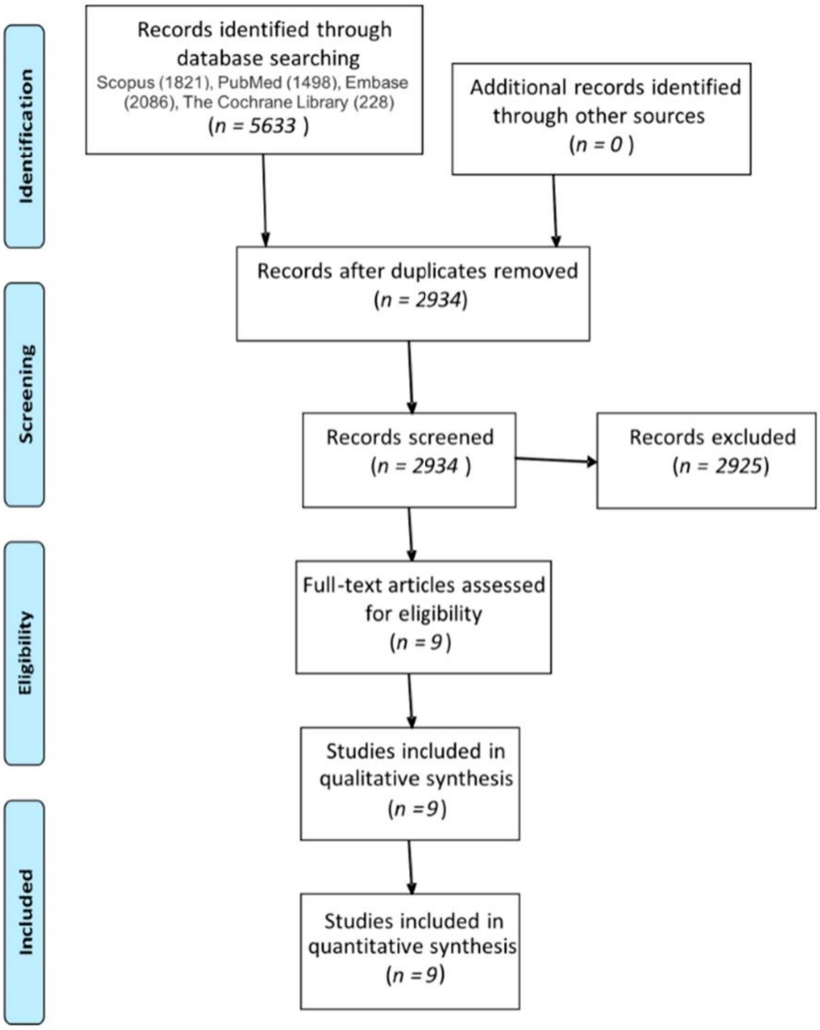

Figure 1. PRISMA flow diagram.

Assessment of Methodological Quality

The Cochrane Collaboration's tool [19] for assessing the risk of bias was used. Any disagreements between them over the eligibility of particular studies were resolved via discussion with a fourth reviewer (A.S.). Cohen's kappa coefficient [20] was calculated for the interrater agreement between reviewers following the assessment of the studies' eligibility. Kappa values ≤ 0 were interpreted as indicating no agreement, 0.01–0.20 as none to slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement.

Table 1. PICOS strategy for study characteristics.

Participants	**Patients Undergoing Total Hip Replacement for Treatment of End-Stage Primary Hip Osteoarthritis**
Intervention	Total hip replacement with use of one of the surgical approaches to the hip joint (anterolateral, posterior, or direct lateral)
Comparisons	Patients undergoing total hip replacement via direct anterior approach to the hip joint
Outcomes	Radiographic analysis (femoral stem alignment, mean radiographic cup inclination, mean radiographic cup anteversion, mean radiographic cup abduction, position in Lewinnek's safe zone)
Study design	Randomized controlled trial

3. Results

3.1. Literature Selection

A narrative investigation of PubMed, Embase, Scopus, and Cochrane Collaboration of Systematic Reviews produced 5633 potentially eligible studies. We used EndNote X9 to remove duplicated studies (2699). The remaining 2934 studies were then read by two independent researchers. A total of 2925 studies were excluded due to not matching the selection criteria. In the end, nine studies were included in the review [8,21–28].

3.1.1. Study Characteristics

Nine randomized controlled trials (RCTs) were analyzed in this systematic review [8,23–30]. Four of them compared DAA to the standard lateral approach (LA) [8,21,22,27], three of them compared DAA to the standard posterior approach (PA) [19,24,28], and two compared DAA to the posterolateral approach (PLA) [25,26].

3.1.2. Participants

Altogether, the radiological analysis of the implants' positioning was performed in 994 extremities: 500 in DAA vs. LA, 287 in DAA vs. PA, and 207 in DAA vs. PLA (Table 2). The age and gender of participants, inclusion/exclusion criteria, and implants used for the THRs are presented in Table 2.

Table 2. Participants' characteristics in analyzed studies.

References, Year Compared Approaches	**Number of Participants in Each Group (Females/Males, Left/Right Hips)**	**Patients' Characteristics Age (years); BMI (kg/m^2)**	**Implants Used**
Nistor [8], 2017 DAA vs. LA	DAA: 35 (F/M: 26: 9, L/R: 19: 16) LA: 35 (F/M: 16: 19, L/R: 18: 17)	DAA: 67 (53.5, 72.5); 27.45 ± 3.76 LA: 64 (54.5, 67.5); 28.63 ± 3.12	Metabloc™ uncemented femoral stem system, cobalt–chrome Versys® 32 mm diameter femoral head, polyethylene liner form Trilogy® acetabular system, and Trilogy® uncemented acetabular system shell, with acetabular self-tapping bone screws if needed (Zimmer Warsaw, IN 46,580, USA).
Reichert [21], 2018 DAA vs. LA	DAA: 73 (F/M: 32: 45, L/R: NA) LA: 50 (F/M: 32: 49, L/R: NA)	DAA 63.2 (44–77); 28.1 ± 3.7 LA: 61.9 (50–78); 28.3 ± 3.4	Trilogy or Allofit cups (Trilogy® Acetabular Hip System; Allofit® Acetabular Cup System), the non-cemented M/L Taper stem, or the cemented M. E. Müller straight stem. Overall, the anterior group included four cemented stems, while the lateral group included five cemented stems.
Dienstknecht [22], 2014 DAA vs. LA	DAA: 55 (F/M 33: 22, L/R: 27:28) LA: 88 (F/M 47: 41, L/R: 47:41)	DAA: 61.9 ± 12.1 (33–85); 27.6 ± 6.0 (15.7–42.0) LA: 61.3 ± 11.6 (35–89); 30.1 ± 5.6 (17.6–48.8)	Pressfit acetabular components and cement-free hydroxyapatite-coated stems with metal heads were used. Five patients in the Bauer group and one patient in the Micro-hip group received a cemented stem because of poor bone stock.

Table 2. *Cont.*

References, Year Compared Approaches	Number of Participants in Each Group (Females/Males, Left/Right Hips)	Patients' Characteristics Age (years); BMI (kg/m^2)	Implants Used
Cheng [23], 2017 DAA vs. PA	DAA: 35 (F/M: 20: 15, L/R: NA) LA: 38 (F/M: 20: 18, L/R: NA)	DAA: 59 (IQR54, 69); 27.7 (25.8, 30.0) LA: 62.5 (IQR55, 69); 28.3 (24.8, 31.1)	R3 acetabular system and Anthology femoral stem.
Taunton [24], 2014 DAA vs. PA	DAA: 27 (F/M: 15: 12, L/R: NA) LA: 27 (F/M: 14: 13, L/R: NA)	DAA: 62.05; 27.7 PA: 66.4; 29.2	The same femoral component design (Corail; DePuy, Warsaw, Indiana) and the same acetabular component design (Pinnacle; DePuy) were used in every case.
Barret [25], 2013 DAA vs. PLA	DAA: 43 (F/M: 14: 29, L/R: 21:22) PLA: 44 (F/M: 25: 19, L/R: 20:24)	DAA: 61.4 ± 9.2; 30.7 ± 5.4 PLA: 63.2 ± 7.7; 29.1 ± 5.0	Corail Total Hip System femoral stem, a Pinnacle Acetabular Cup System cup, an AltrX cross-linked polyethylene liner, and a cobalt chromium-molybdenum femoral head with size 28, 32, or 36 mm.
Zhao [26], 2017 DAA vs. PLA	DAA: 60 (F/M: 36: 24, L/R: NA) PLA: 60 (F/M: 34: 26, L/R: NA)	DAA: 64.88 ± 12.13; 25.58 ± 2.83 PLA:62.18 ± 14.72; 24.35 ± 3.10	N/A
Brun [28], 2019 DAA vs. LA	DAA: 84 (F/M: 59: 25, L/R: NA) LA: 80 (F/M: 50: 30, L/R: NA)	DAA: 67.2 ± 8.6; 27.7 ± 3.6 LA:65.6 ± 8.6; 27.6 ± 3.9	Cemented cup (Marathon; DePuy, Warsaw, IN, USA), uncemented stem (Corail; DePuy), and ceramic head with a diameter of 32 mm (BIOLOX Forte; CeramTec, Plochingen, Germany).
Taunton [27], 2018 DAA vs. PA	DAA: 52 PA: 49	DAA: 65 ± 10 (38–84); 29 ± 22 (19–39) PA: 64 ± 11 (37–85); 30 ± 4 (22–39)	Hemispherical uncemented acetabular component (Pinnacle®; DePuy Orthopaedics Inc, Warsaw, IN, USA), hydroxyapatite-coated femoral stem (Corail®; DePuy Orthopaedics Inc), and Biolox® delta ceramic femoral head (CeramTec GmbH, Plochingen, Germany).

List of abbreviations: F—females, M—males, L—left, R—right, DAA—direct anterior approach, LA—direct lateral approach, PA—posterior approach, PLA—posterolateral approach, NA—not available.

3.1.3. Risk of Bias within Studies

The risk of bias within studies was assessed with the applicable part of the Cochrane Collaboration's tool for assessing the risk of bias, as described in the Materials and Methods section. The results of this assessment are presented in Table 3.

Table 3. Cochrane Collaboration's tool risk of bias assessment.

References	Randomization Process	Deviations from Intended Interventions	Missing Outcome Data	Measurement of the Outcome	Selection of the Reported Result	Overall Bias
Nistor [8]	+	+	+	+	+	+
Reichert [21]	+	+	+	+	+	+
Dienstknecht [22]	+	+	+	Not stated	+	+
Cheng [23]	+	+	+	-	+	+
Taunton [24]	+	+	+	-	+	+
Barret [25]	+	+	+	-	+	+
Zhao [26]	+	+	+	+	+	+
Taunton [27]	+	+	+	-	+	+
Brun [28]	+	+	+	+	+	+

"+" denotes low risk of bias, "-" denotes high risk of bias.

3.2. Femoral Stem Alignment

Seven RCTs compared the femoral stem alignment (Figure 2) in patients that were operated on using DAA to other approaches [8,21–23,25,27,28]. Four of them analyzed groups that were operated using LA, two with PA, and one with PLA (Table 4). The median femoral stem angle was 1.23° varus in DAA, and 2.37° varus in two studies that analyzed LA. However, the reason for such a significant difference might have been a difference in the number of participants in the comparative group in Dienstknecht et al.'s research (55 vs. 88). In Brun et al.'s work, there was no difference in the mean femoral stem position between the two trial groups ($p = 0.443$). In Cheng et al.'s work, the mean femoral stem orientation was $-1.60°$ varus. In Reichert et al.'s work, the alignment of the femoral stem was not measured in value, but the researchers provided information stating that the stems in the DAA group were assessed to be in a neutral position in 92.5% of cases, varus in 5.5%, and valgus in 2%, while in the LA group, 94% were positioned neutrally, 4% varus, and 2% valgus. In Taunton et al.'s work, the researchers remarked that in the DAA group, there were four stems in varus, while in the PA group, there were six stems in varus and two in valgus.

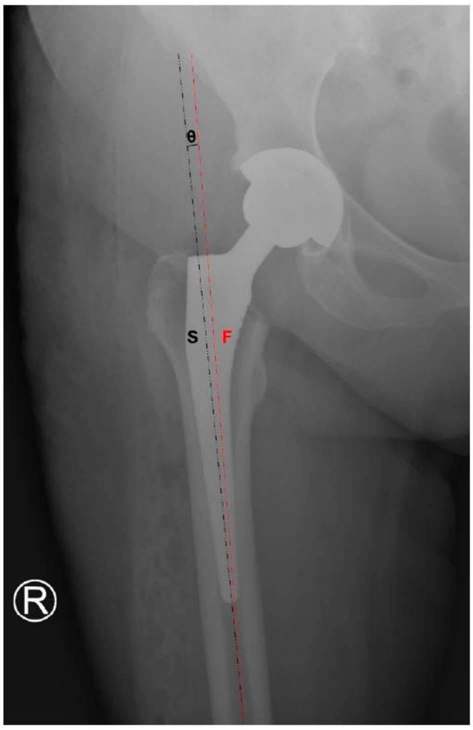

Figure 2. Femoral stem alignment measurement.

Table 4. Femoral stem alignment in analyzed studies.

References, Year Compared Approaches	DAA	LA	PA	PLA
Nistor [8], 2017 DAA vs. LA	1.40° (SD 0.99°) varus	1.29° (SD 1.13°) varus		
Reichert [21], 2018 DAA vs. LA	5.5% varus 2% valgus 92.5% neutral	4% varus 2% valgus 94% neutral		
Dienstknecht [22], 2014 DAA vs. LA	2.6° (SD 2.1°) varus	2.8° (SD 2.2°) varus		
Cheng [23], 2017 DAA vs. PA	1.09° varus	1.62° varus		
Barret [25], 2013 DAA vs. PLA	2% varus 0% valgus 98% neutral			26% varus 0% valgus 74% neutral
Taunton [24], 2014 DAA vs. PA	4 varus/52 operated		6 varus, 2 valgus/49 operated	
Brun [28],2019 DAA vs. LA	3.1° (SD 1.5°) varus	2.9° (SD 1.1°) varus		

3.3. Mean Radiographic Cup Inclination

Nine RCTs compared the mean radiographic cup inclination (Figure 3) between patients that were operated on using DAA and patients that were operated on using other approaches [8,21–28]. Four of them analyzed the groups that were operated on using LA, three using PA, and two using PLA (Table 5). The most significant difference was observed in the DAA vs. LA subanalysis. In the analysis of these two RCTs, the mean cup inclination angles in the DAA and LA groups were 42.68° and 46.29°, respectively. Such a difference might have been due to the unequal number of participants in both included studies (73 vs. 50 and 55 vs. 88). However, in Brun et al.'s work, where the number of patients in both trial groups (80 vs. 84) was comparable, the degree of cup inclination was significantly higher in the DAA group than in the LA group (mean difference = 2.5°; p = 0.023). A similar observation was made in Nistor et al.'s study, where the cup inclination angle difference between the DAA and LA groups was statistically significant with a p-value < 0.001, with lower values in the DAA group. Three RCTs measured the cup inclination angle in the DAA and PA groups, but no statistically significant difference in those studies was observed. Meanwhile, two RCTs compared this angle between DAA and PLA. The mean radiographic cup inclinations were measured to be 43.14° and 42.05°, respectively.

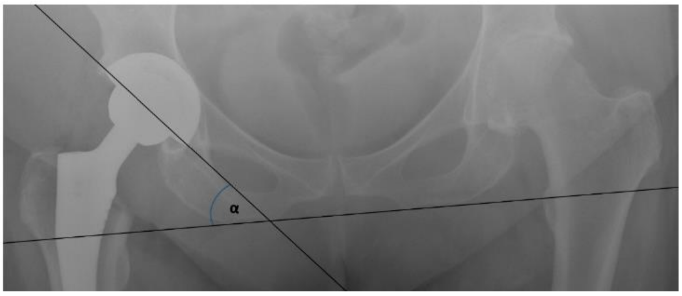

Figure 3. Cup inclination measurement.

Table 5. Mean radiographic cup inclination angles in analyzed studies.

References, Year Compared Approaches	DAA	LA	PA	PLA
Nistor [8], 2017 DAA vs. LA	36.97° (SD 1.85°)	39.63° (SD 2.88°)		
Reichert [21], 2018 DAA vs. LA	38.6° (SD 5.7°)	40.3° (SD 6.2°)		
Dienstknecht [22], 2014 DAA vs. LA	48.1° (SD 6.0°)	49.7° (SD 6.0°)		
Cheng [23], 2017 DAA vs. PA	46.07°		45.86°	
Taunton [24], 2014 DAA vs. PA	38.0°		40.0°	
Barret [25], 2013 DAA vs. PLA	47.1° (SD 6.1°)			42.4° (SD 7.6°)
Zhao [26], 2017 DAA vs. PLA	41.3°			40.8°
Taunton [27], 2018 DAA vs. PA	37° (SD 5°)		39° (SD 6°)	
Brun [28],2019 DAA vs. LA	49.5° (SD 7.4°)	47.0° (SD 6.0°)		

3.4. Mean Radiographic Cup Anteversion

Six RCTs compared the radiographic cup anteversion (Figure 4) in patients that were operated on using DAA to those patients operated on using other approaches [23–28]. Three of the RCTs analyzed groups operated on using PA, two using PLA, and one using LA (Table 6). The mean radiographic cup anteversion in the DAA group was 21.42° compared to 23.01° for the other approaches. However, a subanalysis of DAA vs. PA and DAA vs. PLA showed more significant differences in these measurements. Comparing DAA with PA, it was found that the mean radiographic cup anteversions were 26.52° and 22.70°, respectively. Moreover, in an analysis of the DAA vs. PLA subgroup, the angles were 18.35° vs. 23.20°, respectively. Furthermore, the angle of the cup anteversion was significantly higher in the DAA group compared to the LA group (mean difference = 3.6°; $p < 0.0001$). In four of the mentioned RCTs, the difference in cup positioning was statistically significant with a p-value < 0.05. Moreover, in Cheng et al.'s work, this difference was also recognized and was nearly statistically significant ($p = 0.06$).

Table 6. Mean radiographic cup anteversions in analyzed studies.

References, Year Compared Approaches	DAA	LA	PA	PLA
Cheng [23], 2017 DAA vs. PA	24.57°		20.34°	
Taunton [24], 2014 DAA vs. PA	26°		29°	
Barret [25], 2013 DAA vs. PLA	20.1° (SD 5.9°)			25.8° (SD 8.1°)
Zhao [26], 2017 DAA vs. PLA	17.1°			21.3°
Taunton [27], 2018 DAA vs. PA	23° (SD 4°)		25° (SD 6°)	
Brun [28], 2019 DAA vs. LA	9.4° (SD 4.8°)	5.8° (SD 4.3°)		

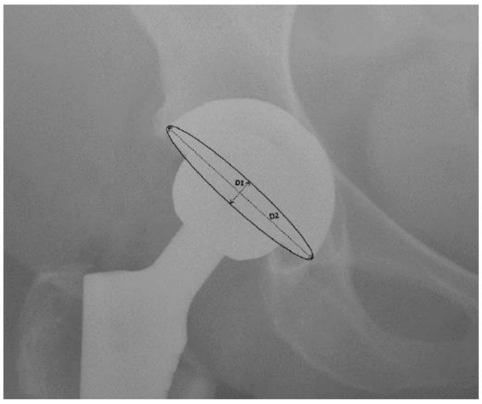

Figure 4. Cup anteversion measurement.

3.5. Leg Length

Three RCTs reported an analysis of leg length discrepancies following THRs [21,24,28]. However, different methods of reporting these values were used. Reichert et al. reported two cases (3%) with a discrepancy of more than 1 cm in comparison to the non-operated limb in the DAA group and 3 cm in the LA group (6%). These values are difficult to compare due to the quite significant difference in the numbers of participants in these studies. Taunton et al. measured the median leg discrepancy (2 mm in the DAA group and 3 mm in the PA group). The result was found to be statistically non-significant ($p = 0.222$). Furthermore, in Brun et al.'s study, there was no difference in the mean leg length between the DAA group and LA group ($p = 0.164$).

3.6. DAA vs. LA

In all four RCTs comparing DAA to LA, the femoral stem positioning did not differ significantly between the groups. In Brun et al.'s study, the angles of both the cup inclination and anteversion were significantly higher in the DA group when compared to the DLA group (mean difference = 2.5°, $p = 0.023$ and mean difference = 3.6°, $p < 0.0001$, respectively). Moreover, in Nistor et al.'s study, the difference in cup inclination angle between the DAA and LA groups was statistically significant with a p-value < 0.001, with lower values in the DAA group. In two other RCTs, the difference in cup inclination angle was not found to be statistically significant. However, there was a significant difference between both studies in terms of the value of this angle. In Reichert et al.'s study, the mean value of this angle in both the DAA and LA groups was almost 10° lower than in Dienstknecht et al.'s research: 38.6 ± 5.7° vs. 48.1 ± 6.0° and 40.3 ± 6.2° vs. 49.7 ± 6.0°, respectively. Such differences might have been caused by the unequal number of participants between both compared groups. In Dienstknecht et al.'s research, the DAA group consisted of 55 participants, while the LA group had 88 participants. In Reichert et al.'s study, the DAA group consisted of 73 patients, while the LA group had 50 patients. In this particular study, such a difference between the groups might have been due to the loss to follow-up of 21 patients from the LA group (29.6%), mainly due to the 'lack of time and interest' (22.5%).

