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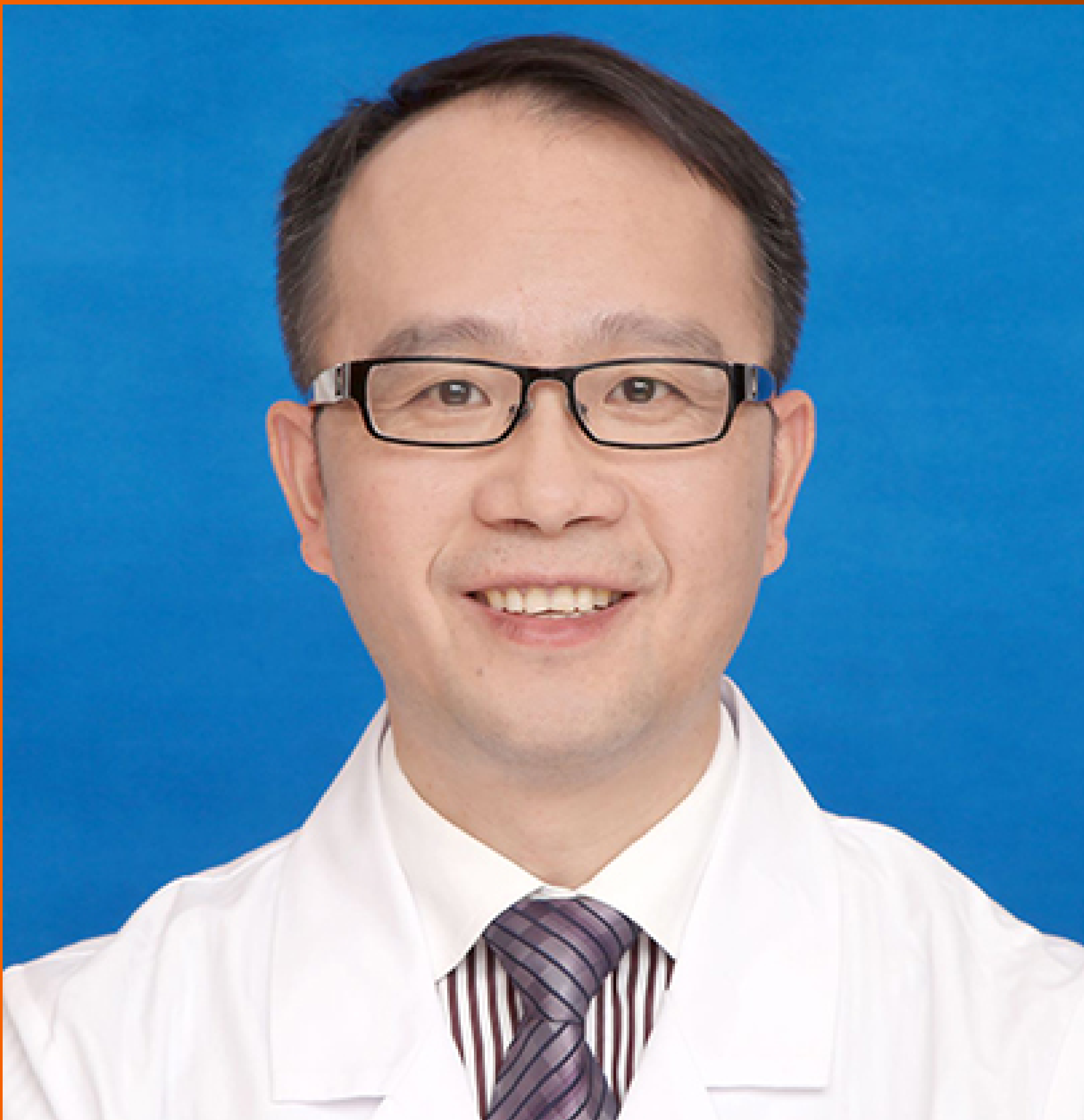