3.7. DAA vs. PA

With regard to the femoral stem alignment and cup inclination, three RCTs reported minor changes that were not statistically significant. However, in Taunton et al.'s research from 2014, a statistically significant difference was observed with regard to cup anteversion, with higher values in the DAA group ($p = 0.004$). In Cheng et al.'s research, similar observations were made with nearly statistical significance ($p = 0.06$). On the other hand, in Taunton et al.'s study from 2018, there was no disparity in terms of the cup anteversion in any group of patients ($p = 0.21$).

3.8. DAA vs. PLA

In both RCTs comparing DAA to PLA, no information concerning leg length after the THR femoral stem alignment or cup abduction angle was reported. Both studies provided statistically significant results of the measurement of cup anteversion angle ($p = 0.0005$ and $p = 0.02$), with lower values for DAA in comparison to PLA. However, values of this angle in both groups significantly differed between studies. In Barret et al.'s study, this angle was $20.1 \pm 5.9°$ and $25.8 \pm 8.1°$ for DAA and PLA, respectively. In Zhao et al.'s study, these values were $17.1 \pm 2.1°$ and $21.3 \pm 2.4°$, respectively. These two RCTs provided different conclusions regarding the measurement of the cup inclination angle. In Barret et al.'s work, the authors showed that this angle was statistically higher in patients that were operated on using DAA than in the PLA group. These observations were not confirmed by Zhao et al.'s research in which these values were lower in the DAA than in the PLA group, but this difference was not statistically significant ($p = 0.57$). Such differences may be explained by the higher BMI values in Barret et al.'s research (29.1 ± 5.0 kg/m^2 vs. 24.35 ± 3.10 kg/m^2, respectively) and the fact that in Zhao et al.'s research, the inclusion criteria contained hips with residual dysplasia (Crowe I and II: DDA group = 6, PLA group = 7) and patients with femoral neck necrosis (Ficat III or IV: DDA group = 13, PLA group = 13). Hips with such characteristics were not included in Barret et al.'s research.

4. Discussion

Achieving the perfect stem and cup position during a THA is one of the toughest challenges. It is estimated that positioning the hip rotation center in 40° of inclination and 20° of anteversion will allow for a good clinical outcome [29,30]. Defining the optimal cup position is one thing, but achieving the targeted position in a reproducible way is even more difficult [31,32].

Proper cup orientation is believed to be the key factor toward achieving a proper cup-head contact area and minimizing its wear [33–36]. There is also an ongoing debate about whether the so-called "safe zones" proposed by Lewinnek et al [15] are really the zones lowering the risk of hip dislocation after a THA [37,38].

Knowledge of how different approaches impact stem and cup positions in a total hip arthroplasty might be crucial for achieving proper implant placement.

Even though the study by Yue et al. [18] reported differences in some radiographic results between LA and DAA, this narrative review is, to our best knowledge, the first study to sum up the radiological results when comparing the use of DAA with other approaches. However, there are some studies that underline the advantages of the DAA with regard to early rehabilitation and early postoperative outcomes [10,14]. The theory behind 'DAA superiority' is motivated by its potentially less invasive character since it is using the natural spaces between muscles.

On the other hand, Takada et al. [39] found that DAA is associated with a higher risk of nerve injury than the anterolateral approach (ALA), which is yet another aspect to consider when choosing the optimal approach. However, the more frequent occurrence of nerve injury in DAA patients did not result in a lesser clinical outcome, as it is the sensory lateral femoral cutaneous nerve, which is usually affected; therefore, it does not impair the motor joint function.

The potential limitation of our study is the lack of overall meta-analysis of the results from different studies. Another limitation is the focus mainly on the radiographic parameters, which are just some aspects of a successful surgery among others, such as the functional outcome, complications, and patient-reported outcome. The fact that our review included studies involving both cemented and cementless arthroplasties could impact the findings and therefore it should also be considered as a limitation.

The main strength of our study is that, to our best knowledge, it is the first to comprehensively compare DAA with other approaches in terms of the radiographic analysis of implant positioning. With the knowledge of how the choice of approach impacts the implant positioning, surgeons can alter their technique depending on the approach they choose in a particular case and achieve the desired result.

5. Conclusions

In conclusion, it can be admitted that according to this systematic review, which considered high-level studies, the type of approach in a total hip replacement may influence the components' positioning during the surgery. Even though some differences in both femoral stem and cup positioning were underlined, there is still an insufficient number of randomized controlled studies analyzing the radiological parameters and comparing THRs performed using DAA and other approaches.

Some authors proposed the regular use of intraoperative fluoroscopy or robotic-assisted surgery in order to place a prosthesis properly. Perhaps this is the way to improve the outcome and standardize femoral stem and cup positioning. Implant placement is an essential step during THR surgery and making the final decision about it is the key toward achieving a satisfying outcome for both the surgeon and the patient. Surgeons must be aware that their choice of approach might impact their judgment on the angles and spaces inside the joint and thus alter the implant positioning.

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References

1. Learmonth, I.D.; Young, C.; Rorabeck, C. The operation of the century: Total hip replacement. *Lancet* **2007**, *370*, 1508–1519. [CrossRef]
2. Chechik, O.; Khashan, M.; Lador, R.; Salai, M.; Amar, E. Surgical approach and prosthesis fixation in hip arthroplasty world wide. *Arch. Orthop. Trauma Surg.* **2013**, *133*, 1595–1600. [CrossRef]
3. Kwon, M.S.; Kuskowski, M.; Mulhall, K.J.; Macaulay, W.E.; Brown, T.; Saleh, K.J. Does Surgical Approach Affect Total Hip Arthroplasty Dislocation Rates? *Clin. Orthop. Relat. Res.* **2006**, *447*, 34–38. [CrossRef]
4. Kucukdurmaz, F.; Sukeik, M.; Parvizi, J. A meta-analysis comparing the direct anterior with other approaches in primary total hip arthroplasty. *Surgeon* **2019**, *17*, 291–299. [CrossRef]
5. Ilchmann, T. Approaches for primary total hip replacement. *Hip Int.* **2014**, *24*, S2–S6. [CrossRef]
6. Graves, S.C.; Dropkin, B.M.; Keeney, B.J.; Lurie, J.D.; Tomek, I.M. Does Surgical Approach Affect Patient-reported Function After Primary THA? *Clin. Orthop. Relat. Res.* **2016**, *474*, 971–981. [CrossRef]
7. Smith-Petersen, M.N. A new supra-articular subperiosteal approach to the hip joint. *J. Bone Joint Surg. Am.* **1917**, *2*, 592–595.
8. Nistor, D.V.; Caterev, S.; Bolboacă, S.D.; Cosma, D.; Lucaciu, D.O.G.; 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.* **2017**, *41*, 2245–2252. [CrossRef]
9. Post, Z.D.; Orozco, F.; Diaz-Ledezma, C.; Hozack, W.J.; Ong, A. Direct anterior approach for total hip arthroplasty: Indications; technique; and results. *J. Am. Acad. Orthop. Surg.* **2014**, *22*, 595–603. [CrossRef]
10. Jelsma, J.; Pijnenburg, R.; Boons, H.W.; Eggen, P.J.; Kleijn, L.L.; Lacroix, H.; Noten, H.J. Limited benefits of the direct anterior approach in primary hip arthroplasty: A prospective single centre cohort study. *J. Orthop.* **2017**, *14*, 53–58. [CrossRef] [PubMed]
11. Kyriakopoulos, G.; Poultsides, L.; Christofilopoulos, P. Total hip arthroplasty through an anterior approach. *EFORT Open Rev.* **2018**, *3*, 574–583. [CrossRef]

12. Wang, Z.; Hou, J.-Z.; Wu, C.-H.; Zhou, Y.-J.; Gu, X.-M.; Wang, H.-H.; Feng, W.; Cheng, Y.-X.; Sheng, X.; Bao, H.-W. A systematic review and meta-analysis of direct anterior approach versus posterior approach in total hip arthroplasty. *J. Orthop. Surg. Res.* **2018**, *13*. [CrossRef]
13. Connolly, K.P.; Kamath, A.F. Direct anterior total hip arthroplasty: Comparative outcomes and contemporary results. *World J. Orthop.* **2016**, *7*, 94. [CrossRef] [PubMed]
14. Rodriguez, J.A.; Deshmukh, A.J.; Rathod, P.A. Does the direct anterior approach in THA offer faster rehabilitation and com-parable safety to the posterior approach? *Clin. Orthop. Relat. Res.* **2014**, *472*, 455–463. [CrossRef]
15. Lewinnek, G.E.; Lewis, J.L.; Tarr, R.; Compere, C.L.; Zimmerman, J.R. Dislocations after total hip replacement arthroplasties. *J. Bone Jt. Surg. Am.* **1978**, *60*, 217–220. [CrossRef]
16. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *Int. J. Surg.* **2010**, *8*, 336–341. [CrossRef] [PubMed]
17. Higgins, J.P.T.; Thomas, J.; Chandler, J.; Cumpston, M.; Li, T.; Page, M.J.; Welch, V.A. Cochrane Handbook for Systematic Reviews of Interventions Version 6.0 (updated July 2019). Cochrane. 2019. Available online: www.training.cochrane.org/handbook (accessed on 8 February 2021).
18. Yue, C.; Kang, P.; Pei, F. Comparison of Direct Anterior and Lateral Approaches in Total Hip Arthroplasty: A Systematic Review and Meta-Analysis (PRISMA). *Medicine* **2015**, *94*, e2126. [CrossRef] [PubMed]
19. Higgins, J.P.; Altman, D.G.; Gøtzsche, P.C.; Jüni, P.; Moher, D.; Oxman, A.D.; Savović, J.; Schulz, K.F.; Weeks, L.; Sterne, J.A. Cochrane Bias Methods Group, Cochrane Statistical Methods Group The cochrane collaboration's tool for assessing risk of bias in randomised trials. *BMJ* **2011**, *343*, d5928. [CrossRef]
20. McHugh, M.L. Interrater reliability: The kappa statistic. *Biochem. Med.* **2012**, *22*, 276–282. [CrossRef]
21. Reichert, J.C.; Von Rottkay, E.; Roth, F.; Renz, T.; Hausmann, J.; Kranz, J.; Rackwitz, L.; Nöth, U.; Rudert, M. A prospective randomized comparison of the minimally invasive direct anterior and the transgluteal approach for primary total hip arthroplasty. *BMC Musculoskelet. Disord.* **2018**, *19*, 241. [CrossRef]
22. Dienstknecht, T.; Luring, C.; Tingart, M.; Grifka, J.; Sendtner, E. Total hip arthroplasty through the mini-incision (mi-cro-hip) approach versus the standard transgluteal (Bauer) approach: A prospective; randomised study. *J. Orthop. Surg.* **2014**, *22*, 168–172. [CrossRef] [PubMed]
23. Cheng, T.E.; Wallis, J.A.; Taylor, N.F.; Holden, C.T.; Marks, P.; Smith, C.L.; Armstrong, M.S.; Singh, P.J. A Prospective Randomized Clinical Trial in Total Hip Arthroplasty—Comparing Early Results Between the Direct Anterior Approach and the Posterior Approach. *J. Arthroplast.* **2017**, *32*, 883–890. [CrossRef] [PubMed]
24. Taunton, M.J.; Bohannon, M.J.; Odum, S.M.; Springer, B.D. Direct Anterior THA yields more rapid voluntary cessation of all walking aids: A Prospective; Randomized Clinical Trial. *J. Arthroplast.* **2014**, *29*, 169–172. [CrossRef]
25. Barrett, W.P.; Turner, S.E.; Leopold, J.P. Prospective Randomized Study of Direct Anterior vs Postero-Lateral Approach for Total Hip Arthroplasty. *J. Arthroplast.* **2013**, *28*, 1634–1638. [CrossRef]
26. Zhao, H.-Y.; Kang, P.-D.; Xia, Y.-Y.; Shi, X.-J.; Nie, Y.; Pei, F.-X. Comparison of early functional recovery following total hip ar-throplasty using a direct anterior or posterolateral approach: A randomized controlled trial. *J. Arthroplast.* **2017**, *32*, 3421–3428. [CrossRef]
27. Taunton, M.J.; Trousdale, R.T.; Sierra, R.J.; Kaufman, K.P.; Pagnano, M.W. Randomized Clinical Trial of Anterior and Miniposterior Approach THA: Which Provides Better Functional Recovery? *Clin. Orthop. Relat. Res.* **2018**, *476*, 216–229. [CrossRef]
28. Brun, O.C.L.; Sund, H.N.; Nordsletten, L.; Rohrl, S.M.; Mjaaland, K.E. Component Placement in Direct Lateral vs. Minimally In-vasive Anterior Approach in Total Hip Arthroplasty: Radiographic Outcomes from a Prospective Randomized Controlled Trial. *J. Arthroplast.* **2019**, *34*, 1718. [CrossRef]
29. Harrison, C.L.; Thomson, A.I.; Cutts, S.; Rowe, P.J.; Riches, P.E. Research Synthesis of Recommended Acetabular Cup Orientations for Total Hip Arthroplasty. *J. Arthroplast.* **2014**, *29*, 377–382. [CrossRef] [PubMed]
30. Board, T.; Bhaskar, D.; Rajpura, A. Current concepts in acetabular positioning in total hip arthroplasty. *Indian J. Orthop.* **2017**, *51*, 386–396. [CrossRef] [PubMed]
31. Scheerlinck, T. Cup positioning in total hip arthroplasty. *Acta Orthop. Belg.* **2014**, *80*, 336–347. [PubMed]
32. Reikerås, O.; Gunderson, R. Components anteversion in primary cementless THA using straight stem and hemispherical cup: A prospective study in 91 hips using CT-scan measurements. *Orthop. Traumatol. Surg. Res.* **2011**, *97*, 615–621. [CrossRef]
33. Angadji, A.; Royle, M.; Collins, S.N.; Shelton, J.C. Influence of cup orientation on the wear performance of metal-on-metal hip replacements. *Proc. Inst. Mech. Eng. Part H J. Eng. Med.* **2009**, *223*, 449–457. [CrossRef] [PubMed]
34. De Haan, R.; Pattyn, C.; Gill, H.S.; Murray, D.W.; Campbell, P.A.; De Smet, K. Correlation between inclination of the acetabular component and metal ion levels in metal-on-metal hip resurfacing replacement. *J. Bone Jt. Surg. Br.* **2008**, *90*, 1291–1297. [CrossRef] [PubMed]
35. Hart, A.J.; Ilo, K.; Underwood, R.; Cann, P.; Henckel, J.; Lewis, A.; Cobb, J.; Skinner, J. The relationship between the angle of version and rate of wear of retrieved met-al-onmetal resurfacings: A prospective; CT-based study. *J. Bone Jt. Surg. Br.* **2011**, *93*, 315–320. [CrossRef] [PubMed]
36. Langton, D.J.; Jameson, S.S.; Joyce, T.J.; Webb, J.; Nargol, A.V.F. The effect of component size and orientation on the concentra-tions of metal ions after resurfacing arthroplasty of the hip. *J. Bone Jt. Surg. Br.* **2008**, *90*, 1143–1151. [CrossRef]

37. Abdel, M.P.; von Roth, P.; Jennings, M.T.; Hanssen, A.D.; Pagnano, M.W. What Safe Zone? The Vast Majority of Dislocated THAs Are Within the Lewinnek Safe Zone for Acetabular Component Position. *Clin. Orthop. Relat. Res.* **2016**, *474*, 386–391. [CrossRef] [PubMed]
38. Tezuka, T.; Heckmann, N.D.; Bodner, R.J.; Dorr, L.D. Functional Safe Zone Is Superior to the Lewinnek Safe Zone for Total Hip Arthroplasty: Why the Lewinnek Safe Zone Is Not Always Predictive of Stability. *J. Arthroplast.* **2019**, *34*, 3–8. [CrossRef]
39. Takada, R.; Jinno, T.; Miyatake, K.; Hirao, M.; Kimura, A.; Koga, D.; Yagishita, K.; Okawa, A. Direct anterior versus anterolateral approach in one-stage supine total hip arthroplasty. Focused on nerve injury: A prospective, randomized, controlled trial. *J. Orthop. Sci.* **2018**, *23*, 783–787. [CrossRef]

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Review

Spinopelvic Alignment and Its Use in Total Hip Replacement Preoperative Planning—Decision Making Guide and Literature Review

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Abstract: Worldwide tendencies to perform large numbers of total hip arthroplasties in the treatment of osteoarthritis are observable over a long period of time. Every year, there is an observable increase in the number of these procedures performed. The outcomes are good but not ideal, especially in groups of patients with spine problems. In recent years, a growing interest in this field may be observed, since spinopelvic alignment seems to have a significant impact on total hip replacement (THR) results. The aim of this study is to describe relations between spine and pelvic alignment and provide practical information about its impact on total hip replacement. The authors performed a literature review based on PubMed, Embase, and Medline and provide practical guidelines based on them and their own experience.

Keywords: spinopelvic; alignment; total; hip; replacement; alloplasty; preoperative; planning

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1. Introduction

Osteoarthritis (OA) affects one in three people over the age of 65, and it is more common among women than men. This multifactorial disease leads to structural changes of the joint, and it is connected to chronic conditions. OA is characterized by pain, stiffness, and decreased range of motion (ROM). These factors lead to poor quality of life—insomnia, depression, lack of confidence, and limitations in daily activities, work, or hobbies. OA causes very serious problems for patients and significant social and economic costs [1].

Total hip replacement (THR) was a revolutionary method used for the treatment of an end-stage osteoarthritis in the hip. The aim of this operation is to increase the patient's range of motion and activity level, alleviate pain, reduce limitations in everyday life, and, ultimately, improve the patients' standard of living [2]. Although the first steps in modern THR date back to the 1940s [3], this technique is constantly enhanced. It should also be pointed out that indications of THR have changed throughout the years. In the past, this procedure was reserved for infirm, ailing people having major difficulties walking. Nowadays, the range of indications is much wider. Contemporary technologies are able to deliver highly advanced implants to meet even the most demanding requirements and assure patients' fully functioning life, full of challenging activities [4]. Our knowledge of total hip replacement, according to the records, is enriched with the classification of architectural hip deformities [5], perioperative care [6], and the use of alternative types of articulations, e.g., dual mobility components [7]. Currently, we can also feature many different bearing types used for THR [8], which improves patient outcomes after an operation.

Despite great advancements and fantastic results of the majority of operations, approximately 10% of patients are still not satisfied with the effect of THR [9,10]. Searching for the reasons of discontent, the following problems seem to play a vital role: insufficient restoration of ROM, perceptible distinction between the length of lower extremities [5], dislocation of prosthesis elements, and need for revision surgery. The key to achieve satisfaction of patients and perform successful THR with positive results is a traditional or digital preoperative strategy, which has been emphasized by many authors throughout the years [5,11–14].

During the last few years, there has been a growing interest in parameters called "spinopelvic alignment". When it comes to preoperative planning before total hip replacement, hip–spine relations seem to play a big role and have been underestimated during recent years. Interest in that relation is growing as it becomes more clear that it has major clinical consequences [15], especially in the risk of dislocations [16]. This study is designed to provide practical advice on preoperative planning for total hip replacement.

2. Materials and Methods

A review of the literature was performed. A search for all articles connected with the topic, with the time frame set to 1900–2021, was performed. Keywords relating to spinopelvic alignment and total hip replacement were searched using the following online databases: Embase, Medline, and PubMed. Search filters included English language studies, research on humans, articles in press, and available abstracts. Papers were included in this review based on their titles; then, their abstract; and, finally, the full paper was assessed. The exclusion criteria were: only the abstract or title were available; the study was in any language other than English; the article was ahead of print; and the study concerned animals. On the next level of preparation, studies were excluded if they did not include information about spinopelvic alignment in total hip replacement or information about it was not relevant. The full text of the articles that met these criteria were obtained; then, a manual search was performed. Finally, papers not up to date with historical findings were excluded, as well as duplicates. A search and risk of bias assessment was performed by a single researcher. Data was extracted from the articles by one author and rechecked by the same author. Analysis and synthesis of studies were performed by one author.

3. What May Influence the Spinopelvic Alignment?

The hip and spine coexist in a biomechanical chain, and require special coordination between them. The lumbosacral joint connects the pelvis with the spine. On each side of the body, the hip joint and sacroiliac joint form spine–pelvic–hip connections, which are crucial in pelvic motion and maintaining appropriate balance during bipedal locomotion. Every ongoing disease process associated with joints mentioned before restricts mobility, decreases stability, and makes activities of daily life difficult.

With age, and due to other conditions, such as osteoarthritis, osteoporosis, or fractures, spinal curvatures evolve, mostly causing an incorrect spinal position and imbalance. The sagittal imbalance has a connection with disability and pain and occurs as a result of decreased lumbar lordosis, increased thoracic kyphosis, contractures in hips or knees, and changes in pelvic parameters mentioned above. Human organisms adjust to the environment and develop compensatory mechanisms to prevent consequences of disbalance [17]. Over the course of a lifetime, compensatory mechanisms are exhausted, which causes pelvic retroversion—the pelvis becomes more horizontal, thinner, and wider. Cervical lordosis, lumbar lordosis, and thoracic kyphosis may become shallower or deeper. Most frequently, lumbar hypolordosis, resulting in hip extension, knee flexion, and ankle flexion [18,19], thoracic hyperkyphosis, and anterior spinal instability occur. This results in inevitable pathologies involving the axial skeleton, hip joints, knee joints, and ankles.

The interaction of the spine with the lower limbs occurs through the pelvis. The mobility of the pelvis acts as a "hinge" between the spine and the hip—it allows one to move upright on the lower limbs [20].

Medical procedures performed on patients should also be taken into account. It was demonstrated that spinal fusion before THR might increase the risk of dislocation and impingement by increasing posterior pelvic tilt [1]. Nevertheless, the more segments are involved, the higher the limitations and the more dysfunctional the hip–spine biomechanics are [1,2].

4. Problems Associated with Improper Spinopelvic Mobility and THR

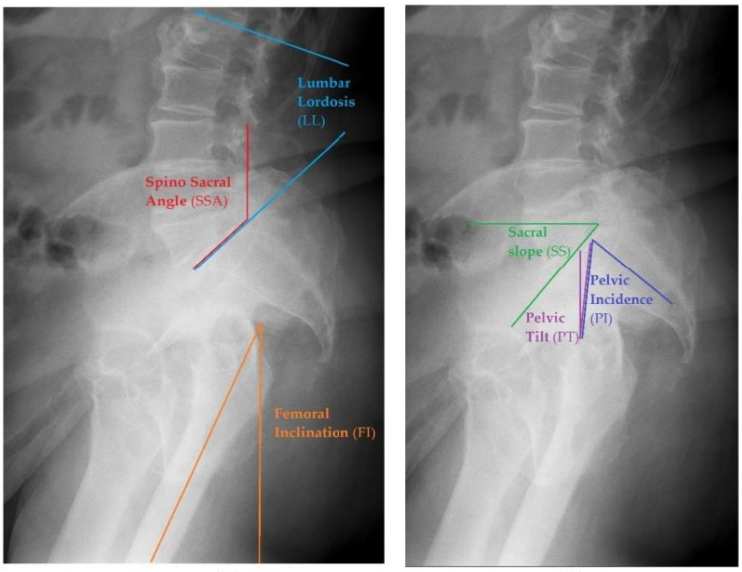
Dislocation of a hip prosthesis is a common complication occurring after the THR. The rate varies from 0.2 to 10% per year [21]. Even in 1980, there were reports of the impact of neuromuscular and cognitive disorders or excessive intake of alcohol beverages on the prevalence of single or recurrent dislocation [22]. Dislocations have a range of other risk factors, such as older age [23], gender, comorbidities such as rheumatoid arthritis (RA) [24], or surgical approach [25]. Another very important role in dislocations after THR is cup and stem position. The reports indicate a correlation between prevalence of posterior dislocation and low cup anteversion [23]. The size of the femoral head articulation is also instrumental in decreasing the risk of dislocation. Larger, 36 mm femoral heads, compared with smaller, 28 mm articulations, lower the incidence of displacement during the first year after primary THR [26].

The "safe zone" (anteversion $15^\circ \pm 10^\circ$, inclination $40^\circ \pm 10^\circ$ of acetabular cup), defined by Lewinnek, was designed to decrease the risk of dislocation after primary THR [16]. However, dislocations still occur [27]. One of the main reasons for that is probably the spine dynamics. Patients with a sagittal spinal deformity (SSD) are not protected by the "safe zone" [28]. SSD means abnormal kyphosis or lordosis, which can result in abnormalities within the pelvis [29].

Since spine dynamics are not the only risk factor, surgeons must be aware of the other ones. Unfortunately, almost all of them cannot be fixed by preoperative planning and special positioning of implants. That is why the surgeon should pay special attention to spine dynamics—one of the most important factors, and one of very few amenable to change by the orthopedic surgeon.

5. Anatomy and Imaging

Before starting the operation, proper planning should be done. Normally, the whole process is done based on antero-posterior pelvic X-ray. In case of any suspicion of abnormalities with spinopelvic alignment, special lateral views could also be useful, as they allow one to perform measurements of more sophisticated parameters of pelvic alignment. This should visualize a part of the body from L1 to the proximal femur, including the pelvis. Example of such X-rays are seen in Figure 1.



(**a**) (**b**)

Figure 1. Examples of different pelvic measurements performed on lateral X-rays of the pelvis with lumbar spine view. (**a**) Spino Sacral Angle, Lumbar Lordosis and femoral Inclination presented on lateral X-ray. (**b**) Sacral Slope, Pelvic Incidence and Pelvic Tilt presented on lateral X-ray.

Radiographic Measurements

- Sacral Slope (SS)—to measure this angle, one needs to draw the straight line of the S1 superior endplate and a leveled line at a right angle to the gravitational force direction (horizontal reference line) [30]. The normal value ranges between 32 and 49° [31].
- Pelvic Tilt (PT)—an angle between the reference vertical line and the line joining the middle of S1 upper endplate and the center of the femoral head. The normal value ranges from 7 to 19° [31].
- Pelvic Incidence (PI)— the angle between the line that is formed by connecting the upper endplate of S1 (at its midpoint) to the femoral head axis. The normal value ranges from 38 to 56° [31].
- Pelvic Femoral Angle (PFA)—the position of the femur in relation to the pelvis. It is the angle centered at the femoral head, between the mid sacral base and down femoral shaft. The normal value ranges from 1 to 17° [31].
- Lumbar Lordosis (LL)—the segmental angle of spinal segment in lordosis, measured between the line on the upper endplate of L1 and the line on the upper endplate of S1(L1 -L5). The normal value ranges from 40 to 58° [31].
- Femoral Inclination (FI)—the angle between a vertical reference line and the axis of the femur. The normal value ranges from 0 to 8° [31].
- Sacro Femoral Angle (SFA)—the angle between the line of the upper endplate of S1 and the axis of the femur. The normal value ranges from 43 to 61° [31]
- Spino Sacral Angle (SSA)—the angle between the line of the upper endplate of S1 and a reference vertical line. The normal value ranges from 119 to 133° [31].

All angles mentioned above refer to an X-ray in standing position, which is the most common way to take radiographs for preoperative planning. It is also advisable to take the radiographs in sitting upright position to view the changing relations between the angles.

It should be taken into account that the position of the torso during sitting may influence spinopelvic alignment and have an impact on the hip joint [32].

6. Approach to Preoperative Planning—Spinopelvic Mobility

When it comes to planning a total hip replacement, surgeons must be aware that the position of the acetabulum changes and depends on the position of the patient. In many cases, surgeons measure the pelvic tilt just before acetabular reaming while the patient is lying in supine position. It should be stressed that the patient is not going to stay in this position the whole time, and placement of the acetabulum should be fitted not only to this position (which slightly differs from standing position), but also to a sitting one.

While changing position from standing to sitting, numerous changes are observed between spine and pelvis (Table 1). While lumbar lordosis decreases, the sacrum moves backward. This leads to an increase in acetabular anteversion [33]. This shows that only part of the movement is performed by the hip joint. Range of movement depends on spinopelvic mobility. In the literature, there are described three types, each of them with a different impact:

Table 1. Spinopelvic mobility types.

Spinopelvic Motion	Pelvic Tilt Change	Hip Bend Change	Lumbar Lordosis	Pelvic Femoral Angle
Normal	20°–35°	55°–70°	20°	45°
Hypermobile	>35°	<55°	>20°	<45°
Stiff	<20°	>70°	<20°	>45°

Not all parameters are equally important in preoperative planning. Essential parts of each of them are connected with one another, giving the following equation:

$$\text{Pelvic Incidence (PI)} = \text{Sacral Slope (SS)} + \text{Pelvic Tilt (PT)}$$

There is no need to measure every angle mentioned above. When it comes to other, more sophisticated ones, they describe more complicated relations between pelvis and spine and are not essential parts of the preoperative planning, although the knowledge may provide a broader view. Since pelvic tilt plays a vital role in the concept of spinopelvic alignment, it is considered the most important parameter [34]. Moreover, other parameters are in close relation to those essential ones from the quotation above, e.g., a decrease of 1° Δ SS results in a 0.9° increase in pelvic femoral angle (PFA) [35]. All those parameters describe a pelvic position which is an important information in preoperative planning (Table 2).

Table 2. Clinical consequences and problems in relation to pelvic position.

Types of Pelvic Position	Clinical Consequences	Potential Problems
In case of android type of pelvis (low PI, low SS, lower rotational movements) there is a tendency to retroversion, which leads to sacroiliac joints stiffness.	Low spinopelvic mobility is compensated by movement in hip joints.	Lower acetabular coverage -> risk of posterior dislocation during sitting
In case of a gynecoid type of pelvis (high PI, high SS, anteversion, higher rotational movements, no osteoarthritis in lumbar spine).	Spinopelvic mobility is restricted by hip joint movements. Lower extension in hip joints.	Higher possibilities of adaptive changes and higher acetabular coverage -> risk of anterior dislocation during standing
In case of lumbar spine stabilization with pelvis, with tendency to anteversion.	Higher acetabular anteversion.	Risk of anterior dislocation during standing
In case of lumbar spine stabilization with pelvis, with tendency to retroversion (flat back).	Lower acetabular anteversion.	Risk of posterior dislocation during sitting

PI, pelvic incidence; SS, sacral slope.

7. Decision Making Proposition

During the last two years, our joint replacement team, which included three high volume surgeons (with over 2000 THR done), performed over 700 joint replacement surgeries, including over 250 total hip replacements. So far, we have noticed only one dislocation of traumatic etiology in a neurologically impaired patient. The recommendations described below (Table 3) include practical tips based on their knowledge and experience, which are supported by the newest literature.

Table 3. Recommendation during THR (total hip replacement) in connection to spinopelvic alignment.

Spinopelvic Alignment	Preoperative Recomandation
Pelvic retroversion	Higher acetabular anteversion and inclination during THR—within limits of Lewinnek's safe zone
Pelvic anteversion	Lower acetabular anteversion and inclination during THR—within limits of Lewinnek's safe zone
Lumbar spine stabilization with pelvic with tendency to anteversion	Higher acetabular anteversion during THR—up to 30°
Lumbar spine stabilization with pelvic with tendency to retroversion	Lower acetabular anteversion during THR—up to 5°
Patients with hypermobile spinopelvic junction	Higher acetabular anteversion during THR—up to 25°
Patients with stiff spinopelvic junction	Higher acetabular inclination during THR—within limits of Lewinnek's safe zone

It is still unknown what the optimal angles of anteversion or inclination are in particular cases of alterations in spinopelvic alignment. The optimal angles, earlier described as the "safe zone"[16], also change and no longer give optimal results [15]. To get better results and "safety", the total hip replacement surgeon, based on recommendations in the table above and their own clinical experience, should decide on the optimal positioning of acetabular component.

8. Discussion

To achieve satisfactory results after THR, a good understanding of the spinopelvic motion, acetabulum location, and risk factors of impingement are needed. So far, many important investigations have been performed in this field. One of the most important was to find a relationship between pelvic tilt (PT) and acetabulum. The growth in anteversion of the acetabular cup for each degree posterior PT equals approximately 0.7°, which clearly shows the impact of PT on the position of the cup [36]. This parameter seems to be crucial during preoperative planning and was used in the algorithm. Another equally important parameter is cup inclination, which increases about 0.3 degrees with 1 degree of increase in pelvic tilt, although this relationship seems to be nonlinear and more complicated, as inclination is more connected with anteversion, and the change does not seem to be linear [37].

Apart from that, it is important to realize that dislocation may not only be correlated with spinopelvic alignment, but also with other factors listed previously [23–25]. The overall risk of dislocation is probably connected with all of them.

Another issue that is worth attention is spinal fusion in relation to THR. The latter should be a priority. Afterwards, if there are indications, spinal fusion can be carried out. There is one exception in which the order should be reversed. The spinal fusion may be done earlier than THR when the patient's pelvic retroversion is increased [1,2]. Another approach may cause risk to THR stability [38]. As noted in the literature, the dislocation rate in patients with lumbar spine fusion (LSF) after THR is 1.7%, in patients with THR without spine pathology is 2.3%, in patients with THR with spine pathology at 3.3%, and in patients with THR after LSF is 4.6% [39]. Other works give more information regarding how not only the timing of the operations but also the range of lumbar fusions can affect the dislocation rate. It is estimated that the dislocation rate for THR patients without prior spinal fusion was 2.4%, 4.3% for patients with one to two levels fused, and 7.5% for patients with three to five levels fused [40].

New technologies of, and approaches to, hip alloplasty allow surgeons to operate on patients even with a high degree of stiffness between spine and pelvis. If the patient's ante-inclination values change less than 5 degrees between sitting and standing position (acetabulum does not accommodate during spinopelvic motion), there is a higher risk of dislocation. In this case, the surgeon has to use a dual mobility articulation cup, making THR. Dual mobility cup (DMC) comprises a small head connected to a polyethylene liner. The aim of DMC is to enhance ROM and better stabilization [41]. It provides a lesser risk of dislocation in cases more prone to that complication—especially in case of neurological diseases, accompanied by increased or decreased muscle tonicity, e.g., multiple sclerosis, or bone defects [41].

The literature review performed in this study excluded data that was not in English, or without abstract or title. That is one of the main limitations. Another limitation is a quality of the study. Some studies enrolled in this review were performed on relatively small groups of patients; the results of the same studies performed on bigger groups may slightly differ.

To our best knowledge, there is no data concerning the impact of total knee replacement or foot and ankle problems on spinopelvic alignment. Since all parts of the lower limb may affect the result of THR, further research is needed in this field [18,19].

9. Conclusions

Spinopelvic alignment seems to play a vital role in understanding hip joint biomechanics and the impact of residual changes in the spine on hip mobility. This knowledge is essential for hip replacement surgeons, as it is a way to avoid postoperative complications, such as prosthesis dislocations, range of movement limitations, or prolonged pain after surgery. The crucial element of performing the surgery with a result satisfactory for the patient is preoperative planning. The algorithms mentioned above may be useful tools for a surgeon in the decision making process. Hopefully, a complete understanding of spinopelvic relations will increase satisfaction rates among patients after total hip replacement and contribute to further improvements in operation technique.

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References

1. Wareńczak, A.; Lisiński, P. Does total hip replacement impact on postural stability? *BMC Musculoskelet. Disord.* **2019**, *20*, 229. [CrossRef] [PubMed]
2. Tsinaslanidis, G.; Tsinaslanidis, P.; Mahajan, R.H. Perioperative Pain Management in Patients Undergoing Total Hip Arthroplasty: Where Do We Currently Stand? *Cureus* **2020**, *12*, e9049. [CrossRef]
3. Law, W.A. Post-operative study of vitallium mould arthroplasty of the hip. *J. Bone Jt. Surg Br.* **1948**, *30*, 76–83. [CrossRef]
4. Learmonth, I.D.; Young, C.; Rorabeck, C. The operation of the century: Total hip replacement. *Lancet* **2007**, *370*, 1508–1519. [CrossRef]
5. Kase, M.; O'Loughlin, P.F.; Aït-Si-Selmi, T.; Pagenstert, G.; Langlois, J.; Bothorel, H.; Bonnin, M.P. Pre-operative templating in THA. Part I: A classification of architectural hip deformities. *Arch. Orthop. Trauma Surg.* **2019**, *140*, 129–137. [CrossRef] [PubMed]

6. Wainwright, T.W.; Gill, M.; McDonald, D.A.; Middleton, R.G.; Reed, M.; Sahota, O.; Yates, P.; Ljungqvist, O. Consensus statement for perioperative care in total hip replacement and total knee replacement surgery: Enhanced Recovery After Surgery (ERAS®) Society recommendations. *Acta Orthop.* **2020**, *91*, 3–19. [CrossRef]
7. Darrith, B.; Courtney, P.M.; Della Valle, C.J. Outcomes of dual mobility components in total hip arthroplasty. *Bone Jt. J.* **2018**, *100-B*, 11–19. [CrossRef] [PubMed]
8. Mohanty, S.S.; Mohan, H.; Rathod, T.N.; Kamble, P. Patient satisfaction related outcome after total hip arthroplasty; does bearing surface play a role? *J. Clin. Orthop. Trauma* **2020**, *11* (Suppl. 2), S196–S200. [CrossRef]
9. Bourne, R.B.; Chesworth, B.; Davis, A.; Mahomed, N.; Charron, K. Comparing Patient Outcomes After THA and TKA: Is There a Difference? *Clin. Orthop. Relat. Res.* **2009**, *468*, 542–546. [CrossRef]
10. Tang, H.; Du, H.; Tang, Q.; Yang, D.; Shao, H.; Zhou, Y. Chinese patients' satisfaction with total hip arthroplasty: What is important and dissatisfactory? *J. Arthroplast.* **2014**, *29*, 2245–2250. [CrossRef]
11. Glassman, A.H. Preoperative planning for primarytotal hip arthroplasty. *Oper. Tech. Orthop.* **1995**, *5*, 296–305. [CrossRef]
12. Shemesh, S.S.; Robinson, J.; Keswani, A.; Bronson, M.J.; Moucha, C.S.; Chen, D. The Accuracy of Digital Templating for Primary Total Hip Arthroplasty: Is There a Difference Between Direct Anterior and Posterior Approaches? *J. Arthroplast.* **2017**, *32*, 1884–1889. [CrossRef]
13. Liebs, T.; Nasser, L.; Herzberg, W.; Ruther, W.; Hassenpflug, J. The influence of femoral offset on health-related quality of life after total hip replacement. *Bone Jt. J.* **2014**, *96*, 36–42. [CrossRef] [PubMed]
14. Rondon, A.; Sariali, E.; Vallet, Q.; Grimal, Q. Modal analysis for the assessment of cementless hip stem primary stability in preoperative THA planning. *Med. Eng. Phys.* **2017**, *49*, 79–88. [CrossRef] [PubMed]
15. Lazennec, J.-Y.; Brusson, A.; Rousseau, M.-A. Hip–spine relations and sagittal balance clinical consequences. *Eur. Spine J.* **2011**, *20*, 686–698. [CrossRef] [PubMed]
16. Lewinnek, G.E.; Lewis, J.L.; Tarr, R.; Compere, C.L.; Zimmerman, J.R. Dislocations after total hip-replacement arthroplasties. *J. Bone Jt. Surg Am.* **1978**, *60*, 120–217. [CrossRef]
17. Barrey, C.; Roussouly, P.; Le Huec, J.-C.; D'Acunzi, G.; Perrin, G. Compensatory mechanisms contributing to keep the sagittal balance of the spine. *Eur. Spine J.* **2013**, *22*, S834–S841. [CrossRef]
18. Lee, S.H.; Lim, C.W.; Choi, K.Y.; Jo, S. Effect of Spine-Pelvis Relationship in Total Hip Arthroplasty. *Hip Pelvis* **2019**, *31*, 4–10. [CrossRef]
19. Barrey, C.; Jund, J.; Noseda, O.; Roussouly, P. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases. A comparative study about 85 cases. *Eur. Spine J.* **2007**, *16*, 1459–1467. [CrossRef]
20. Pizones, J.; García-Rey, E. Pelvic motion the key to understanding spine–hip interaction. *EFORT Open Rev.* **2020**, *5*, 522–533. [CrossRef]
21. Dargel, J.; Oppermann, J.; Brüggemann, G.-P.; Eysel, P. Dislocation Following Total Hip Replacement. *Dtsch. Aerzteblatt Online* **2014**, *111*, 884–890. [CrossRef] [PubMed]
22. Fackler, C.D.; Poss, R. Dislocation in total hip arthroplasties. *Clin. Orthop. Relat. Res.* **1980**, *151*, 169–178. [CrossRef]
23. Paterno, S.A.; Lachiewicz, P.F.; Kelley, S.S. The influence of patient-related factors and position of the acetabular component on the rate of dislocation after total hip replacement. *J. Bone Jt. Surg.* **1997**, *79*, 1202. [CrossRef] [PubMed]
24. Khatod, M.; Barber, T.; Paxton, E.; Namba, R.; Fithian, D. An Analysis of the Risk of Hip Dislocation with a Contemporary Total Joint Registry. *Clin. Orthop. Relat. Res.* **2006**, *447*, 19–23. [CrossRef] [PubMed]
25. Masonis, J.L.; Bourne, R.B. Surgical Approach, Abductor Function, and Total Hip Arthroplasty Dislocation. *Clin. Orthop. Relat. Res.* **2002**, *405*, 46–53. [CrossRef]
26. Howie, D.W.; Holubowycz, O.T.; Middleton, R. Large femoral heads decrease the incidence of dislocation after total hip arthroplasty: A randomized controlled trial. *J. Bone Jt. Surg.* **2012**, *94*, 1095–1102. [CrossRef] [PubMed]
27. Abdel, M.P.; von Roth, P.; Jennings, M.T.; Hanssen, A.D.; Pagnano, M.W. What Safe Zone? The Vast Majority of Dislocated THAs Are Within the Lewinnek Safe Zone for Acetabular Component Position. *Clin. Orthop. Relat. Res.* **2016**, *474*, 386–391. [CrossRef]
28. DelSole, E.M.; Vigdorchik, J.; Schwarzkopf, R.; Errico, T.; Buckland, A. Total Hip Arthroplasty in the Spinal Deformity Population: Does Degree of Sagittal Deformity Affect Rates of Safe Zone Placement, Instability, or Revision? *J. Arthroplast.* **2017**, *32*, 1910–1917. [CrossRef]
29. Roussouly, P.; Nnadi, C. Sagittal plane deformity: An overview of interpretation and management. *Eur. Spine J.* **2010**, *19*, 1824–1836. [CrossRef] [PubMed]
30. Imai, N.; Suzuki, H.; Sakagami, A.; Hirano, Y.; Endo, N. Correlation of the anatomical sacral slope with pelvic incidence in female patients with developmental hip dysplasia: A retrospective cross-sectional study. *J. Orthop. Surg. Res.* **2020**, *15*, 1–6. [CrossRef]
31. Wang, W.J.; Liu, F.; Zhu, Y.; Sun, M.; Qiu, Y.; Weng, W.J. Sagittal alignment of the spine-pelvis-lower extremity axis in patients with severe knee osteoarthritis. *Bone Jt. Res.* **2016**, *5*, 198–205. [CrossRef] [PubMed]
32. Suzuki, H.; Endo, K.; Sawaji, Y.; Matsuoka, Y.; Nishimura, H.; Takamatsu, T.; Murata, K.; Seki, T.; Konishi, T.; Aihara, T.; et al. Radiographic Assessment of Spinopelvic Sagittal Alignment from Sitting to Standing Position. *Spine Surg. Relat. Res.* **2018**, *2*, 290–293. [CrossRef] [PubMed]
33. Homma, Y.; Ishii, S.; Yanagisawa, N.; Ochi, H.; Baba, T.; Nojiri, H.; Okuda, T.; Kaneko, K. Pelvic mobility before and after total hip arthroplasty. *Int. Orthop.* **2020**, *44*, 2267–2274. [CrossRef]