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MINIREVIEWS

Effective time, correction speed and termination time of hemi-epiphysiodesis in children

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Abstract

In children with asymmetric growth on the medial and lateral side of limbs, if there still remains growth potential, the guided growth technique of hemi-epiphysiodesis on one side of the epiphysis is recognized as a safe and effective method. However, when the hemi-epiphysiodesis start to correct the deformities, how many degrees could hemi-epiphysiodesis bring every month and when to remove the hemi-epiphysiodesis implant without rebound phenomenon are still on debate. This article reviews the current studies focus on the effective time, correction speed and termination time of hemi-epiphysiodesis.

Key Words: Hemi-epiphysiodesis; Percutaneous epiphysiodesis; Transphyseal screws; Eight plate

Core Tip: Epiphysiodesis is an effective treatment for limb deformity in children with unclosed epiphyseal. When the hemi-epiphysiodesis start to correct the deformities, how many degrees could hemi-epiphysiodesis bring every month and when to remove the hemi-epiphysiodesis implant without rebound phenomenon are still on debate. This article reviews the current studies focus on the effective time, correction speed and termination time of hemi-epiphysiodesis.

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INTRODUCTION

Epiphysiodesis is an effective treatment for limb deformity in children with growth potential[1-6]. At present, there are two main methods for epiphysiodesis in children with limb deformity. One is permanent epiphysiodesis. Percutaneous epiphysiodesis trans-epiphyseal screws (PETS) were proposed by Métaizeau *et al*[7] for epiphyseal plate fixation. They suggested that this technique is a simple operation with short operation time and fast postoperative rehabilitation, which is a reliable treatment method with few complications. The other is temporary epiphysiodesis, and the current mainstream procedure is a guided growth technique called eight plate, which relies on the tension band principle. The correction rates observed were about 30 percent faster than those observed with the once widely used stapling, and there was no permanent growth arrest. If the timing of epiphysiodesis is not well chosen, the opposite deformity will occur, so Eastwood *et al*[8] pointed out that the correct timing of intervention is still the biggest surgical challenge. Siemensma recommended that the best treatment timing is dependent on the location of the deformity, distance of physeal bar, and calculated length discrepancy at skeletal maturity[9]. However, when the hemi-epiphysiodesis start to correct the deformities, how many degrees could hemi-epiphysiodesis bring every month and when to remove the hemi-epiphysiodesis implant without rebound phenomenon are still on debate. This article reviews the current studies focus on the effective time, correction speed and termination time of hemi-epiphysiodesis.

EPIPHYSIODESIS BY PETS

A study by Martínez *et al*[10] included six patients, three male and three female. The data they used was a median age of 11 (8-14) years. The median time from surgery to final measured Angle correction was 12 (11-13) months, and the median mechanical lateral distal femoral angle (mLDFA) correction velocity was 0.55°/mo (0.43-0.71°/mo). In their follow-up study[11], Martínez *et al*[10] suggested that the median correction time was 12.3 (9.2-22.3) mo and the correction rate was 0.45°/mo (1.0-3.75°/mo). In 2012, Sung *et al*[12] proposed that in young children (boys 14 years old or younger, girls 12 years old or younger), the correction rates of distal femur, proximal tibia and distal tibia valgus deformity were 0.71°/mo (8.5°/year), 0.40°/mo (4.8°/year) and 0.48°/mo (5.8°/year), respectively. In older children, distal femur, proximal tibia, and distal tibia valgus deformity correction rate of 0.39°/mo (4.7°/year), 0.29°/mo (3.5°/year) and 0.48°/mo (5.8°/year). They also pointed out that the correction rate of distal femur was significantly lower in older children, which had similar conclusions in other studies. This may be related to the fact that the growth rate of the distal femur growth plate (9 mm/year) is higher than that of the proximal tibial growth plate (6 mm/mo)[13]. In the study of Khoury *et al*[14], 60 patients (105 epiphyses) underwent percutaneous screw epiphyseal fixation or hemi-epiphyseal fixation, and 30 patients (66 epiphyses) underwent hemi-epiphyseal plate screw fixation to correct angulation deformity. After follow-up, the mean correction rate of distal femur was 0.75 ± 0.45°/mo. Park *et al*[15] compared the outcomes of PETS with tension band plate techniques (TBP) in a comparative study in which 90 Limbs were treated with PETS in 33 patients and 60 Limbs were treated with TBP in 24 patients. In the distal femur, the mean correction rate of PETS group was higher than that of TBP group (0.92°/mo *vs* 0.64°/mo) and proximal tibia (0.72°/mo *vs* 0.55°/mo). The correction rate observed in the study was faster for PETS than for TBP. Compared with TBP, PETS correction may be more suitable for patients with close bone maturity. In recent years, Abdelaziz *et al*[16] improved the technique of percutaneous epiphyseal plate screws. They changed the direction of screw entry to retrograde, starting from epiphyseal to metaphyseal. It used the technique on 40 patients, 17 women (29 epiphyses) and 23 men (36 epiphyses). The mean age was 11.75 (8.4-14.5) years for females and 13.75 (11.75-15.6) years for males. The mean mLDFA correction was 1.3° (0.5-1.857°) per month and the mean time to correction was 5.9 mo, they also noted that the mean correction was 1.2°/mo in the female group and 1.35°/mo in the male group. In the above studies using averages as indicators, the mean correction rate was 0.92/°mo and the median was 0.835°/mo.

Other studies used different correction judgment indicators. Mesa *et al*[17] used the tibiofemoral Angle (the intersection Angle between the mechanical axis of the femur and the mechanical axis of the tibia), and the included male and female children were 14 years and 7 mo (12.7-15.1 years) and 13 years and 6 mo (12.9-14.8 years), respectively. The average correction was 0.73° ± 0.45°/mo, and the average removal time of the percutaneous hollow screw was 20.2 (18.9-25) months. In the study of Hu *et al*[18], a total of 41 patients were treated with cortical bone screws in 8 of them. The index of correction was tibial talar Angle (the Angle between the center line of the tibial intercondylar eminence and the level of the ankle space and the articular surface of the fornix of the talus). The average correction rate was 0.61°/mo. The average correction time was 22.25 ± 4.04 mo (17-27 mo).

EPIPHYSIODESIS BY EIGHT PLATE

Measured by mLDFA/mechanical medial proximal tibia angle

In the prospective series of studies conducted by Stevens *et al*[19], patients were followed for 14 to 26 mo after surgery, and 32 of 34 patients completed correction within an average of 11 mo. Among them, 4 patients with bilateral idiopathic valgus had malformed rebound. In the study of Burghardt *et al*[19], a total of 11 patients were followed up and the eight plates were removed. The mean age at insertion was 10 years and 2 mo, and the mean time from insertion to removal was 9.5 mo. The mean mechanical axis deviation (MAD) was improved by 32.7 mm. Seven patients were evaluated using mLDFA, with a mean age of 10.2 years, a mean correction time of 10.3 mo, and a mean correction rate of 0.9/mo. Burghardt *et al*[20] noted that because the femur grows faster than the tibia, patients with splay plates for the femur should be seen every three to four months, while patients with splay plates for the tibia should be seen every four to six months to monitor growth and deformity correction. Burghardt *et al*[21] included 43 patients in their follow-up results, whose average age was 9 years and 7 mo (4-14), at the time of insertion of the figure eight plate. The average implantation time of the plate was 14.2 (5.0-27.4) mo. Average distal femoral mechanical lateral angle was 10.00° (1-18°), the average correction rate was 0.65°/mo (0.05 to 1.22°/mo). Average proximal tibial medial angle change was 7.78° (0 to 14°), the average correction rate was 0.58°/mo (0.13 to 1.67°/mo). The mean mechanical axis displacement was improved by 25.4 (0-74) mm, and the mean improvement rate was 1.73 (0-6.4) mm/mo. After a longer follow-up (more than 10 mo), the average rebound distance of the 10 affected limbs was 15.7 mm, and the rebound speed was 1.0 mm/ mo (Table 1).