34. Luthringer, T.A.; Vigdorchik, J. A Preoperative Workup of a “Hip-Spine” Total Hip Arthroplasty Patient: A Simplified Ap-proach to a Complex Problem. *J. Arthroplast.* **2019**, *34*, S57–S70. [CrossRef] [PubMed]
35. Heckmann, N.; McKnight, B.; Stefl, M.; Trasolini, N.A.; Ike, H.; Dorr, L.D. Late Dislocation Following Total Hip Arthroplasty. *J. Bone Jt. Surg.* **2018**, *100*, 1845–1853. [CrossRef]
36. Lembeck, B.; Mueller, O.; Reize, P.; Wuelker, N. Pelvic tilt makes acetabular cup navigation inaccurate. *Acta Orthop.* **2005**, *76*, 517–523. [CrossRef]
37. Roettges, P.S.; Hannallah, J.R.; Smith, J.L.; Ruth, J.T. Predictability of Pelvic Tilt During Total Hip Arthroplasty Using a Traction Table. *J. Arthroplast.* **2018**, *33*, 2556–2559. [CrossRef] [PubMed]
38. Buckland, A.J.; Vigdorchik, J.; Schwab, F.J.; Errico, T.; Lafage, R.; Ames, C.; Bess, S.; Smith, J.; Mundis, G.M.; Lafage, V. Acetabular Anteversion Changes Due to Spinal Deformity Correction: Bridging the Gap Between Hip and Spine Surgeons. *J. Bone Jt. Surg.* **2015**, *97*, 1913–1920. [CrossRef] [PubMed]
39. Bala, A.; Chona, D.V.; Amanatullah, D.F.; Hu, S.S.; Wood, K.B.; Alamin, T.F.; Cheng, I. Timing of Lumbar Spinal Fusion Affects Total Hip Arthroplasty Outcomes. *JAAOS Glob. Res. Rev.* **2019**, *3*, e00133. [CrossRef] [PubMed]
40. Gu, J.; Feng, H.; Feng, X.; Zhou, Y. Degeneration of three or more lumbar discs significantly decreases lumbar spine/hip ROM ratio during position change from standing to sitting in AVN patients before THA. *BMC Musculoskelet. Disord.* **2020**, *21*, 39. [CrossRef] [PubMed]
41. Onochi, Y.; Fukui, K.; Kaneuji, A.; Ichiseki, T.; Wang, X.; Kawahara, N. Dual mobility acetabular construct with freedom constrained liner for treatment of recurrent dislocations after total hip arthroplasty: A case report and literature review. *Int. J. Surg. Case Rep.* **2020**, *75*, 94–99. [CrossRef] [PubMed]

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HIP ARTHROPLASTY

Analysis of biomechanical gait parameters in patients after total hip replacement operated via anterolateral approach depending on size of the femoral head implant: retrospective matched-cohort study

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Abstract

Introduction Total hip replacement (THR) is considered one of the most effective medical procedures in treatment of osteoarthritis. Since its introduction, there has been a worldwide debate over proper implant selection in terms of size, bearing type and shape. Following study was designed to assess the importance of femoral head size in long-term follow-up.

Materials and methods A cohort of 30 patients with primary end stage osteoarthritis who underwent total hip replacement was analysed retrospectively. A homogenous group was chosen with no major differences in BMI. Patients' gait parameters were measured in a biomechanics laboratory using the 3D BTS Smart system. WOMAC and VAS questionnaires were used to assess patient reported outcome.

Results The subgroup with larger implant head size had several outcomes significantly superior to the subgroup with standard head size and non-inferior to healthy hips. Following variables were measured during this study: time of support phase, time of swing phase, double support time, walking hip extension angle.

Conclusions Use of larger sized femoral heads during THR gives better results in terms of gait pattern. Since restoring the gait pattern is one of the aspects of rehabilitation and returning to daily activities it seems to be an important observation.

Keywords Total hip replacement · Arthroplasty · Gait · Large head · Biomechanics · Pattern

Introduction

Total hip replacement (THR) is considered to be one of the most effective medical procedures, being even named as the operation of the century [1]. It is estimated that the number of patients undergoing this surgery in the United States in 2020 will reach almost 500 thousand [2].

Since its introduction, there has been a worldwide debate over proper implant selection in terms of size, bearing type and shape [3–5]. Surgeons put effort into choosing the best combination of implant components to achieve personalization of the prosthesis and maximize the therapeutic effect of the surgical procedure. One of the most important aspects is femoral head size which has had a growing interest over the recent years. The average diameter of femoral head components used in THR grew throughout the years—from 22 mm in the 1960s to 32 mm in the 2000s, which is the most often used size nowadays. Over the recent years there was a notable number of large femoral heads (> = 36 mm) used in several registers [6–9]. There are many studies providing strong evidence that the range of motion, risk of dislocation, functional results, pain and prosthesis wear are dependent on femoral head size. Majority of them favour larger ones [10–19].

However, in the most recent reliable reviews, there are interesting observations made which make surgeons reconsider their decisions during THA. Studies prove that hip function and patient-reported outcome do not improve in THA with heads diameter between 32 to 36 mm. That should

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be considered along with evidence that hip range of motion increases with larger bearing sizes up to 36–38 mm, and also that 36 mm or larger femoral heads provide greater stability compared to 28 mm or smaller, and probably even to 32 mm [10, 17, 18].

There are also some complications after THA, which are being explained by larger femoral head use. One of them is a possible cause–effect relation between large femoral heads and taper corrosion but it is still controversial. Another controversy is the potential causative effect of larger head size on the incidence of groin pain due to iliopsoas impingement after THA. Since neither was clearly proven, both complications need further investigation [20–23].

There are several high-quality studies analysing factors mentioned above, but there is still a limited number of research concentrating on gait pattern after total hip replacement and its dependence on the implant head size. Since the femoral head size has a proven impact on range of motion, it is highly probable that it also alters the gait pattern or at least some parameters of gait that may be important in the rehabilitation process [18, 24].

Choosing adequate implants during total hip replacement might be crucial for improving the outcome and maximizing the results of the surgery. It might expedite restoring limb function and hip biomechanics, rehabilitation and help lower socioeconomic factors associated with total joint replacement.

Hypothesis of authors of this manuscript is that larger femoral heads allow to restore a healthy gait pattern due to the more anatomical femoral head size; thus, restoring more native hip biomechanics.

The aim of this study was to assess potential differences in lower limb biomechanics during gait in patients following primary total hip replacement surgery performed via anterolateral approach depending on femoral head diameter and to compare the results of the operated limb to the healthy one. As a secondary outcome authors wanted to inspect any correlation between gait parameters and patient-reported outcome and investigate possible superiority of larger femoral head implants over smaller ones in terms of postoperative gait biomechanics.

Materials and methods

This study was conducted according to the Consolidated Standards of Reporting Trials (CONSORT) and an appropriate checklist was presented to the editors of the Journal [25]. This study was retrospectively registered on ClinicalTrials.gov (Registration number: NCT04521842). Institutional Ethics Committee approval was obtained and every participant signed a written consent to participate.

A consecutive series of 19 patients who received an uncemented Maxera Taperloc (Warsaw, IN, USA) metal-on-conventional-polyethylene THA system with head diameter of 36 mm between May of 2017 and June of 2017 was identified. Patients included in the study were: (1) aged > 60 years, (2) had BMI (kg/m2) < 40, (3) were able to walk for 10 m, (4) had leg length discrepancy < 5 mm, (5) knee flexion angle > 90 degrees, (6) hip extension angle < 0 degrees, and (7) hip flexion angle > 90 degrees, (8) complaining and radiologically confirmed single limb hip osteoarthritis, confirmed grade III and IV in Kellgren-Lawrence scale [26]. All participants received on-label use of an uncemented hip system as a treatment for end-stage hip osteoarthritis. Exclusion criteria included (1) patients with severe deformity with and (2) patients who underwent any other lower limb surgery before or after the THA, (3) patients with neurological disorders, (4) or severely impaired balance.

For the present analysis, the following demographic patient data were queried: sex, age at surgery (years), and BMI. A total of 16 patients treated with Maxera Taperloc (Warsaw, IN, USA) hip system met the inclusion criteria. All patients at the institution have a standard antero-posterior pelvic weight-bearing radiographic examination for evaluating intraarticular grade of osteoarthritis, leg discrepancy and assessment of hip joint alignment. Every patient fulfils the WOMAC questionnaire on the day of the admission to the hospital to assess hip joint function.

All surgeries were performed in a level III academic hospital. All operations were performed by an experienced total joint replacement surgeon.

All patients were operated in the lateral decubitus position. Surgical technique using natural interval in gluteal muscles and dissecting only one-third of its attachment was used. Incision in line with the axis of femoral shaft was performed with 1/3 distally and 2/3 proximally to the tip of the greater trochanter. Further blunt dissection of connective and fat tissue was done to visualize iliotibial tract. The latter structure was then incised in a slightly curved way so to stay in line with fibers of tensor fascia lata. After moving fascia aside, visualization of gluteus medius was done. Natural interval of 1/3 anterior part of the gluteus medius was found and carefully dissected from the bone. Then the femoral neck was easily palpable and the joint capsule was opened with a longitudinal dissection above the femoral neck. After completing the approach the hip joint was dislocated, the femoral neck was cut accordingly to manufacturer technique. All acetabular cups were templated in the position of 40–45 degrees inclination and 10–15 degrees anteversion to the supine anterior pelvic plane. All stems were uncemented. Proper prosthesis placement was confirmed on X-ray images taken on the following day. No leg discrepancy was observed.

Flexion and extension exercises of the ankle and isometric quadriceps contraction exercises were introduced on the first post-operative day, with full weight-bearing within pain tolerance. The duration of the exercises was 40 min to 1 h 3 times per day. All exercises were done bedside without using additional tools. The aim of mobilisation with a physiotherapist was to obtain flexion of the hip of 90°. Other methods of mobilisation included using a walker shoe and walking with crutches were introduced by the third day post-op. Patient-reported outcome (PRO) and gait pattern analysis of the large head diameter study cohort were compared to a 1:1 matched-control cohort of patients treated with the standard head diameter.

From May until June 2017, 16 patients underwent THA using the standard head diameter of 28–32 mm with use of Allofit Taperloc (Warsaw, IN, USA) hip system at our institution. For these patients, as well as the large-head diameter cohort, a propensity score based on age, sex, BMI, WOMAC, VAS score was generated.

Additionally, healthy volunteers (15 subjects) were recruited from the department employees' families. All of them were examined prior to the gait analysis to exclude any lower limb pathologies and balance disorders. Healthy subjects from the control group and Allofit patients were matched to Maxera patients using a 0.1 propensity score threshold with priority given to exact matches.

All measurements were performed at least 3.5 years after the surgery (mean follow-up: 44 months). All patients underwent the same rehabilitation protocol in the same rehabilitation department immediately after the discharge from the orthopaedic ward. It was continued until the patient had the feeling that the function of their hip was restored to satisfactory level. Before gait pattern analysis all potential factors, such as comorbidities or pain, which might have influenced the results were excluded. Leg length and range of motion were measured in every case since these parameters might negatively affect the gait pattern, as proved in several studies [27–29].

Gait analysis

Gait analysis was performed in University Biomechanical Lab using the BTS SMART Analyzer (BTS Bioengineering, Quincy, MA, USA) system for three-dimensional gait analysis by an experienced physiotherapist, with specialty in lower limbs biomechanics, who was unaware of patients implant size. All measurements and analysis were performed according to the Davis protocol [30].

Participants were asked to walk a 10-m distance in their normal tempo four times. During walking, their movement was recorded with use of markers placed on the base of the sacral bone, both anterior superior iliac spines, both greater trochanters, both lateral sides of the femur (half distance between greater trochanter and lateral femoral condyle), both sides on the fibular head, both lateral sides of the shin (half distance between head of the fibula and lateral malleolus), both bases of 5th metatarsal bone and calcaneal tuberosity.

Immediately before measurements, every participant was asked to walk through a marked route as many times as they wanted to feel fully comfortable with markers to minimize potential influence on their hip biomechanics. Measurements were performed and compared for both healthy and operated limbs of every patient (control group). Analysed parameters were time of support phase, double-support time, drop of contralateral side of pelvis during support, time of swing phase, length of step, mean walking speed, walking cadence.

Patient-reported outcome

All participants fulfilled WOMAC (The Western Ontario and McMaster Universities Osteoarthritis Index) and VAS (Visual Analog Scale) questionnaires preoperatively during admission to the hospital and postoperatively during gait pattern analysis visit. The WOMAC questionnaire contains 24 questions concerning: pain, joint stiffness and physical functioning. The maximum result is 96, which represents the worst outcome [31–33]. The VAS score is a continuous scale consisting of a line for each symptom. A score of 0 represents "no pain" and a score of 10 represents "worst imaginable pain" [34].

Radiographic evaluation

All patients preoperatively and at the final follow-up underwent radiographic examination in a supine position and with a 15° bilateral internal rotation of the hip joint with the center of the X-ray beam over the symphysis.

Cup inclination angles were measured on postoperative anteroposterior radiographs, as described in the study by Wan et al. [35]. Radiographic cup anteversion was measured with the method described by Lewinnek et al. [36] (femoral offset was measured as the perpendicular distance from the center of rotation of the femoral head to the central axis of the femur) [37]. Cup offset was measured as the horizontal distance from the center of rotation to the vertical tangent of Koehler's teardrop's lateral side [38]. Leg length was measured as the length of a vertical line drawn from the most prominent point of the lesser trochanter perpendicular to a horizontal line drawn between the two acetabular teardrops [39]. All measures were compared to the preoperative values and differences between groups were analysed.

Table 1 Characteristic of participants in the large and standard head diameter matched cohort groups

	Participants characteristics			
	Large head	Standard head	Healthy volunteers	*p* value
BMI (body mass index—kg/m2)	29.55 (SD = 4.52)	29.53 (SD = 3.33)	29.49 (SD = 4.00)	> 0.05
Age (years)	70.0 (SD = 9.52)	68.0 (SD = 10.87)	69.0 (SD = 10.22)	> 0.05
Male:female	6:9	7:8	7:8	> 0.05
Right:left	10:5	11:4	10:5	> 0.05

Table 2 WOMAC scores preoperatively

WOMAC	Large head	Standard head	*p* value
Mean total	66.97 (SD = 10.23)	67.33 (SD = 12.11)	> 0.5
Mean function	43.66 (SD = 13.98)	44.60 (SD = 14.54)	> 0.5
Mean pain	11.47 (SD = 3.44)	11.73 (SD = 3.9)	> 0.5
Mean stiffness	4.33 (SD = 1.68)	4.66 (SD = 1.62)	> 0.5

Table 3 VAS preoperatively

VAS	Large head	Standard head	*p* value
Mean total	7.6 (SD = 2.12)	7.7 (SD = 2.23)	> 0.5

Statistical analysis

Results were analysed statistically. As all variables were continuous and the comparisons were performed between variables in unpaired groups, either Student's *t* test for unpaired groups or Mann–Whitney *U* test were utilized, according to the normal distribution. Normality of distribution was tested using the Shapiro–Wilk test and the *p* value below 0.05 was considered significant.

Results

A total of 15 patients from either large head diameter cohort (94%) or standard head diameter (94%) matched-control cohort completed the whole assessment at the final follow-up. In the large head diameter group one patient suffered from periprosthetic femur fracture due to the vehicle accident 2 years postoperatively, and in standard head diameter group one patient underwent two-stage revision hip replacement due to the late infection.

Mean age in large head diameter group was 70 years (SD = 9.52), while in standard head diameter group 68 years (SD = 10.87). Mean BMI (body mass index—kg/m2) in both groups was respectively 29.55 (SD = 4.52) and 29.53 (SD = 3.33) (Tables 1, 2, 3).

Table 4 Comparison of gait parameters between 28–32 mm femoral head and healthy hips (HH)

	Standard femoral head size		HH	*p* value	
	OL	HL		OL vs HH	HL vs HH
Support phase [%]	72.3	70.8	61.0	0.012	0.023
Swing phase [%]	27.7	29.2	39.0	0.007	0.005
Contralateral pelvic drop [°]	9.0	8.5	7.0	0.034	0.036
Stride length [m]	0.31	0.44	0.73	0.001	0.021
Double support [%]	20.3		13.0	0.001	
Mean gait velocity [m/s]	0.52		1.39	0.007	
Walking cadence [steps/min]	75.4		113.8	0.004	

OL operated limb, *HL* healthy limb

Gait analysis

In group with standard head size, there was significantly higher time of support phase both in operated limb (72.3% vs. 61.0%, $p = 0.012$) and healthy limb (70.8% vs. 61.0%, $p = 0.023$); double-support time (20.3% vs. 13.0%, $p = 0.001$) as well as drop of contralateral side of pelvis during support both in operated limb (9.0 degrees vs. 7.0 degrees, $p = 0.034$) and healthy limb (8.5 degrees vs. 7.0 degrees, $p = 0.036$) compared with volunteers' healthy hips. There was significantly shorter time of swing phase both in operated limb (27.7% vs. 39.0%, $p = 0.007$) and healthy limb (29.2% vs. 39.0%, $p = 0.005$); length of step both in operated limb (0.31 m vs. 0.73 m, $p = 0.001$) and healthy limb (0.44 m vs. 0.73 m, $p = 0.021$); lower mean walking speed (0.52 m/s vs.1.39 m/s, $p = 0.007$) and walking cadence (75.4 steps/min vs. 113.8 steps/min, $p = 0.004$) than in volunteers' healthy hips (Table 4).

In group with large head size many more outcomes were restored to values not differing significantly from norms for healthy hips: time of support phase size both in operated limb (64.1% vs. 61.0%, $p = 0.065$) and healthy limb (64.0% vs. 61.0%, $p = 0.064$); time of swing phase both in operated limb (35.9% vs. 39.0%, $p = 0.059$) and

Table 5 Comparison of gait parameters between 36 mm femoral head and healthy hips (HH)

	Large femoral head size		HH	p value	
	OL	HL		OL vs HH	HL vs HH
Support phase [%]	64.1	64.0	61.0	0.065	0.064
Swing phase [%]	35.9	36.0	39.0	0.059	0.06
Contralateral pelvic drop [°]	8.5	8.0	7.0	0.023	0.046
Stride length [m]	0.5	0.6	0.73	0.022	0.041
Double support [%]	16.4		13.0	0.057	
Mean gait velocity [m/s]	0.7		1.39	0.022	
Walking cadence [steps/min]	87.3		113.8	0.032	

OL operated limb, *HL* healthy limb

healthy limb (36.0% vs. 39.0%, $p=0.06$); double support time (16.4% vs. 13.0%, $p=0.057$). However, drop of contralateral side of pelvis during support was higher in group with large head size than in healthy hips, both in operated limb (8.5 degrees vs. 7.0 degrees, $p=0.023$) and healthy limb (8.0 degrees vs. 7.0 degrees, $p=0.046$). Shorter than norms were: length of step of both operated limb (0.5 m vs. 0.73 m, $p=0.022$) and healthy limb (0.6 m vs. 0.73 m, $p=0.041$); mean walking speed (0.7 m/s vs.1.39 m/s, $p=0.025$) and walking cadence (87.3 steps/min vs. 113.8 steps/min, $p=0.032$) (Table 5).

Both objective and subjective outcomes differed between the group with large head size and the group with standard head size. As to objective outcomes, the group with large head size had significantly shorter time of support phase than the group with standard head size both in operated limb (64.1% vs. 72.3%, $p=0.02$) and healthy limb (64.0% vs. 70.8%, $p=0.015$) and shorter double support time (16.4% vs. 20.3%, $p=0.027$). The group with large head size had significantly greater time of swing phase both in operated limb (35.9% vs. 27.7%, $p=0.018$) and healthy limb (36.0% vs. 29.2%, $p=0.03$); stride length in operated limb (0.5 m vs. 0.31 m, $p=0.043$); mean gait velocity (0.7 m/s vs. 0.52 m/s, $p=0.03$); walking cadence (87.3 steps/min vs 75.4 steps/min, $p=0.011$). There was no statistically significant difference in other analysed parameters (Table 6).

Table 7 WOMAC postoperatively

WOMAC	Large head	Standard head	p value
Mean total	18.20 (SD=6.23)	30.45 (SD=9.30)	<0.05
Mean function	15.18 (SD=6.83)	24.96 (SD=13.36)	<0.05
Mean pain	4.5 (SD=2.59)	8.73 (SD=4.05)	>0.5
Mean stiffness	2.53 (SD=1.67)	3.66 (SD=2.01)	>0.5

Table 8 VAS postoperatively

VAS	Large head	Standard head	p value
Mean total	1.4 (SD=0.7)	2.23 (SD=1.92)	<0.05

Patient-reported outcome

As to the patient-reported outcome measures, the group with large head size had significantly lower VAS score at rest (1.4 ± 0.7 vs. 2.23 ± 1.92, $p=0.041$), Physical Function part of WOMAC score (15.18 vs. 24.96, $p<0.05$) and WOMAC score as a whole (18.2 vs. 30.45, $p<0.05$) (Tables 7, 8).

Radiological analysis

None of the analysed radiographic parameters differed significantly between the groups (Table 9). In both groups, one patient was identified as having the cup placed outside of the target zone.

Table 6 Comparison of gait parameters between group with 28–32 mm femoral head and group with 36 mm femoral head

	Large femoral head size		Standard femoral head size		p value	
	OL	HL	OL	HL	OL	HL
Support phase [%]	64.1	64.0	72.3	70.8	0.02	0.015
Swing phase [%]	35.9	36.0	27.7	29.2	0.018	0.03
Contralateral pelvic drop [°]	8.5	8.0	9.0	8.5	0.09	0.086
Stride length [m]	0.5	0.6	0.31	0.44	0.043	0.12
Double support [%]	16.4		20.3		0.027	
Mean gait velocity [m/s]	0.7		0.52		0.03	
Walking cadence [steps/min]	87.3		75.4		0.011	

OL operated limb, *HL* healthy limb

Table 9 Radiological parameters postoperatively

Parameter	Large head	Standard head	*p* value
Cup anteversion [°]	12.20 (SD = 2.32)	12.45 (SD = 2.12)	> 0.5
Cup inclination [°]	41.78 (SD = 2.83)	42.46 (SD = 2.23)	> 0.5
Femoral offset [mm]	46.63 (SD = 4.44)	43.63 (SD = 3.23)	> 0.5
Cup offset [mm]	30.45 (SD = 4.00)	29.03 (SD = 2.03)	> 0.5
No. of patients with leg discrepancy > 5 mm	0	0	> 0.5

Discussion

There are a few aspects on which we can assess the outcome of THR, most important among them being gait biomechanics restoration, patient-reported outcome, implant positioning and its wear.

In terms of gait characteristics, there are several deviations reported concerning both patients with hip osteoarthritis and following THR. It is well proven that those with hip OA have reduced stride length and reduced cadence, reduced gait velocity, and reduced joint excursion [24, 40, 41]. Patients after THR walk with lesser hip-abduction and sagittal-plane range of motion. It is believed that it might be a consequence of a pain-avoidance mechanism developed as an adaptation to joint disease. What is more, there are publications underlining that lower limb biomechanics during gait does not return to normal after THR [26, 42]. In one of these studies the follow-up was only about 11 months on average and participants were operated with lateral approach with one-third anterior and two thirds posterior hip adductors dissection. Authors in surgical technique dissect only one third using natural interval in gluteal muscles attachment. This technique allows for restoration of gluteal muscles in more than 50% of their native attachment. It seems that this enables faster rehabilitation and facilitates regaining full strength and length of the gluteal muscle tendon.

There is an ongoing debate about advantages and disadvantages of both standard and large femoral heads use during THA, concerning patient-reported outcomes, rates of dislocations, range of motion, bearing wear, taper corrosion, etc [3]. There is a limited number of studies analysing gait patterns after THA with use of different head sizes. The results of this study do not fully support conclusions made by Beaulieu et al. [26]. Several gait parameters of participants from large femoral head groups did not differ significantly from the healthy control groups. These are time of support phase both in operated and healthy limbs, time of swing phase and bipedal support time.

In this study, we noticed a significant correlation between gait pattern and the femoral head size used. Comparison between groups with different femoral head sizes performed in this study seems to carry no risk of bias, as the difference in VAS score during the double-support phase between them was statistically insignificant. These gait parameters may be important in case of rehabilitation. Since the aim of the treatment is to regain function and relieve pain, bringing back physiological gait pattern or at least making it more similar to physiological is an important step forward in achieving better functional results.

Physiological patterns have always been a reference for physiotherapists and our study seems to indicate a way to obtain better gait patterns. To our best knowledge, so far no papers favouring larger femoral heads with regard to gait pattern restoration in anterolateral approach THA have been published.

The study by Grip et al. [43], compared several movement patterns during walking, squats and stair climbing in groups with use of conventional head size implants (mean: 32.7 mm), large ones (mean: 53.5 mm) and control healthy group with use of wearable IMU-based motion analysis system. No significant differences were found when comparing gait parameters between large and conventional head size groups. The large femoral head group had significantly smaller average hip flexion–extension range of motion (ROM) during gait compared to controls. Significant differences in terms of range of motion parameters were also found between operated and non-operated limbs.. However, in this particular study participants were not randomized, no blinding was performed, thus potential risk of bias in this study might be higher. All patients included in this study were operated from a posterior approach. It is a strong limitation of the study since the size of the femoral head may reveal its effect on gait parameters in different approaches only.

In the study by Zagra et al. authors performed randomized-controlled trials comparing gait recovery between participants who received 28 mm, 36 mm, and ≥ 42 mm femoral head during THR [44]. Spatiotemporal gait parameters, kinematic or kinetic gait parameters were analysed during 4-months rehabilitation period. We believe that such period after the surgery is too short to fully evaluate gait pattern parameters after THA, as it was proven that functional outcome improves even up to 7 years following the surgery [45, 46]. No significant differences were observed between groups during this follow-up.

Additionally, in two studies mentioned above [26, 43], patients were operated via posterior approach. This approach is associated with irreversible damage to the posterior hip capsule, hip external rotators and pelvic stabilizers, what might be the reason for such results.

What is more, participants with large femoral heads had significantly better results in VAS and WOMAC score. Such results correspond partially to only one study by Matsushita et al. where researchers proved better functional results in daily living activities for total hip replacement with 36 mm head diameter [47]. However, in the most recently published systematic review [3] comparing 32 and 36 mm heads, it was suggested that there are no functional benefits of using larger heads. On the other hand, in two studies analysed in this publication [17, 18] participants were operated from the posterior approach, only one study was a prospectively randomized one, while in the other participants were operated by 17 different surgeons and were not randomized to receive a particular head size.

During the course of this study no prosthesis dislocation nor revision surgery due to other reasons were observed. In the systematic review [3], there was a lower risk of revision due to dislocation in the group with 36 mm head in comparison to 32- and 28-mm ones. This difference between the two studies might be due to the much smaller number of participants and shorter follow-up.

Conclusions

This study is the first matched-cohort study to assess gait pattern parameters pre- and postoperatively in at least 3.5 years follow-up in patients undergoing total hip replacement with use of 28–32 mm and 36 mm head diameters prosthesis operated from the antero-lateral approach. In our study, participants treated with use of large femoral heads had significantly better gait patterns. Despite the quite small number of participants included in this study, a conclusion could be drawn that large heads used in THA seem to have an impact on gait restoration, making it more similar to the healthy participants' one.

Results of this study might opt for performing THA with use of 36 mm heads. Even though there are several studies and systematic reviews concentrating on outcome, wear and revision rate in use of different femoral head sizes, more studies should analyse gait patterns following total hip replacement in terms of different implants, implant positioning or surgical approach.

Our study seems to be the first ever matched-cohort trial to analyse differences in functional outcome between different head sizes in patients operated from the anterolateral approach. Because of that, it can give a broader view on restoring function of affected legs which may be important in making decisions about operation. Our observations should make surgeons operating from anterolateral approach and using small femoral head sizes reconsider their decisions about implant parameters and in this case try to use larger femoral heads. What is more it can also be helpful information for physiotherapists, since patients operated from anterolateral approach with larger femoral heads used may achieve better functional results so there might be an indication to introduce specific exercises and rehabilitation protocols.

Furthermore, use of larger femoral heads could result in more physiological function of the hip and the whole limb, faster postoperative recovery, and increase patient's satisfaction with the treatment.

In the future, next high-quality studies with randomization and multi-center studies should be performed to assess gait differences between uses of different femoral head diameters in total hip replacement. What is more, rehabilitation protocols following THR should be more emphasized in the literature to elaborate standardized, high-quality physiotherapy to restore gait pattern from the pre-disease period and improve functional outcome after THR. It might quicken returning to health, normal life functioning and potentially lower the number of revision surgeries.

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Availability of data and materials The datasets used and/or analysed during the current study will be available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical approval The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Ethics Committee of Medical University of Warsaw (Approval Number: AKBE/59/17).

Informed consent Informed consent was obtained from all subjects involved in the study.

References

1. Learmonth ID, Young C, Rorabeck C (2007) The operation of the century: total hip replacement. Lancet 370(9597):1508–1519. https://doi.org/10.1016/S0140-6736(07)60457-7
2. Singh JA, Yu S, Chen L, Cleveland JD (2019) Rates of total joint replacement in the united states: future projections to 2020–2040 using the national inpatient sample. J Rheumatol 46(9):1134–1140. https://doi.org/10.3899/jrheum.170990 (**Epub 2019 Apr 15 PMID: 30988126**)
3. Tsikandylakis G, Mohaddes M, Cnudde P, Eskelinen A, Kärrholm J, Rolfson O (2018) Head size in primary total hip arthroplasty. EFORT Open Rev 3(5):225–231. https://doi.org/10.1302/2058-5241.3.170061 (**Published 2018 May 21**)
4. Yin S, Zhang D, Du H, Du H, Yin Z, Qiu Y (2015) Is there any difference in survivorship of total hip arthroplasty with different bearing surfaces? A systematic review and network meta-analysis. Int J Clin Exp Med 8(11):21871–21885 (**Published 2015 Nov 15**)
5. López-López JA, Humphriss RL, Beswick AD et al (2017) Choice of implant combinations in total hip replacement: systematic review and network meta-analysis. BMJ 359:j4651. https://doi.org/10.1136/bmj.j4651 (**Published 2017 Nov 2**)
6. Kärrholm J, Mohaddes M, Odin D et al (2018) The Swedish Hip Arthroplasty Register - Annual Report 2017. https://registercentrum.blob.core.windows.net/shpr/r/Eng_Arsrapport_2017_Hoftprotes_final-Syx2fJPhMN.pdf
7. Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). Hip, Knee & Shoulder Arthroplasty: 2019 Annual Report; Adelaide: AOA, 2019
8. Ben-Shlomo Y, Blom A, Boulton C, Brittain R, Clark E, Craig R, Dawson-Bowling S, Deere K, Esler C, Goldberg A, Gregson C, Howard P, Hunt L, Judge A, Lawrence S, Lenguerrand E, McCormack V, Newell C, Porteous M, Powers-Freeling L, Price A, Prieto-Alhambra D, Reed M, Rees J, Royall M, Sayers A, Stonadge J, Swanson M, Taylor D, Watts A, Whitehouse M, Wilkinson M, Wilton T, Young E (2019) The national joint registry 16th annual report 2019 [Internet]. National Joint Registry, London. PMID: 32744812
9. Danish Hip Arthroplasty Register (2018) Annual Report 2018. http://danskhoftealloplastikregister.dk/wp-content/uploads/2015/11/DHR-årsrapport-2018_til-offentliggørelse.pdf
10. Burroughs BR, Hallstrom B, Golladay GJ, Hoeffel D, Harris WH (2005) Range of motion and stability in total hip arthroplasty with 28-, 32-, 38-, and 44-mm femoral head sizes. J Arthroplasty 20:11–19
11. Jinno T, Koga D, Asou Y et al (2017) Intraoperative evaluation of the effects of femoral component offset and head size on joint stability in total hip arthroplasty. J Orthop Surg (Hong Kong) 25:2309499016684298
12. Delay C, Putman S, Dereudre G et al (2016) Is there any range-of-motion advantage to using bearings larger than 36mm in primary hip arthroplasty: a case-control study comparing 36-mm and large-diameter heads. Orthop Traumatol Surg Res 102:735–740
13. Kostensalo I, Junnila M, Virolainen P et al (2013) Effect of femoral head size on risk of revision for dislocation after total hip arthroplasty: a population-based analysis of 42,379 primary procedures from the Finnish Arthroplasty Register. Acta Orthop 84:342–347
14. Hailer NP, Weiss RJ, Stark A, Kärrholm J (2012) The risk of revision due to dislocation after total hip arthroplasty depends on surgical approach, femoral head size, sex, and primary diagnosis. An analysis of 78,098 operations in the Swedish Hip Arthroplasty Register. Acta Orthop 83:442–448
15. Cafri G, Paxton EW, Love R, Bini SA, Kurtz SM (2017) Is there a difference in revision risk between metal and ceramic heads on highly crosslinked polyethylene liners? Clin Orthop Relat Res 475:1349–1355
16. Zijlstra WP, De Hartog B, Van Steenbergen LN, Scheurs BW, Nelissen RGHH (2017) Effect of femoral head size and surgical approach on risk of revision for dislocation after total hip arthroplasty. Acta Orthop 88:395–401
17. Hanna SA, Sewell MD, Sri-Ram K et al (2012) The effect of femoral head size on functional outcome in primary total hip arthroplasty: a single-blinded randomised controlled trial. Hip Int 22:592–597
18. Allen CL, Hooper GJ, Frampton CM (2014) Do larger femoral heads improve the functional outcome in total hip arthroplasty? J Arthroplasty 29:401–404
19. Hagio K, Saito M, Okawa T et al (2016) Polyethylene wear associated with 26- and 32-mm heads in total hip arthroplasty: a multicenter, prospective study. J Arthroplasty 31:2805–2809
20. Dyrkacz RM, Brandt JM, Ojo OA, Turgeon TR, Wyss UP (2013) The influence of head size on corrosion and fretting behaviour at the head-neck interface of artificial hip joints. J Arthroplasty 28:1036–1040
21. Carli A, Politis A, Zukor D, Huk O, Antoniou J (2015) Clinically significant corrosion at the head-neck taper interface in total hip arthroplasty: a systematic review and case series. Hip Int 25:7–14
22. DelBalso C, Teeter MG, Tan SC, Howard JL, Lanting BA (2016) Trunnionosis: Does head size affect fretting and corrosion in total hip arthroplasty? J Arthroplasty 31:2332–2336
23. Lachiewicz PF, Soileau ES, Martell JM (2016) Wear and osteolysis of highly crosslinked polyethylene at 10 to 14 years: the effect of femoral head size. Clin Orthop Relat Res 474:365–371
24. Ewen AM, Stewart S, St Clair GA, Kashyap SN, Caplan N (2012) Post-operative gait analysis in total hip replacement patients–a review of current literature and meta-analysis. Gait Posture 36:1–6. https://doi.org/10.1016/j.gaitpost.2011.12.024
25. Begg C, Cho M, Eastwood S, Horton R, Moher D, Olkin I et al (1996) Improving the quality of reporting of randomized controlled trials: the CONSORT statement. JAMA 276:637–639 (**PMID: 0008773637**)
26. Beaulieu ML, Lamontagne M, Beaulé PE (2010) Lower limb biomechanics during gait do not return to normal following total hip arthroplasty. Gait Posture 32(2):269–273. https://doi.org/10.1016/j.gaitpost.2010.05.007
27. Zhang Y, He W, Cheng T, Zhang X (2015) Total hip arthroplasty: leg length discrepancy affects functional outcomes and patient's gait. Cell Biochem Biophys 72(1):215–219. https://doi.org/10.1007/s12013-014-0440-4 (**PMID: 25516289**)
28. Chen G, Nie Y, Xie J, Cao G, Huang Q, Pei F (2018) Gait analysis of leg length discrepancy-differentiated hip replacement patients with developmental dysplasia: a midterm follow-up. J Arthroplasty 33(5):1437–1441. https://doi.org/10.1016/j.arth.2017.12.013 (**Epub 2017 Dec 21 PMID: 29402716**)
29. Colgan G, Walsh M, Bennett D, Rice J, O'Brien T (2016) Gait analysis and hip extensor function early post total hip replacement. J Orthop 13(3):171–176. https://doi.org/10.1016/j.jor.2016.03.005 (**Published 2016 Apr 6**)
30. Davis RB, Ounpuu S, Tyburski D, Gage JR (1991) A gait analysis data collection and reduction technique. Hum Movement Sci 10:575–587
31. Escobar A et al (2007) Responsiveness and clinically important differences for the WOMAC and SF-36 after total knee replacement. Osteoarthr Cartil 15(3):273–280. https://doi.org/10.1016/j.joca.2006.09.001
32. ACR. The Western Ontario and McMaster Universities Osteoarthritis Index. [cited 2015 March 18]

33. Available from: http://www.performanceptpc.com/paperwork/womac.pdf.
34 Hawker GA et al (2011) Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). Arthritis Care Res 63(11):S240–S252. https://doi.org/10.1002/acr.20543
35. Wan Z, Malik A, Jaramaz B, Chao L, Dorr LD (2009) Imaging and navigation measurement of acetabular component position in THA. Clin Orthop Relat Res 467(1):32–42
36 Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR (1978) Dislocations after total hip-replacement arthroplasties. J Bone Jt Surg 60(2):217–220 (**Pmid:641088**)
37. Cassidy KA, Noticewala MS, Macaulay W, Lee JH, Geller JA (2012) Effect of femoral offset on pain and function after total hip arthroplasty. J Arthroplasty 27(10):1863–1869 (**Pmid:22810007**)
38 Jolles BM, Zangger P, Leyvraz PF (2002) Factors predisposing to dislocation after primary total hip arthroplasty: a multivariate analysis. J Arthroplasty 17(3):282–288 (**Pmid:11938502**)
39. Matsuda K, Nakamura S, Matsushita T (2006) A simple method to minimize limb-length discrepancy after hip arthroplasty. Acta Orthop 77(3):375–379. https://doi.org/10.1080/17453670610046280
40. Foucher KC, Schlink BR, Shakoor N, Wimmer MA (2012) Sagittal plane hip motion reversals during walking are associated with disease severity and poorer function in subjects with hip osteoarthritis. J Biomech 45:1360–1365. https://doi.org/10.1016/j.jbiomech.2012.03.008
41. Kubota M, Shimada S, Kobayashi S, Sasaki S, Kitade I, Matsumura M et al (2007) Quantitative gait analysis of patients with bilateral hip osteoarthritis excluding the influence of walking speed. J Orthop Sci 12:451–457. https://doi.org/10.1007/s00776-007-1160-z
42. Lamontagne M, Beaulieu ML, Beaulé PE (2011) Comparison of joint mechanics of both lower limbs of THA patients with healthy participants during stair ascent and descent. J Orthop Res 29(3):305–311. https://doi.org/10.1002/jor.21248 (**Published correction appears in J Orthop Res. 2011 Sep;29(9):1457**)
43. Grip H, Nilsson KG, Häger CK, Lundström R, Öhberg F (2019) Does the femoral head size in hip arthroplasty influence lower body movements during squats, gait and stair walking? A clinical pilot study based on wearable motion sensors. Sensors (Basel) 19(14):3240. https://doi.org/10.3390/s19143240 (**Published 2019 Jul 23**)
44. Zagra L, Anasetti F, Bianchi L, Licari V, Giacometti CR (2013) No difference in gait recovery after THA with different head diameters: a prospective randomized study. Clin Orthop Relat Res 471(12):3830–3837. https://doi.org/10.1007/s11999-013-2926-6
45. Nilsdotter AK, Isaksson F (2010) Patient relevant outcome 7 years after total hip replacement for OA - a prospective study. BMC Musculoskelet Disord 11:47. https://doi.org/10.1186/1471-2474-11-47 (**Published 2010 Mar 11**)
46. Shan L, Shan B, Graham D, Saxena A (2014) Total hip replacement: a systematic review and meta-analysis on mid-term quality of life. Osteoarthritis Cartilage 22(3):389–406. https://doi.org/10.1016/j.joca.2013.12.006
47 Matsushita I, Morita Y, Ito Y, Gejo R, Kimura T (2011) Activities of daily living after total hip arthroplasty Is a 32-mm femoral head superior to a 26-mm head for improving daily activities? Int Orthop 35(1):25–29. https://doi.org/10.1007/s00264-009-0909-8

Posture stability and risk of fall test in the objective assessment of balance in patients with ectopic bone tissue after total hip replacement

Stabilność postawy i test ryzyka upadku w obiektywnej ocenie balansu u pacjentów z ektopową tkanką kostną po endoprotezoplastyce całkowitej stawu biodrowego

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Abstract

Introduction. Total hip replacement is an operative treatment method for end-stage osteoarthritis, considered the most effective nowadays. One of the typical complications after the procedure is heterotopic ossification which may influence patient posture stability and increase the risk of falls.
Aim. The study aimed to assess whether patients developing heterotopic ossifications after total hip replacement have a higher risk of falls in comparison to the matched-cohort group without them.
Materials and methods. 46 out of 312 patients undergoing a total hip replacement in 2020 who developed heterotopic ossifications were observed. For these patients, a propensity score based on age, sex, and BMI was generated, and a matched-cohort control group consisting of 39 patients was selected. Each patient was operated on via an anterolateral approach, and an uncemented total hip prosthesis was implanted. Patients from both cohorts underwent postoperative radiological and biomechanical assessment and fulfilled WOMAC and Oxford questionnaires pre-and postoperatively. Statistical analyses of the results were performed.
Results. There were statistically significant differences between cohorts in the postural stability test (4.9±1.1 vs 2.0±1.0 p<0.05), antero-posterior stability index (3.6±1.2 vs 1.6±0.9, p<0.05), medio-lateral stability index (3.0±1.3 vs 1.0±0.7, p<0.05) and risk of fall test (9.8±1.0 vs 7.8±1.0, p<0.05). No statistically significant differences were observed in the WOMAC and Oxford questionnaires.
Conclusions. Our study proved that heterotopic ossifications, which appear in hip abductor muscles, could have an impact on balance and the risk of falls in patients after total hip replacement. In the elderly population, this can result in serious consequences such as a periprosthetic fracture or head trauma after total hip replacement.