Jelinek *et al*[22] conducted a comparative study, including a total of 35 patients, among whom 17 were treated with eight plates. The average age of patients were 11.6 ± 3.8 years old (2.9-16), and the removal time of internal fixation was 11.9 ± 6.8 mo (1.9-27.9 mo). The mean mLDFA correction rate of the distal femur was 1°/mo. Two patients had hyperorthosis after the first orthosis, requiring hemi-epiphyseal fixation on the contralateral epiphyseal. Jelinek *et al*[22] points out that there is insufficient data on the need for excessive correction, and therefore recommends that all cases be followed up at a three-month interval. If the patient is expected to grow rapidly, such as in the preadolescent stage, especially if the femur and tibial epiphyses are being treated simultaneously, it is necessary to shorten the interval between follow-up visits. A total of 40 patients were included in the study by Kumar *et al*[23], 3 patients were lost to follow-up, and 37 patients followed up for more than 2 years were evaluated. There were 19 cases in the eight plate group, the mean age was 7.8 years (4-12), the mean mLDFA correction rate was 1.3°/mo, and the mean correction time was 10.3 mo. The study of Eltayeby *et al*[24] included 35 patients with genu valva deformity, who were followed up 7-25 mo after surgery, with an average age of 12.2 mo, and the average age of patients was 11 years old (3-15). The average speed of correction was 0.74°/mo. The authors concluded that the initial screw Angle (0°-30°) had no significant effect on the orthopedic rate when using tension band plates for hemiepiphysiodesis, and therefore recommended that surgeons should avoid the insertion of growth plates according to the anatomical limitations, rather than favoring a parallel, divergent, or highly divergent configuration. The study of Danino *et al*[25] included a total of 206 patients, whose average age at the time of surgery was 12.5 years old, and the average follow-up time was 16 mo. 93% of the femoral distal mLDFA was 85°-89°. Two percent had no corrective effect, and five percent were overcorrected. The correction rate of femur was significantly faster than that of tibia (0.85°/mo and 0.78°/mo, respectively), and the correction rate of femoral varus deformity was significantly faster than that of varus deformity (0.90°/mo and 0.77°/mo, respectively). No such difference was found in the tibia. Subsequently, Danino *et al*[26] included a total of 537 patients on the basis of previous studies, with an average age of 11.35 years at the time of plate implantation and an average follow-up of 16 mo after plate implantation. Of the femur correction, 444 (85%) patients completed treatment, of which 311 (70%) were corrected to the standard force line (mLDFA 85°-89°). 75 cases have not been corrected and the deformity is still worsening. mLDFA changes at an average of 0.77°/mo. In the correction of the tibia, 341 patients (75%) completed the treatment, of which 250 patients (80%) were corrected to the standard force line [mechanical medial proximal tibia angle (mMPTA) 85°-89°]. 107 (24%) had not yet achieved correction and the deformity was still increasing. The mean change in the medial proximal tibial Angle was 0.79°/mo.

Ding *et al*[27] included a total of 27 patients in their study, including 15 males and 12 females, with an average age of 6.3 years. Postoperative follow-up was 1.9-5.9 years (mean 3.8 years). Twenty-four patients achieved complete correction and three patients did not achieve complete correction. Distal femur Angle correction 8.41°/year, proximal tibia Angle correction 15.19°/year, internal fixation time was 0.9-1.9 years, with an average of 1 year. One case of rebound deformity occurred 2 years after the operation, and reoperation was performed. In contrast to some studies[28,29], Ding *et al*'s results showed that the average correction speed of tibia was faster than that of femur. They hypothesized that this might have something to do with the difference in mean age between the two groups: 3.8 years in the tibia group and 8.6 years in the femur group[27].

Özdemir *et al*’s study[30] included a total of 77 children with a mean age of 93 ± 36 mo and a mean follow-up of 36 ± 17 mo (12-88 mo) after implantation. The average removal time was 18 ± 8 mo (7-47 mo). The mechanical lateral Angle correction rate of the distal femur was 0.94 ± 0.43°/mo. The average age of children in Dai *et al*[31] study was younger and the overall correction speed was higher than that in other studies. A total of 66 patients were enrolled. The mean age at surgery was 4.69 years, the mean time to deformity correction was 13.26 mo, and the mean follow-up time after removal of the eight plates was 12.71 mo (12-24 mo). The mean mLDFA correction was 13.38° (2.6-32.7°) and the mean mMPTA correction was 10.05° (0.45-22.21°). Overall femur correction speed (1.28°/mo) was significantly higher than tibia correction speed (0.83°/mo). For the femur, the rate of correction of varus deformity was significantly higher than that of valgus deformity (1.50°/mo *vs* 1.16°/mo). However, for tibia, the rate of correction of valgus malformations was significantly higher than that of varus malformations (1.03°/mo *vs* 0.66°/mo). 3 cases of knee valgus showed rebound after removal of the eight plate.

Table 1 All the researches using eight plate and measured by mechanical lateral distal femoral angle/mechanical medial proximal tibia angle

Ref.	Patients included	Average age	Average speed (°/mo)	Average time (mo)
Stevens *et al*[19], 2007	32	-	-	11
Burghardt *et al*[20], 2008	7	10.2	0.9	10.3
Burghardt *et al*[21], 2010	43	9.7	0.65	14.2
Jelinek *et al*[22], 2012	17	11.6	1	11.9
Kumar *et al*[23], 2016	19	7.8	1.3	10.3
Eltayeby *et al*[24], 2019	35	11	0.74	12.2
Danino *et al*[25], 2019	206	12.5	0.85	16
Danino *et al*[26], 2018	444	11.4	0.77	16
Ding *et al*[27], 2019	27	6.3	0.7	12
Özdemir *et al*[30], 2021	77	7.8	0.94	18
Dai *et al*[31], 2021	66	4.7	1.28	13.3
Park *et al*[32], 2017	20	-	1.03	13.7
Feng *et al*[33], 2023	26	6.2	0.9	22.7
Radtke *et al*[34], 2020	139	-	0.4	11.1

Park *et al*[32] compared the efficacy of 8-figure plate and 3.5 mm reconstructed plate, and 20 patients were fixed with 8-figure plate. 35 cases were fixed with reconstruction plates. The average correction time of 8-figure plate and reconstruction plate was 13.7 mo and 19.7 mo, respectively. The mean correction Angle of the distal lateral Angle of the mechanical femur was 9.0° for the 8-figure plate and 9.9° for the reconstructed plate. The mean correction Angle of the proximal medial tibial Angle was 7.1° with the figure eight plate and 9.0° with the reconstructed plate. There was no significant difference in the Angle correction rate between the distal femur (1.03°/mo *vs* 0.77°/mo) and the proximal tibia (0.66°/mo *vs* 0.63°/mo). Two cases of malformed rebound were observed in the study, requiring a second hemiepiphysial arrest.

Feng *et al*[33] retrospectively analyzed the clinical data of 26 children with X-linked hypophosphatemic rickets treated with 8-figure plates. The median age was 6.2 years, ranging from 2 to 13 years. The mean mechanical lateral Angle of the distal femur (mLDFA) was 11.7 ± 8.7°, and the mMPTA was 8.4 ± 5.0°. The mean time for deformity correction was 22.7 mo (7-60 mo), and the mean follow-up time after eight plate removal was 43.9 mo (24-101 mo). The femoral correction speed (0.9°/mo) was significantly higher than that of the proximal tibia (0.6°/mo). One patient experienced rebound after removal of the eight plate.