Key words: total hip replacement, heterotopic ossification, posture stability, risk of fall, biomechanical assessment

Streszczenie

Wstęp. Endoprotezoplastyka całkowita stawu biodrowego jest operacyjną metodą leczenia schyłkowej choroby zwyrodnieniowej stawów uznawaną obecnie za najskuteczniejszą. Jednym z typowych powikłań po zabiegu są skostnienia pozaszkieletowe, które mogą wpływać na stabilność postawy pacjenta i zwiększać ryzyko upadków.
Cel. Celem badania była ocena, czy pacjenci, u których dochodzi do powstania skostnień pozaszkieletowych po całkowitej aloplastyce stawu biodrowego mają większe ryzyko upadków w porównaniu z grupą z dobranej kohorty bez skostnień.
Materiał i metody. Zaobserwowano 46 z 312 pacjentów poddanych całkowitej aloplastyce stawu biodrowego w 2020 roku, u których rozwinęły się heterotopowe skostnienia. Dla tych pacjentów wygenerowano wskaźnik skłonności oparty na wieku, płci oraz BMI i wybrano dopasowaną grupę kontrolną składającą się z 39 pacjentów. Każdy pacjent był operowany z dostępu przednio-bocznego z użyciem bezcementowej protezy całkowitej stawu biodrowego. Pacjenci z obu kohort przeszli pooperacyjną ocenę radiologiczną i biomechaniczną oraz wypełnili przed- i pooperacyjnie kwestionariusze WOMAC i Oxford. Przeprowadzono analizę statystyczną wyników.
Wyniki. Wystąpiły statystycznie istotne różnice między kohortami w teście stabilności postawy (4,9±1,1 vs 2,0±1,0 p<0,05), wskaźniku stabilności przednio-tylnej (3,6±1,2 vs 1,6±0,9, p<0,05), wskaźniku stabilności przyśrodkowo-bocznej (3,0±1,3 vs 1,0±0,7, p<0,05) oraz test ryzyka upadku (9,8±1,0 vs 7,8±1,0, p<0,05). Nie zaobserwowano statystycznie istotnych różnic w kwestionariuszach WOMAC i Oxford.
Wnioski. Nasze badanie wykazało, że heterotopowe skostnienia pojawiające się w mięśniach odwodzących biodra mogą mieć wpływ na równowagę i ryzyko upadków u pacjentów po całkowitej aloplastyce stawu biodrowego. W populacji osób starszych po całkowitej aloplastyce stawu biodrowego może to skutkować bardzo poważnymi konsekwencjami, takimi jak złamanie okołoprotezowe lub uraz głowy.

Słowa kluczowe: aloplastyka stawu biodrowego, skostnienia pozaszkieletowe, stabilność postawy, ryzyko upadków, ocena biomechaniczna.

Introduction

Total hip replacement (THR) is an operative treatment method for end-stage osteoarthritis, considered the most effective nowadays [1]. Due to the high prevalence of osteoarthritis among the population, the number of THR per year is constantly growing. It is estimated that about 10% of men and 13% of women over 60 years old suffer from symptomatic hip osteoarthritis [2]. These numbers are even higher in older people, making the disease typical for elderly patients and THR a typical operation. Data shows that in 2010 only in the US 2.5 million individuals (1.4 million women and 1.1 million men) underwent THR [3].

One of the typical complications that occur after this procedure is heterotopic ossification (HO). According to current studies, abnormal bone formation after trauma or hip replacement may occur in even 90% of cases [4]. Heterotopic ossifications bring about the following symptoms: pain, swelling, erythema, and warmth, along with joint immobility [5]. These factors could have an impact on maintaining the posture, especially in patients after THR.

It is well known since the 90s that the risk of falls among the population older than 65 is high. Data shows that over 30% of these people experience such an incident at least once a year [6]. The majority of them do not have further consequences; however, about 10% result in severe trauma to the head and musculoskeletal system [7]. Falls of people who underwent THR are sometimes connected with periprosthetic fractures, the treatment of which is much more complicated and associated with a higher risk of failure than treatment of common fractures of the lower limb. What may even worsen the situation is that older people often suffer from many diseases, including osteoporosis or neoplasm, which increase the risk of fracture. The rate of falls is even higher among patients hospitalised due to hip fractures. In the first month after returning home, about 14% of patients fall [8]. During the 6 months after hospitalisation, it reaches 53% [9]. So far, the influence of heterotopic ossifications on the risk of falls is unknown in the literature.

Aim of the study

The study's primary aim was to assess whether patients who developed ectopic bone formation after total hip replacement have a higher risk of falls and inferior posture stability compared to the matched-cohort group without bone formation. The secondary aim was to assess whether there were any differences in patient-reported outcome measures.

Materials and methods

This study was conducted according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) Statement. The study protocol was designed as a retrospective matched-cohort observational study. This study was approved by Institutional Bioethics Committee (Number: KB/102/2007) and was registered on ClinicalTrials.gov (Registration number: NCT05218954).

Between January 2020 and December 2020, 312 patients suffering from primary hip osteoarthritis undergoing total hip replacement were observed. During the standard 6-weeks, 3-months, and 6-months follow-up visit, every patient had an AP pelvic weight-bearing x-ray. All patients were qualified and operated on by a fellowship-trained single surgeon. For the present analysis, the following demographic patient data were queried: sex, age at surgery (years), and BMI. 49 patients who developed ectopic bone formation were observed. A propensity score based on age, sex, and BMI were generated for these patients. Patients with HO were matched to patients without HO, operated by the same surgical team, using the same approach and implants with a 0.1 propensity score threshold, and priority given to exact matches.

All patients were operated through an anterolateral approach, lying on the healthy side with one-third of medium gluteal muscle dissection. Uncemented Taperloc/Allofit total hip implants (Zimmer Biomet, Warsaw, IN, USA) were used in each case (Fig. 1). Femoral neck dissection was performed after full joint dislocation between the tip of the greater trochanter to the point 10 mm proximal to the lesser trochanter. The acetabular cup was placed aiming 30-40 degrees of acetabular cup inclination and 10 degrees of anteversion. The femoral stem was aimed to be placed in the anatomical axis of the femur. The postoperative protocol included chemical and mechanical thromboprophylaxis unless specifically contraindicated. All patients received one dose of parenteral antibiotics at the induction of anaesthesia and two further doses post-operatively. No pre- or postoperative ectopic bone formation prophylaxis was performed. Flexion and extension exercises of the hip, knee, and ankle and isometric quadriceps contraction exercises were started on the first postoperative day, with full weight-bearing as tolerated. Mobilisation with a physiotherapist aimed to obtain a flexion-extension range

Fig. 1. A postoperative AP X-ray showing the pelvis and hip joints with the present uncemented Taperloc/Allofit prosthesis implanted on the right side with current Brooker grade I heterotopic ossification.

of motion of the hip of 0-90°, mobilising and safely walking with crutches by the third postoperative day.

At the 6-month follow-up visit, radiographs analysis in terms of any ectopic bone formation was performed using Brooker's classification [10].

All patients fulfilled WOMAC (The Western Ontario and McMaster Universities Arthritis Index) and Oxford questionnaires preoperatively on the 6-month follow-up visit.

Both cohorts underwent biomechanical assessment, performed by two independent blinded researchers (PC, KŻ) who were doctors and unaware if patients developed ectopic bone following total hip replacement. Every analysis was performed using the Biodex Balance System (Biodex, Inc, Shirley, NY), with participants feet standing steadily on the platform. Every participant was protected from falling with the use of support. The device screen was installed at the level of the patient's sight to avoid taking an uncomfortable position that might have influenced the results.

Postural stability test was performed, containing the results from three measurements. Every measurement has been performed on the 12th level of the platform stability for 20 seconds with a 10-second break between every test. Results obtained from the participants were recorded as stability index (SI) values that represent deviations of platform position from the vertical in degrees. The higher the SI values, the more difficult it was for participants to maintain stability during the test.

Risk of fall test - a single test consisting of the results obtained from three measurements. Each measurement was performed with the Biodex Balance System platform set to constant instability at level 6 of the platform stability for 20 seconds with a 10-second rest time between attempts. The person conducting the test informed the patient in advance of how the test would proceed and then gave verbal instructions during each test. The patients were positioned in the centre of the platform, both feet set with their feet shoulder-width apart. The final result of each test was a computerised risk of fall assessment report with patient scores related to normative data.

Methodology of Statistical Analysis

Statistical analysis of results was performed. The t-student test or the U Mann-Whitney test was used for quantitative variables, according to the normality of distribution examined with the Shapiro-Wilk test. For qualitative variables, the chi-square test was performed.

All statistical analyses were performed using the STATISTICA 8.0 PL package (StatSoft, Inc. 2008). Auxiliary calculations, other charts and tables will be made in the MS Excel 2003 spreadsheet (Microsoft Corporation).

Results

49 (15.7%) patients with HO were observed. A total of 39 patients from no HO matched-cohort control group and 46 from the HO group completed the full assessment at the final 6-month follow-up. 3 patients were excluded from the final evaluation due to the absence at the follow-up, malleolus fracture and undergoing a total hip replacement in the contralateral hip 3 months after the first one.

The baseline characteristics of participants are depicted in table 1.

Table 1. Baseline characteristics.

	Baseline characteristics		
	Patients with heterotopic ossifications	Patients without heterotopic ossifications	p-value
BMI (body mass index – kg/m²)	27.4 (SD = 4.3)	27.4 (SD = 4.6)	> 0.05
Age (years)	71.0 (SD = 8.8)	70.2 (SD = 9.4)	> 0.05
female:male	23:23	21:18	> 0.05
right:left	28:18	23:16	> 0.05

There were statistically significant (p value <0.05) differences between the group of patients with HO and those without HO in the results of the postural stability test, the antero-posterior stability index, the medio-lateral stability index and the result of the risk of fall test. There were no statistically significant (p>0.05) differences in the results of the biomechanical tests during the comparative analysis between groups of patients with different classes of ossification, except for the groups with stage I and stage IV heterotopic ossification - statistically significant differences were obtained (p <0.05) in all performed tests. All of these tests were performed at the 6-month follow-up visit. Results are presented in Table 2 and Table 3.

Table 2. Results of biomechanical assessment – comparison of both study cohorts.

	Patients with HO	Patients without HO	p-value
Postural stability test	4.9 (SD = 1.1)	2.0 (SD = 1.0)	< 0.05
Antero-posterior stability index	3.6 (SD = 1.2)	1.6 (SD = 0.9)	< 0.05
Medio-lateral stability index	3.0 (SD = 1.3)	1.0 (SD = 0.7)	< 0.05
Risk of fall test	9.8 (SD = 1.0)	7.7 (SD = 1.0)	< 0.05

Table 3. Results of biomechanical evaluation in groups with different grades of heterotopic ossification.

	Patients with grade I HO	Patients with grade II HO	Patients with grade III HO	Patients with grade IV HO
Number of patients (percentage of the entire group)	23 (50%)	9 (19.5%)	10 (21.7%)	4 (8.7%)
Postural stability test	4.0 (SD = 1.3)	4.4 (SD = 1.2)	4.9 (SD = 1.3)	6.3 (SD = 1.0)
Antero-posterior stability index	2.7 (SD = 1.1)	3.0 (SD = 1.2)	3.5 (SD = 1.4)	4.6 (SD = 1.2)
Medio-lateral stability index	2.1 (SD = 0.9)	2.6 (SD = 0.8)	2.9 (SD = 0.8)	4.0 (SD = 1.2)
Risk of fall test	8.2 (SD = 1.2)	8.7 (SD = 1.0)	9.7 (SD = 1.2)	11.1 (SD= 1.6)

No statistically significant differences were observed in the results of the WOMAC and Oxford questionnaires. Results are depicted in Table 4.

Table 4. Results of the WOMAC and Oxford questionnaires collected at the 6-month follow-up visit.

	Patients with HO	Patients without HO	p-value
Oxford	26.5 (SD = 11.9)	27.8 (SD = 12.3)	> 0.05
WOMAC – mean total	644.0 (SD = 592.2)	593.2 (SD = 497.6)	> 0.05
WOMAC – mean pain subscale	94.5 (SD = 114.8)	101.5 (SD = 117.6)	> 0.05
WOMAC – mean stiffness subscale	43.9 (SD = 50.0)	38.4 (SD = 43.5)	> 0.05
WOMAC – mean function subscale	505.5 (SD = 445.1)	441.6 (SD = 366.3)	> 0.05

Discussion

To the best of our knowledge, no literature is available to analyse the risk of falls among patients after total hip replacement and heterotopic ossifications. It is one of the most important facts due to a lack of knowledge in this field of orthopaedics.

Some articles discuss the influence of HO on the clinical status of patients. Rudiger et al. [11] emphasise in their study that Brooker grade IV ossifications significantly influence poor scores of patient-reported outcomes after THR. In another study by Pohl et al. [12], the authors point out that patients who developed Brooker III or IV ossifications had a poorer range of motion and did not improve postoperative hip joint mobility compared to patients with Brooker grade 0, I or II. The presented study does not seem to confirm these observations, and appropriate analyses have not been conducted to confirm or deny these observations.

Some studies analyse the balance and the risk of falls in patients before and after THR [13,14,15]. These studies examine dynamic [14], static [15] or both dynamic and static balance [13] of patients pre-and postoperatively. Additionally, these studies have a different follow-up period - from 4 months to 3 years. It was observed that the risk of falls after THR is reduced due to the improvement in patient balance; however, they had residual balance deficits, which may still affect the risk of falls, although to a lesser extent than preoperative balance.

Comparing total hip replacement with total knee replacement (TKR), there is quite a significant difference in the risk of falls between patients after TKR and THR. The latter group shows twice the risk of falls [16].

A few recent papers described the incidence of heterotopic ossifications after total hip replacement [17,18,19]. In the presented study, the group of patients with HO accounted for 15.7% of the entire study group. As is observed in the studies mentioned above, the numbers of patients affected by HO vary significantly, which was also confirmed in the review article by Zhu et al. [20] – the incidence of HO varied from 5.2 to 87 %. Such a variation probably depends on many factors, such as age, gender, preoperative diagnosis, treatment method, surgical approach or choice of implants. Some of these factors were analysed by Pavlou et al. [21]. In the study by Okano et al. [19], only female patients were included. Perhaps it was the reason for a small number of heterotopic ossification cases because the male gender is considered a predisposing factor [18, 20, 21]. This study does not confirm this observation. However, Pavlou et al. [21] also listed two other significant risk factors besides the male gender, namely lateral approach to the hip during surgery and the use of bone cement for acetabular and stem seating. All patients in the presented study were operated on an anterolateral approach; therefore, it cannot be clearly stated that it had any influence on the increased risk of heterotopic ossification development. Taking into account the second predisposing factor mentioned by Pavlou et al. means that the use of bone cement and press-fit implants in the group of patients analysed in this study could affect such a small number of HO cases.

Previous papers show that falls after total hip replacement are quite common, and over 50% of falls occur in the first year after surgery [22]. To find the reason for such worrisome data, many analyses were performed. So far, it has been proved that sex, drug use or comorbidities do not have a statistically significant impact on the risk of falls, and the only factor that seems to play a role is patients' age [23]. Other papers show the essential role of preoperative strength of hip abductors and fall history [24]. Since both factors seem to have something in common, it could be a point of interest for studies. Hip abductor muscles show a decrease in strength with age [25]. Moreover, despite careful stitching of the muscles, performing THR through an anterolateral or direct lateral approach causes damage to them, which also affects the functioning of hip abductors and may increase the risk of falls. What is more, this decrease may even worsen with a shortening of the leg because the tip of the greater trochanter and the acetabulum are closer, and the tension of gluteus medius and gluteus minimus diminishes which is something commonly seen in arthritic hip joints. If one side is affected more, it can give signs of leg discrepancy - distance is even more shortened due to pelvic rotation.

This study shows a significant effect of heterotopic ossification on an increased risk of falls, especially in the group with Brooker grade III and IV, compared to the group of patients who did not develop HO postoperatively. Similar conclusions can be drawn by analysing the results of the postural stability tests - statistically significant differences were obtained in the results between the cohorts with and without ossification and between the group with ossification grade I and grade IV according to the Brooker scale. The presented results show a significant impact of ossification on postural stability and an increased risk of falls.

The results observed in this study are not so surprising after analysis of the biomechanics of human posture, which is far more complicated than it appears to be. Upright posture is often compared to a pendulum turned upside down with the axis of rotation situated in the ankle joint [26, 27]. In case of balance disturbances, the mechanism is changed into a double-pendular [28] with a secondary counter-phase pendulum with an axis of rotation in the hip joint. Both these models are generated with the contribution of sensory-motor control mechanisms to prevent any physical manifestation of disbalance. That model seems to stay contrary to the previous one, which only takes into account a one-pendular model [29].

Conclusion

Our study proved that heterotopic ossifications that appear in hip abductor muscles could impact balance and risk of falls in patients after total hip replacement. That supports our previous hypothesis. Heterotopic ossification is not only a complication that can result in pain, swelling, erythema, and warmth, along with joint immobility but may also cause more serious problems such as falls. After total hip replacement in the elderly, it can lead to severe consequences, such as a periprosthetic fracture or head trauma.

Based on our study, the group of patients that develops heterotopic bone tissue after total hip replacement is not very numerous. However, taking this cohort into account, it is worth considering the rationale for prophylaxis against heterotopic bone formations and adding, for example, indomethacin prophylaxis to the standard postoperative treatment protocol that, till now, includes thromboprophylaxis and analgesic treatment.

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References

1. Mariconda M, Galasso O, Costa GG et al.: Quality of life and functionality after total hip arthroplasty: a long-term follow-up study. BMC Musculoskelet Disord 2011; 12:222. doi: 10.1186/1471-2474-12-222.
2. Zhang Y, Jordan JM: Epidemiology of osteoarthritis. Clin Geriatr Med 2010; 26(3):355-369. doi: 10.1016/j.cger.2010.03.001.
3. Maradit Kremers H, Larson DR, Crowson CS et al.: Prevalence of Total Hip and Knee Replacement in the United States. J Bone Joint Surg Am 2015; 97(17):1386-1397. doi: 10.2106/JBJS.N.01141.
4. Ranganathan K, Loder S, Agarwal S, et al.: Heterotopic Ossification: Basic-Science Principles and Clinical Correlates. J Bone Joint Surg Am 2015; 97(13):1101-1111. doi: 10.2106/JBJS.N.01056.
5. Mujtaba B, Taher A, Fiala MJ, et al.: Heterotopic ossification: radiological and pathological review. Radiol Oncol 2019; 53(3):275-284. doi: 10.2478/raon-2019-0039.
6. Lord SR, Ward JA, Williams P, et al.: An epidemiological study of falls in older community-dwelling women: the Randwick falls and fractures study. Aust J Public Health 1993; 17:240-254.
7. van Weel C, Vermeulen H, van den Bosch W: Falls, a community care perspective. Lancet 1995; 345: 1549-1551.
8. Mahoney J, Sagar M, Dunham NC, et al.: Risk of falls after hospital discharge. J Am Geriatr Soc 1994; 42(3):269-274.
9. Shumway-Cook A, Ciol M, Gruber W, et al.: Incidence of and Risk Factors for Falls Following Hip Fracture in Community-dwelling Older Adults. Phys Ther 2005; 85(7):648-655.
10. Hug KT, Alton TB, Gee AO: Classifications in brief: Brooker classification of heterotopic ossification after total hip arthroplasty. Clin Orthop Relat Res. 2015; Jun;473(6):2154-7. doi: 10.1007/s11999-014-4076-x.
11. Rüdiger HA, Dittrich M, Robinson J et al.: The Impact of Heterotopic Ossification on Self-Reported Outcomes After Total Hip Arthroplasty Using the Direct Anterior Approach. J Bone Joint Surg Am 2020; 102(Suppl 2):91-98. doi: 10.2106/JBJS.20.00071.
12. Pohl F, Seufert J, Tauscher A et al.: The influence of heterotopic ossification on functional status of hip joint following total hip arthroplasty. Strahlenther Onkol 2005; 181(8):529-533. doi: 10.1007/s00066-005-1352-4.
13. Majewski M, Bischoff-Ferrari HA, Grüneberg C et al.: Improvements in balance after total hip replacement. J Bone Joint Surg Br 2005; 87(10):1337-1343. doi: 10.1302/0301-620X.87B10.16605.
14. Lugade V, Klausmeier V, Jewett B et al.: Short-term recovery of balance control after total hip arthroplasty. Clin Orthop Relat Res 2008; 466(12):3051-3058. doi:10.1007/s11999-008-0488-9.
15. Pop T, Szymczyk D, Majewska J et al.: The Assessment of Static Balance in Patients after Total Hip Replacement in the Period of 2-3 Years after Surgery. BioMed Research International vol. 2018; Article ID 3707254, 8 pages, 2018. doi: 10.1155/2018/3707254.
16. Riddle DL, Golladay GJ: Preoperative Risk Factors for Postoperative Falls in Persons Undergoing Hip or Knee Arthroplasty: A Longitudinal Study of Data From the Osteoarthritis Initiative. Arch Phys Med Rehabil 2018; 99(5):967-972. doi: 10.1016/j.apmr.2017.12.030.
17. Spinarelli A, Patella V, Petrera M et al.: Heterotopic ossification after total hip arthroplasty: our experience. Musculoskelet Surg 2011; 95(1):1-5. doi: 10.1007/s12306-010-0091-6.
18. Biz C, Pavan D, Frizziero A et al.: Heterotopic ossification following hip arthroplasty: a comparative radiographic study about its development with the use of three different kinds of implants. J Orthop Surg Res 2015; 10, 176. doi: 10.1186/s13018-015-0317-2
19. Okano K, Aoyagi K, Osaki M et al.: Bone mineral density is not related to heterotopic ossification after total hip arthroplasty. Int Orthop 2012; 36(6):1163-1166. doi: 10.1007/s00264-011-1446-9.
20. Zhu Y, Zhang F, Chen W et al.: A meta-analysis of incidence and risk factors for heterotopic ossification after total hip arthroplasty. Arch Orthop Trauma Surg 2015; 135(9):1307-1314. doi: 10.1007/s00402-015-2277-8.
21. Pavlou G, Salhab M, Murugesan L et al.: Risk Factors for Heterotopic Ossification in Primary Total Hip Arthroplasty. HIP International 2012; 22(1):50-55. doi: 10.5301/HIP.2012.9057.
22. Hunter SW, Bobos P, Somerville L et al.: Prevalence and Risk Factors of Falls in Adults 1 Year After Total Hip Arthroplasty for Osteoarthritis: A Cross-Sectional Study. Am J Phys Med Rehabil 2020; 99(9):853-857. doi: 10.1097/PHM.0000000000001456.
23. Riddle DL, Golladay GJ: Preoperative Risk Factors for Postoperative Falls in Persons Undergoing Hip or Knee Arthroplasty: A Longitudinal Study of Data From the Osteoarthritis Initiative. Arch Phys Med Rehabil 2018; 99(5):967-972. doi: 10.1016/j.apmr.2017.12.030.
24. Ninomiya K, Takahira N, Ikeda T et al.: Predictors of falls in patients during the first year after total hip arthroplasty: A prospective cohort study. Health Sci Rep 2020; 3(3):e184. doi: 10.1002/hsr2.184.
25. Johnson M, Mille ML, Martinez K et al.: Age-related changes in hip abductor and adductor joint torques. Archives of physical medicine and rehabilitation 2004; 85:593-597. doi: 10.1016/j.apmr.2003.07.022.
26. Jeka J, Kiemel T, Creath R et al.: Controlling Human Upright Posture: Velocity Information is More Accurate than Position or Acceleration. J of Neurophysiology 2004; 92:2368–2379.
27. Peterka RJ: Sensorimotor integration in human postural control. J of Neurophysiology 2002; 88:1097–1118.
28. Horak FB, Nashner LM: Central programming of postural movements: adaptation to altered support surface configurations. J of Neurophysiology 1986; 55(6):1369–1381.
29. Creath R, Kiemel T, Horak F et al.: A unified view of quiet and perturbed stance: Simultaneous co-existing ankle and hip strategies. Neuroscience Letters 2005; 377(2):75–80.

Original paper

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Hip hemiprosthesis due to femoral neck fracture in the elderly population – are we doing it right?

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Abstract

Introduction: Femoral neck fracture is one of the most common orthopaedic traumas affecting the elderly population. The standard treatment method is hip hemiarthroplasty and total hip arthroplasty. In hip hemiprostheses surgeons mainly have to reconstruct the femoral offset and limbs' length to obtain the correct gait biomechanics and a satisfactory surgical outcome.
The aim of this study is to examine the radiological results of patients after hip hemiarthroplasty for femoral neck fracture and to evaluate the reconstruction of the femoral offset using standard neck angle stems.
Material and methods: A consecutive series of 97 patients diagnosed with femoral neck fracture treated with a hip hemiprosthesis between 2017 and 2021 was identified and met the inclusion criteria. On preoperative images, the neck-shaft angle and the femoral offset on the healthy limb were measured. The femoral offset of the operated limb was measured on the postoperative X-rays.
Results: There was a significant positive moderate correlation between neck-shaft angle and femoral offset change ($r = 0.568$, $p < 0.0001$). There was a statistically significant difference between femoral offset change and neck-shaft angle (24:52 vs. 14:7, $p = 0.005$). This means that in patients with coxa vara the change in femoral offset was more often < –5 mm. Less than half of operated patients had the femoral offset restored within a safe range (between –5 and 5 mm).
Conclusions: Our study proved that it is sometimes hard to achieve femoral offset within a safe range while performing hip hemiarthroplasty in patients with coxa vara. The topic of using high offset stems in partial hip arthroplasty has not been thoroughly researched worldwide. However, taking into account the results of our study, during a hip hemiarthroplasty the usage of high offset stems for varus hips should be considered in order to improve the clinical outcome and improve patients' quality of life and functioning.

Key words: neck-shaft angle, hip hemiprosthesis, femoral offset, radiographic evaluation.

Introduction

Femoral neck fracture (FNF) is one of the most common orthopaedic traumas affecting the elderly population. It is one, besides the peritrochanteric fracture, of the osteoporotic fractures, which also include distal radius fractures and vertebral compression fractures. Femoral neck fractures are associated with high morbidity and mortality of patients due to the immobilization of the patients in bed, accompanying comorbidities and the advanced age of the patients most often affected by the injury.

There are a few ways of surgical treatment of the FNF. If the bone quality is high and the femoral head is not displaced, which is a favourable factor of good blood supply to the bone, it is possible to fix the fracture with a plate or screws. In elderly patients with osteoporotic bone and displaced femoral heads it is better to choose

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between hip hemiarthroplasty, or total hip arthroplasty if FNF is also accompanied by hip osteoarthritis. In this study, the authors' main focus was on hip hemiarthroplasty.

The American Joint Replacement Registry (AJRR) from 2021 [1] revealed that between 2012 and 2020 there were 105,743 hip arthroplasty procedures for femoral neck fracture, of which 82,594 (78%) procedures were partial hip arthroplasties. The data from the Primary Partial Hip Replacement Supplementary Report [2] for the 2021 Australian Orthopaedic Association National Joint Replacement Registry showed that in the period from 2003 to 2020, 107,628 partial hip prostheses were made, and a femoral neck fracture was the main indication for this operation in over 90% of cases.

Although the percentage of hip hemiarthroplasty has been gradually declining year by year, according to the American Joint Replacement Registry, it is still an important treatment for femoral neck fractures.

In order to achieve a satisfactory result after hip arthroplasty, the correct relationship between anatomical structures such as acetabular offset, femoral offset (FO), acetabular anteversion and inclination, centre of rotation, and limb length must be restored. Due to the lack of interference in the acetabular structure during hip hemiprosthesis surgery, mainly the FO and length of the limbs must be reconstructed. Restoration of each of these components is essential for proper gait biomechanics and a satisfactory surgical outcome for the patient.

Neglecting these parameters may result in inefficiency of the abductor muscles stabilizing the pelvis, resulting in pelvic drop, limping due to limb shortening, abnormal gait pattern or chronic pain in the area of the hip joint and the operated limb associated with bone impingement, or increased tension in the gluteus medius and minimus attached to the greater trochanter. Inefficiency of abductor muscles, among other conditions such as gluteus medius and minimus tendinopathies, trochanteric bursitis or damage to muscles and tendons during total or partial hip arthroplasty surgery may also lead to chronic lateral hip pain, called greater trochanteric pain syndrome [3].

In the literature, it was observed that patients with coxa vara have higher FO and therefore performing total hip replacement with standard stem was associated with not restoring proper gluteus muscle tension and pelvic imbalance. High-offset stems were introduced to the market to allow such patients to restore proper biomechanics of the hip joint.

One of our observations on postoperative radiographs of patients operated on for femoral neck fracture is the difficulty in recreating the FO and appropriate muscle tension in patients with varus hips. In such patients, a better solution seems to be the use of high offset stems to better reproduce the FO and the biomechanics of the joint.

Inflammatory joint diseases such as rheumatoid arthritis lead to osteoporosis and increase the risk of fractures. For hip surgical procedures in these diseases a total hip replacement is preferred; however, partial hip replacement in some circumstances may also be considered.

Importantly, the indications for surgery are patient's pain and disability, not age, especially in inflammatory joint diseases, which affect a younger population than osteoarthritis. Each discussion on the effectiveness of the surgical method, and in particular the discussion of less frequently used methods in some indications, provides important information that can be used by patients also with diseases other than osteoarthritis and osteoporosis.

The purpose of the study is to assess the radiological results after partial hip arthroplasty in patients who underwent procedures performed for femoral neck fracture. It also aims to evaluate the reconstruction of the FO using standard neck angle stems.

This study does not require approval by the institutional review board of the Medical University of Warsaw.

Material and methods

A consecutive series of 116 patients who were diagnosed with femoral neck fracture qualified for and treated with partial hip arthroplasty between January of 2017 and December of 2021 was identified. Patients included in the study were: aged ≥ 60 years on the day of surgery, diagnosed with femoral neck fracture, qualified for surgery with use of hip hemiarthroplasty and those who had pre- and postoperative radiological control appropriate for analysis. The exclusion criteria were: age < 60 years, concomitant hip osteoarthritis in affected limb and qualification for treatment other than hip hemiarthroplasty, non-diagnostic radiograph in forced position.

For the present analysis, demographic data such as gender and age at surgery (years) were collected. A total of 97 patients treated with a cemented Taperloc (Zimmer Biomet, Warsaw, IN, USA) stem with bipolar head met the inclusion criteria. All operations were performed in a level III academic hospital. All patients were operated on in the lateral decubitus position. Surgical technique using the natural interval in gluteal muscles and dissecting only one third of its attachment was used. An incision in line with the axis of the femoral shaft was performed with ⅓ distally and ⅔ proximally to the tip of the greater trochanter.

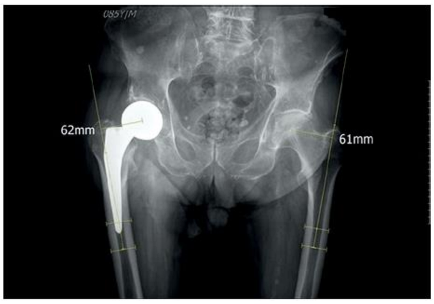

Fig. 1. Postoperative femoral offset restored within safe range compared to the contralateral hip.

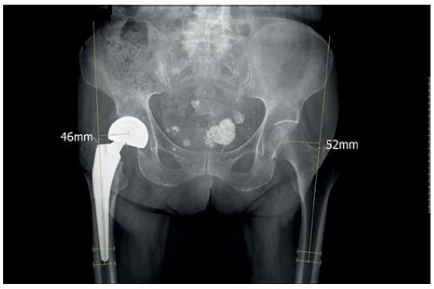

Fig. 2. Postoperative femoral offset reconstructed with less than –5 mm compared to the contralateral hip in a patient with a neck-shaft angle < 130 degrees.

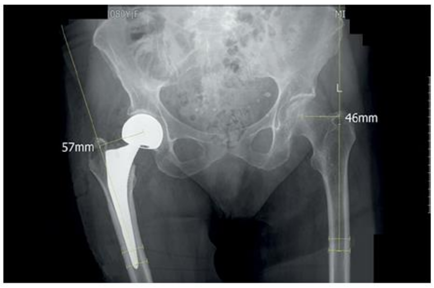

Fig. 3. Postoperative femoral offset reconstructed with more than 5 mm compared to the contralateral hip in a patient with a neck-shaft angle > 130 degrees.

Further blunt dissection of connective and fat tissue was done to visualize the iliotibial tract. The latter structure was then incised in a slightly curved way to stay in line with fibres of the tensor fascia lata. After moving the fascia aside, visualization of the gluteus medius was done. The natural interval of the anterior third of the gluteus medius was found and carefully dissected from the bone. Then the femoral neck was easily palpable and the joint capsule was opened with a longitudinal dissection above the femoral neck.

After completing the approach the hip joint was dislocated and the femoral neck was cut accordingly to manufacturer's technique. Then, after head and neck resection, the medullary canal was prepared for the appropriate stem size using rasps and a correct-sized stem was placed using bone cement. The acetabulum was revised to confirm the absence of unnecessary tissue, then a bipolar head was attached and the prosthesis was repositioned. Proper prosthesis placement was confirmed on X-ray images taken on the following day.

Radiographic evaluation

Pre- and postoperative radiographic examination of the pelvis including both hip joints in the anterior-posterior projection in the supine position was performed during patients' hospitalisations. Retrospective analysis of radiographic images was performed. On preoperative images, the neck angle and the FO on the healthy limb were measured, and the femoral neck fracture was classified using the Pauwels and Garden scales. The FO of the operated limb was measured on the postoperative X-rays (Figs. 1–3).

Finally, 97 patients were included in the study, 3 patients were excluded from further measurements and analyses due to excessive forced rotation of the lower limbs on radiographs due to severe pain.

Statistical analysis

Statistical analysis of the obtained results was performed. Pearson's correlation coefficient was used to measure the association between neck-shaft angles and FO changes. For categorical variables Fisher's exact test was used. An α-value of 0.05 was used to determine the statistical significance of all the analyses. All statistical analyses were conducted using SAS software, Version 9.4 for Windows (SAS Institute Inc., NC, USA).

Results

There was a significant positive moderate correlation between neck-shaft angle value and FO change (r = 0.568, p < 0.0001). There was a statistically signif-

Table I. Baseline characteristics in both groups of patients

Variable	Neck-shaft angle equal to or higher than 130 degrees	Neck-shaft angle less than 130 degrees	*p*-value
Gender (males, females)	15 : 61	5 : 16	> 0.05
Operated side (left, right)	32 : 44	6 : 15	> 0.05

Table II. Information about patients' age, femoral offset change and neck-shaft angle value

Parameter	Mean value	Minimum value	Maximum value
Age [years]	83.14 (SD = 7.83)	60.00	95.00
Femoral offset change [mm]	–3.19 (SD = 9.23)	–28.00	16.00
Neck-shaft angle value [degrees]	134.16 (SD = 6.00)	118.00	149.00

SD – significant difference.

Table III. Number of patients in individual groups ($p = 0.005$ in two-sided probability test)

Change in femoral offset	Neck-shaft angle equal to or higher than 130 degrees	Neck-shaft angle less than 130 degrees
Femoral offset change equal to or higher than –5 mm	52 (53.6%)	7 (7.2%)
Femoral offset change less than –5 mm	24 (24.7%)	14 (14.4%)

icant difference between FO change and neck-shaft angle value (24 : 52 vs. 14 : 7, $p = 0.005$). This means that in patients with a neck-shaft angle less than 130 degrees, that is, patients with coxa vara, the change in FO was less than –5 mm more often (14 out of 21 patients) than in patients with a neck-shaft angle equal to or higher than 130 degrees (24 out of 76 patients).

It also means that in patients with a neck-shaft angle equal to or higher than 130 degrees, the change in FO was more often greater than –5 mm (52 vs. 24 patients). Forty-two out of 97 patients had the FO restored within a safe range (between –5 mm and 5 mm), 38 patients had a FO change less than –5 mm and 17 patients had a FO change greater than 5 mm.

The patients' characteristic and the information about patients' age, FO change and neck-shaft angle value are presented in Tables I–III.

Discussion

The available databases lack studies which evaluate the reproduction of the FO according to the neck-shaft angle using a standard prosthesis stem in partial hip arthroplasty. One of the most important reasons for addressing the topic is the lack of knowledge in this area of orthopaedics.

Femoral offset represents the simplified length of the biomechanical lever arm of the abductor muscles. Inadequate FO reconstruction after total hip arthroplasty (THA) is associated with an increased risk of postoperative dislocation, limping, leg-length discrepancy and component wear, as well as impingement-free range of motion [4].

There are some recent papers describing FO restoration in patients treated with bipolar hip arthroplasty (BHA) due to displaced femoral neck fracture and its influence on clinical outcome [4–7].

Ji et al. [5] stated that when performing partial hip arthroplasty with a Smith & Nephew standard angle stem (neck-shaft angle 131 degrees), 23% of patients whose FO changed by more than 20% of the preoperative value did not have a properly restored FO which significantly worsens the outcomes of the Harris Hip Score (HHS) and Modified Barthel Index (MBI).

Kim et al. [6] retrospectively analysed a group of 77 patients who underwent BHA due to FNF. As a result of the surgery, both FO and leg length were increased. The researchers revealed a negative relationship between FO restoration and HHS during the entire follow-up period.

In the study by Buecking et al. [4] the authors focused on clinical outcomes such as HHS, timed up and go (TUG) and Lawton Instrumental Activities of Daily Living (IADL) and found a significant positive correlation between FO and HHS and IADL. The authors noted a linear relationship and excellent correlation between postoperative FO and the contralateral FO. It is worth noting that most likely the perfect correlation is the result of preoperative planning resulting in more frequent use of a lateral stem rather than a standard one.

With regard to the clinical outcome after bipolar hip arthroplasty, Kizkapan et al. [7] evaluated factors affecting the risk of dislocation after BHA. According to the authors, decreased FO on the operated side and larger neck-shaft angle (more valgus hip) on the non-operative side significantly raise the risk of dislocation.

It is noteworthy that the survey was conducted among patients burdened with a very high risk of dislocation (8.6%). This may be a result of the selected surgical access – all patients were operated on from a posterior approach. It is stated that the mentioned approach is associated with an increased risk of dislocation [8, 9].

In our study, all patients were operated on from an anterolateral approach. However, unfortunately, due to the lack of follow-up, we do not have data on the occurrence of prosthetic dislocations in the study group.

Unfortunately, none of the articles checked the correlation between stem neck-shaft angle and preoperative patients' neck-shaft angle. The present study focused precisely on the values of angles and the possibility of the most accurate restoration of FO, but it is not a typical clinical study with an assessment of the functioning of patients. There was no follow-up and the outcomes were not checked with the questionnaires used in the above studies [4–7]; therefore the authors cannot refer to the mentioned studies in these matters.

Thus, taking into account the results of articles mentioned above [4–7], it seems that restoring FO with meticulous templating in patients undergoing bipolar hip arthroplasty due to femoral neck fracture is essential.

There are several articles that have focused on the assessment of abductor muscle strength depending on the reconstructed FO after total hip arthroplasty [10, 11]. Tezuka et al. [10] examined changes in the hip joint centre (HJC) and FO during THA and their influence on the strength of abductor muscles. They concluded that the infero-medial cup position and hence the medial shift of the HJC and the compensating FO increase optimized hip abductor muscle strength. Such positioning and selection of implants also have a positive effect on the functioning of the patient [12].

In the study by Mahmood et al. [11], the authors divided 222 patients after THA in terms of reconstructed FO into those with reduced offset (shortening of more than 5 mm), with correct offset (within 5 mm restoration) and with increased offset (over 5 mm). Analysis of the results showed that patients with reduced offset had worse patient reported outcome measures and had statistically significantly lower abductor muscle strength.

In total hip arthroplasty, selecting the right FO in order to ensure good hip abductors tension depends on the position of the acetabulum, especially its depth in the medial lateral axis.

In the case of BHA where the HJC is not changed, it is important to recreate the FO as close as possible to the baseline to maintain proper abductor muscle strength and avoid patient's limping and dissatisfaction with the procedure.

Incorrect reconstruction of the FO, especially increasing its value, may adversely affect the patient's functioning [13, 14]. Although in the study by Weber et al. [13] the usage or simulation of the use of high offset stem increased the range of motion (ROM) in each case, increasing ROM in the hip joint improved the patient's functioning in activities of daily living only in less than 10% of patients. Therefore, the authors emphasize that each patient should have the FO reconstructed individually.

Liebs et al. [14] divided patients after THA into three cohorts as in the study by Mahmood et al. [11] They revealed that the greater the postoperative FO, the worse the patient's score on the pain subscale from the Western Ontario and McMaster Universities Arthritis Index (WOMAC) questionnaire.

However, another study by Foy et al. [15] analysed 157 patients in the context of lateral hip pain depending on the change in FO after THA. In contrast to the previous study, the authors did not detect a statistically significant correlation between the occurrence of lateral hip pain and the change in FO.

A condition that is worth mentioning in the discussion is called greater trochanteric pain syndrome. The most common manifestation of this disorder is chronic lateral hip pain, which is aggravated by weight bearing activities and side lying at night. In more developed and advanced stages it can present as weakness and Trendelenburg's gait.

Onset of symptoms is related to, among other factors, the pathology of gluteus medius and/or gluteus minimus muscles and their tendons. Inflammation of bursae surrounding the greater trochanter is responsible for the minority of all cases of posterolateral hip pain. Soft tissue damage resulting from the surgical approach causes the majority of them. It seems that type of surgical approach has a greater impact on the occurrence of posterolateral hip pain than increased FO [3, 16, 17].

The present study analysed patients after BHA, unfortunately only with the use of standard neck-shaft angle stems. One question that may arise is whether lateralised stems could be used during BHA due to femoral neck fracture and what the survival of high offset stems would be in such patients. Some studies analysing the survivorship of high offset stems suggest that lateralized stems have shorter survival periods than standard stems [18, 19] or that high offset stems have a high risk of loosening and surgery failure [20].

Conversely, there are studies which indicate a very good survival time or predicted survivorship of high offset stems [21–24]. It seems to be a more complex and multifactorial issue, and it cannot be said with certainty that patients with a high offset stem during bipolar hip arthroplasty will require revision surgery in a shorter period of time.

Also positive for the topic discussed are the recent results presented by members of the Hip Fracture Evaluation with Alternatives of Total Hip Arthroplasty versus HemiArthroplasty (HEALTH) Investigators.

Namely, cooperating researchers presented the results of their international study which showed that the incidence of secondary procedures after total and partial hip arthroplasty (hemi-hip replacement) did not differ between the two group [25].

In this study the patients after THA presented modestly better function at 24 months, but as can be expected with a slightly higher incidence of serious adverse events than hemiarthroplasty patients with displaced femoral neck fractures.

Study limitations

The authors of this article admit that the study has some weaknesses. Firstly, no rotational correction was used during the measurements of the offsets. However, patients whose pelvis/lower limbs were too rotated, which prevented performing proper measurements, were excluded from further X-ray evaluation.

Secondly, it is a study that analyses only the radiological results of the performed operations, without taking into account the follow-up of patients or the patient reported outcome measurements.

Third, the operations were performed by several different surgeons, so there is a risk that the results will vary by operating surgeon.

This study, however, also has strengths. To the best of our knowledge, this is the first study, which aims to accurately check the correlation between the patients' native neck-shaft angle and the postoperative change in FO.

Conclusions

Our study proved that it is sometimes hard to achieve FO within a safe range while performing partial hip arthroplasty in patients with coxa vara. The topic of using high offset stems in partial hip arthroplasty has not been thoroughly researched worldwide.

However, taking into account the results of our study, during a hip hemiprosthesis procedure due to femoral neck fracture, the neck-shaft angle of the healthy hip should be measured and the use of a high offset stem for varus hips should be considered in order to improve the clinical outcome of the treatment and improve the quality of life and functioning of the patient.

For these reasons, we hope that this publication will become an incentive for other orthopaedic clinical centres to conduct similar measurements and analyses among their own patient cohorts.

The authors declare no conflict of interest.

References

1. American Joint Replacement Registry (AJRR): 2021 Annual Report. Rosemont, IL: American Academy of Orthopaedic Surgeons (AAOS), 2021. Available at: https://www.aaos.org/registries/publications/ajrr-annual-report/.
2. Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). Primary Partial Hip Replacement: Supplementary Report, in Hip, Knee & Shoulder Arthroplasty: 2021 Annual Report, AOA, Adelaide; 2021: 1–32. Available at: https://aoanjrr.sahmri.com/annual-reports-2021/supplementary.
3. Williams BS, Cohen SP. Greater trochanteric pain syndrome: a review of anatomy, diagnosis and treatment. Anesth Analg 2009; 108: 1662–1670, DOI: 10.1213/ane.0b013e31819d6562.
4. Buecking B, Boese CK, Bergmeister VA, et al. Functional implications of femoral offset following hemiarthroplasty for displaced femoral neck fracture. Int Orthop 2016; 40: 1515–1521, DOI: 10.1007/s00264-015-2828-1.
5. Ji HM, Won SH, Han J, Won YY. Does femoral offset recover and affect the functional outcome of patients with displaced femoral neck fracture following hemiarthroplasty? Injury 2017; 48: 1170–1174, DOI: 10.1016/j.injury.2017.03.022.
6. Kim SS, Kim HJ, Shim CH. Relationships between femoral offset change and clinical score following bipolar hip arthroplasty in femoral neck fractures. Hip Pelvis 2021; 33: 78–86, DOI: 10.5371/hp.2021.33.2.78.
7. Kizkapan TB, Misir A, Uzun E, et al. Factors affecting dislocation after bipolar hemiarthroplasty in patients with femoral neck fracture. Injury 2020; 51: 663–669, DOI: 10.1016/j.injury.2020.01.025.
8. Jobory A, Kärrholm J, Hansson S, et al. Dislocation of hemiarthroplasty after hip fracture is common and the risk is increased with posterior approach: result from a national cohort of 25,678 individuals in the Swedish Hip Arthroplasty Register. Acta Orthop 2021; 92: 413–418, DOI: 10.1080/17453674.2021.1906517.
9. Abram SG, Murray JB. Outcomes of 807 Thompson hip hemiarthroplasty procedures and the effect of surgical approach on dislocation rates. Injury 2015; 46: 1013–1017, DOI: 10.1016/j.injury.2014.12.016.

10. Tezuka T, Inaba Y, Kobayashi N, et al. Effects of hip joint center location and femoral offset on abductor muscle strength after total hip arthroplasty. Mod Rheumatol 2015; 25: 630–636, DOI: 10.3109/14397595.2014.988863.
11. Mahmood SS, Mukka SS, Crnalic S, et al. Association between changes in global femoral offset after total hip arthroplasty and function, quality of life, and abductor muscle strength. A prospective cohort study of 222 patients. Acta Orthop 2016; 87: 36–41, DOI: 10.3109/17453674.2015.1091955.
12. Clement ND, Patrick-Patel RS, MacDonald D, Breusch SJ. Total hip replacement: increasing femoral offset improves functional outcome. Arch Orthop Trauma Surg 2016; 136: 1317–1323, DOI: 10.1007/s00402-016-2527-4.
13. Weber M, Merle C, Nawabi DH, et al. Inaccurate offset restoration in total hip arthroplasty results in reduced range of motion. Sci Rep 2020; 10: 13208, DOI: 10.1038/s41598-020-70059-1.
14. Liebs TR, Nasser L, Herzberg W, et al. The influence of femoral offset on health-related quality of life after total hip replacement. Bone Joint J 2014; 96–B: 36–42, DOI: 10.1302/0301-620X.96B1.31530.
15. Foy M, Kielminski D, Cavazos D, et al. Changes in femoral offset is not associated with increased incidence of lateral hip pain following total hip arthroplasty. J Clin Orthop Trauma 2020; 16: 132–135, DOI: 10.1016/j.jcot.2020.12.010.
16. Abdulkarim A, Keegan C, Bajwa R, Sheehan E. Lateral trochanteric pain following total hip arthroplasty: radiographic assessment of altered biomechanics as a potential aetiology. Ir J Med Sci 2018; 187: 663–668, DOI: 10.1007/s11845-017-1701-1.
17. Moerenhout K, Benoit B, Gaspard HS, et al. Greater trochanteric pain after primary total hip replacement, comparing the anterior and posterior approach: a secondary analysis of a randomized trial. Orthop Traumatol Surg Res 2021; 107: 102709, DOI: 10.1016/j.otsr.2020.08.011.
18. Melbye SM, Haug SCD, Fenstad AM, et al. How does implant survivorship vary with different corail femoral stem variants? Results of 51,212 cases with up to 30 years of follow-up from the Norwegian arthroplasty register. Clin Orthop Relat Res 2021; 479: 2169–2180, DOI: 10.1097/CORR.0000000000001940.
19. Cantin O, Viste A, Desmarchelier R, et al. Compared fixation and survival of 280 lateralised vs 527 standard cementless stems after two years (1–7). Orthop Traumatol Surg Res 2015; 101: 775–780, DOI: 10.1016/j.otsr.2015.08.002.
20. Courtin C, Viste A, Subtil F, et al. Cementless lateralized stems in primary THA: mid-term survival and risk factors for failure in 172 stems. Orthop Traumatol Surg Res 2017; 103: 15–19, DOI: 10.1016/j.otsr.2016.10.011.
21. Panichkul P, McCalden RW, MacDonald SJ, et al. Minimum 15-year results of a dual-offset uncemented femoral stem in total hip arthroplasty. J Arthroplasty 2019; 34: 2992–2998, DOI: 10.1016/j.arth.2019.07.003.
22. Dikmen G, Ozden VE, Beksac B, Tozun IR. Dual offset metaphyseal-filling stems in primary total hip arthroplasty in dysplastic hips after a minimum follow-up of ten years. Int Orthop 2019; 43: 2039–2046, DOI: 10.1007/s00264-018-4161-y.
23. Peng L, Ma J, Zeng Y, et al. Clinical and radiological results of high offset tri-lock bone preservation stem in unilateral primary total hip arthroplasty at a minimum follow-up of 3 years. J Orthop Surg Res 2021; 16: 635, DOI: 10.1186/s13018-021-02787-7.
24. Danesh-Clough T, Bourne RB, Rorabeck CH, McCalden R. The mid-term results of a dual offset uncemented stem for total hip arthroplasty. J Arthroplasty 2007; 22: 195–203, DOI: 10.1016/j.arth.2006.04.006.
25. Mohit Bhandari, Einhorn TA, Guyatt G, et al. Total hip arthroplasty or hemiarthroplasty for hip fractures. N Engl J Med 2019; 381: 2199–2208, DOI: 10.1056/NEJMoa1906190.

Podsumowanie i wnioski

Powyższe publikacje wchodzące w skład cyklu tworzącego powyższą pracę doktorską analizują czynniki wpływające na powodzenie i optymalizację wyników leczenia operacyjnego choroby zwyrodnieniowej stawu biodrowego. Biorąc pod uwagę, że liczba pacjentów wymagających leczenia operacyjnego będzie wzrastać w najbliższym czasie ze względu na epidemię otyłości oraz coraz bardziej powszechny siedzący tryb życia, techniki operacyjne powinny dążyć do zapewnienia chorym jak najmniejszej liczby powikłań oraz jak najlepszego wyniku klinicznego.

Wnioski

Analiza parametrów osadzenia implantów endoprotezy stawu biodrowego jest kluczowa dla sukcesu operacji, minimalizując ryzyko powikłań takich jak obluzowanie implantu czy ograniczenie ruchomości stawu. Precyzyjne określenie pozycji centrum rotacji, offsetu udowego i panewkowego oraz kątów inklinacji i antewersji pozwala na optymalne rozłożenie sił w stawie, poprawę funkcji ruchowych i redukcję bólu pooperacyjnego.

Analiza porównawcza parametrów osadzenia implantów endoprotezy w różnych dostępach operacyjnych pokazuje, że dostęp DAA może istotnie różnić się od innych dostępów pod względem antewersji i inklinacji panewki stawu biodrowego. Choć nie wykazano istotnych statystycznie różnic w osadzeniu trzpienia endoprotezy ani różnicy długości kończyn, wyniki te sugerują, że wybór odpowiedniego dostępu może mieć kluczowe znaczenie dla optymalnych wyników operacyjnych i rehabilitacyjnych pacjentów po endoprotezoplastyce stawu biodrowego.

Autorzy przedstawili kompleksowy przegląd literatury oraz wytyczne dotyczące odpowiedniego osadzenia elementów endoprotezy stawu biodrowego, uwzględniając parametry spinopelvic alignment. Zaproponowano wytyczne oceny mobilności miednicy oraz sztywności odcinka L-S kręgosłupa na podstawie pomiarów kątów takich jak Sacral Slope, Pelvic Tilt, Pelvic Incidence, Pelvic Femoral Angle, Lumbar Lordosis, Femoral Inclination oraz Spino Sacral Angle. Wskazano, że precyzyjna ocena tych parametrów na radiogramach pozwala na dostosowanie planu operacyjnego, co może istotnie wpłynąć na wyniki zabiegu oraz rehabilitację pacjenta po artroplastyce stawu biodrowego.

Wykazano istotne różnice w parametrach chodu pomiędzy pacjentami operowanymi z użyciem implantów o różnych średnicach głowy kości udowej a zdrowymi osobami kontrolnymi. Pacjenci z implantami o średnicy 36 mm wykazywali parametry chodu bliższe normie, z krótszym czasem fazy przenoszenia, krótszymi krokami oraz niższą prędkością kroku w porównaniu do osób z mniejszymi implantami. Wybór odpowiedniego implantu może istotnie wpłynąć na rekonstrukcję naturalnego modelu chodu oraz rehabilitację po artroplastyce stawu biodrowego.

Ponadto wykazano istotny związek między kątem szyjkowo-trzonowym a zmianą offsetu udowego (FO) po zabiegu endoprotezoplastyki połowiczej. Pacjenci z kątem udowo-szyjkowym poniżej 120 stopni mieli tendencję do większych zmian FO pooperacyjnie, co może prowadzić do niewłaściwego osadzenia implantu. Wyniki te podkreślają konieczność dostosowania typu trzpienia do indywidualnych cech anatomicznych pacjenta przed operacją, aby zapewnić prawidłowe odtworzenie FO oraz uniknąć powikłań związanych z niestabilnością implantu.

Analiza równowagi pokazała istotne różnice w stabilności postawy oraz ryzyku upadków między pacjentami z heterotopowymi skostnieniami po całkowitej aloplastyce stawu biodrowego a grupą kontrolną bez skostnień. Wyniki sugerują, że obecność skostnień pozaszkieletowych może znacząco wpływać na równowagę pacjentów po THA, zwiększając ryzyko upadków i potencjalnych powikłań, takich jak złamanie okołoprotezowe. Konieczne jest dalsze zrozumienie mechanizmów i strategii prewencyjnych w tej grupie pacjentów, aby poprawić wyniki rehabilitacyjne i zapobiec poważnym komplikacjom.

Kolejne publikacje są konieczne do dalszej optymalizacji wyników endoprotezoplastyki stawu biodrowego.

Piśmiennictwo

1. Allen KD, Thoma LM, Golightly YM. Epidemiology of osteoarthritis. Osteoarthritis Cartilage. 2022 Feb;30(2):184-195. doi: 10.1016/j.joca.2021.04.020. Epub 2021 Sep 14. PMID: 34534661; PMCID: PMC10735233.
2. Zhang Y, Jordan JM: Epidemiology of osteoarthritis. Clin Geriatr. Med 2010; 26(3):355-369. doi: 10.1016/j.cger.2010.03.001.
3. Katz JN, Arant KR, Loeser RF. Diagnosis and Treatment of Hip and Knee Osteoarthritis: A Review. JAMA. 2021 Feb 9;325(6):568-578. doi: 10.1001/jama.2020.22171. PMID: 33560326; PMCID: PMC8225295.
4. Singh JA, Yu S, Chen L, Cleveland JD (2019) Rates of total joint replacement in the united states: future projections to 2020–2040 using the national inpatient sample. J Rheumatol 46(9):1134–1140. https:// doi. org/ 10. 3899/ jrheum. 170990 (Epub 2019 Apr 15 PMID: 30988126)
5. Matharu GS, Culliford DJ, Blom AW, Judge A. Projections for primary hip and knee replacement surgery up to the year 2060: an analysis based on data from The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. Ann R Coll Surg Engl. 2022 Jun;104(6):443-448. doi: 10.1308/rcsann.2021.0206. Epub 2021 Dec 23. PMID: 34939832; PMCID: PMC9157920.
6. Learmonth ID, Young C, Rorabeck C (2007) The operation of the century: total hip replacement. Lancet 370(9597):1508–1519.https:// doi. org/ 10. 1016/ S0140-6736(07) 60457-7
7. Vaishy A, Arif M, Aanand R, Singh K, Rulaniya HK, Kumawat N, Choudhary R, Choudhary P. Implant positioning in total hip arthroplasty: influence of horizontal and vertical offset on functionality of prosthetic hip joint. Int Orthop. 2022 Jul;46(7):1501-1506. doi: 10.1007/s00264-022-05364-7. Epub 2022 Mar 15. PMID: 35288768.
8. Vanrusselt J, Vansevenant M, Vanderschueren G, Vanhoenacker F. Postoperative radiograph of the hip arthroplasty: what the radiologist should know. Insights Imaging. 2015 Dec;6(6):591-600. doi: 10.1007/s13244-015-0438-5. Epub 2015 Oct 20. PMID: 26487647; PMCID: PMC4656234.
9. Huppertz A, Radmer S, Wagner M, Roessler T, Hamm B, Sparmann M. Computed tomography for preoperative planning in total hip arthroplasty: what radiologists

need to know. Skeletal Radiol. 2014 Aug;43(8):1041-51. doi: 10.1007/s00256-014-1853-2.

10. Riley GM, McWalter EJ, Stevens KJ, Safran MR, Lattanzi R, Gold GE. MRI of the hip for the evaluation of femoroacetabular impingement; past, present, and future. J Magn Reson Imaging. 2015 Mar;41(3):558-72. doi: 10.1002/jmri.24725. Epub 2014 Aug 23. PMID: 25155435; PMCID: PMC4336232.
11. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am. 1978 Mar;60(2):217-20. PMID: 641088.
12. Abdel MP, von Roth P, Jennings MT, Hanssen AD, Pagnano MW. What Safe Zone? The Vast Majority of Dislocated THAs Are Within the Lewinnek Safe Zone for Acetabular Component Position. Clin Orthop Relat Res. 2016 Feb;474(2):386-91. doi: 10.1007/s11999-015-4432-5. PMID: 26150264; PMCID: PMC4709312.
13. Lum ZC, Dorr LD. Restoration of center of rotation and balance of THR. J Orthop. 2018;15(4):992–6.
14. Lecerf G, Fessy MH, Philippot R, et al. Femoral offset: anatomical concept, definition, assessment, implications for preoperative templating and hip arthroplasty. Orthop Traumatol Surg Res.2009;95:210–9.
15. Bonnin MP, Pooler HA, Basiglini L. Do we medialise the hip centre of rotation in total hip arthroplasty? Influence of acetabular offset and surgical technique. Hip Int. 2012;22(04):371–8.
16. Little NJ, Busch CA, Gallagher JA. Acetabular polyethylene wear and acetabular inclination and femoral offset. Clin Orthop Relat Res. 2009;467(11):2895–900.
17. Yeh KL, Wu TY, Ma HH. Ellipse method for measuring Liaw's anteversion of the acetabular component after total hip arthroplasty. BMC Musculoskelet Disord. 2020;21:667.
18. Konyves A, Bannister GC. The importance of leg length discrepancy after total hip arthroplasty. J Bone Jt Surg Br. 2005;87:155–7.
19. Jelsma, J.; Pijnenburg, R.; Boons, H.W.; Eggen, P.J.; Kleijn, L.L.; Lacroix, H.; Noten, H.J. Limited benefits of the direct anterior approach in primary hip arthroplasty: A prospective single centre cohort study. J. Orthop. 2017, 14, 53–58. [CrossRef] [PubMed]
20. Kyriakopoulos, G.; Poultsides, L.; Christofilopoulos, P. Total hip arthroplasty through an anterior approach. EFORT Open Rev.2018, 3, 574–583. [CrossRef]

21. Shuichi Eto, Katherine Hwang, James I. Huddleston, Derek F. Amanatullah, William J. Maloney, Stuart B. Goodman, The Direct Anterior Approach is Associated With Early Revision Total Hip Arthroplasty, The Journal of Arthroplasty,Volume 32, Issue 3, 2017, Pages 1001-1005, ISSN 0883-5403, https://doi.org/10.1016/j.arth.2016.09.012.
22. Pizones J, García-Rey E. Pelvic motion the key to understanding spine-hip interaction. EFORT Open Rev. 2020 Sep 30;5(9):522-533. doi: 10.1302/2058-5241.5.200032. PMID: 33072404; PMCID: PMC7528668.
23. Kim Y, Vergari C, Shimizu Y, Tokuyasu H, Takemoto M. The Impact of Hip Mobility on Lumbar and Pelvic Mobility before and after Total Hip Arthroplasty. J Clin Med. 2022 Dec 31;12(1):331. doi: 10.3390/jcm12010331. PMID: 36615131; PMCID: PMC9821212.
24. Malkani AL, Garber AT, Ong KL, Dimar JR, Baykal D, Glassman SD, Cochran AR, Berry DJ. Total Hip Arthroplasty in Patients With Previous Lumbar Fusion Surgery: Are There More Dislocations and Revisions? J Arthroplasty. 2018 Apr;33(4):1189-1193. doi: 10.1016/j.arth.2017.10.041. Epub 2017 Oct 31. PMID: 29174406.
25. Hagio K, Saito M, Okawa T et al (2016) Polyethylene wear associated with 26- and 32-mm heads in total hip arthroplasty: a multicenter, prospective study. J Arthroplasty 31:2805–2809
26. Tsikandylakis G, Mohaddes M, Cnudde P, Eskelinen A, Karrholm J, Rolfson O (2018) Head size in primary total hip arthroplasty. EFORT Open Rev 3(5):225–231. https:// doi. org/ 10.1302/ 2058- 5241.3. 170061 (Published 2018 May 21)
27. Burroughs BR, Hallstrom B, Golladay GJ, Hoeffel D, Harris WH (2005) Range of motion and stability in total hip arthroplasty with 28-, 32-, 38-, and 44-mm femoral head sizes. J Arthroplasty 20:11–19
28. Zhu Y, Zhang F, Chen W et al.: A meta-analysis of incidence and risk factors for heterotopic ossification after total hip arthroplasty. Arch Orthop Trauma Surg 2015; 135(9):1307-1314. doi: 10.1007/s00402- 015-2277-8.
29. Pohl F, Seufert J, Tauscher A et al.: The influence of heterotopic ossification on functional status of hip joint following total hip arthroplasty. Strahlenther Onkol 2005; 181(8):529-533. doi: 10.1007/s00066-005-1352-4.

30. Shumway-Cook A, Ciol M, Gruber W, et al.: Incidence of and Risk Factors for Falls Following Hip Fracture in Community-dwelling Older Adults. Phys Ther 2005; 85(7):648-655.
31. Capone A, Congia S, Civinini R, Marongiu G. Periprosthetic fractures: epidemiology and current treatment. Clin Cases Miner Bone Metab. 2017 May-Aug;14(2):189-196. doi: 10.11138/ccmbm/2017.14.1.189. Epub 2017 Oct 25. PMID: 29263732; PMCID: PMC5726208.