Radtke *et al*[34] retrospectively analyzed the data of 355 patients with femoral neck fracture and divided them into idiopathic group and pathological group. The children ranged in age from 4 to 16 years, with an average age of 12.18 years. The average correction time was 17.32 mo (2-62 mo). The mean time from (hemi-) epiphysiodesis to implant removal in the idiopathic and pathological groups was 13.24 mo and 21.3 mo, respectively. Among them, 139 patients were idiopathic eversion deformity group, the average correction time was 11.07, and the average correction rate was 0.4°/mo. The time for removal of internal fixation for idiopathic varus malformations was 18.39 mo, compared with 24.9 mo for the varus group and 20 mo for the valgus group. In the entire idiopathic malformation group, 13 patients showed rebound.

MEASURED BY TIBIFEMORAL ANGLE

Boero *et al*[35] divided 58 patients into idiopathic and pathological groups according to the cause, with 30 cases of idiopathic deformity and 28 cases of pathological deformity. The age ranged from 2 years 3 mo to 14 years 11 mo, with an average of 10 years 10 mo. The figure eight plate was removed an average of 14 mo (2-37 mo) after implantation. The mean tibifemoral angle (TFA) correction for all patients was 11 ± 4.9° (0-25°), and the mean monthly correction was 0.93 ± 0.82°. In idiopathic group, the average correction time was 11 mo, and the average correction rate was 0.82/mo. In the pathological group, the mean correction time was 18 mo and the mean correction rate was 0.72°/mo. In the study of Gigante *et al*[36], 7 people were included, and the average correction time was 20 mo (7-30 mo). The average correction speed of the tibia was 0.49°/mo and that of the femur was 1.73°/mo.

Vaishya *et al*[37] included 24 participants, with an average corrected deformity rate of 0.91°/mo and an average correction time of 17 mo (10-28 mo). In Ballal *et al*'s study[38], 25 children were followed up for an average of 12.4 mo (6-32 mo) after plate removal. The mean age was 11.6 years (5.5-14.9 years). The mean time to correction was 16.1 mo (7-37.3 mo). The distal femur is corrected an average of 0.7° (0.3-1.5°)/mo, the proximal tibia is corrected an average of 0.5° (0.1-

1.0°)/mo, and if the femur and tibia are treated together, the average correction is 1.2° (0.1-2.2°)/mo.

Kulkarni *et al*[39] included a total of 24 patients in their study, with an average of 15.6 mo (7-29 mo) of 8-figure plate implantation. The tibiofemoral Angle in the genu valgus group was improved from 19.89° (10-40°) to 5.72° (2-10°). The average tibiofemoral Angle of patients with varus was improved from 28.27° before operation (range: 13°-41°) to 1.59° after operation (range: 0°-8°). The overall correction rate was 1.53°/mo (1.67°/mo for younger than 5 years and 1.39°/mo for older than 5 years).

Jamil *et al*[40] evaluated a total of 17 patients with a median age of 4.0 (3.0-6.0) years by using the MAD and TFA on the full-length X-rays of the lower limbs in standing position. Of the 22 knee joints successfully treated, the mean correction rate of the proximal tibia was 0.71° (0.39-1.55°)/mo, and the mean correction rate of the distal femur was 0.67° (0.61-1.38°)/mo. The median correction rate was 0.71°/mo. The median correction time was 20 mo.

MEASURED BY OTHER PARAMETERS

Zajonz *et al*[41] included a total of 105 children in their study, with a median age of 12.7 years at the time of treatment. The median time for removal of the figure eight plate was 13 mo. The mean interankle correction distance was 0 ± 2.1 cm, the mean anatomic femoro-tibial Angle was 9 ± 2.7°, and the mean mechanical lateral Angle of the distal femur was 7 ± 7.72. The medial Angle of the proximal tibia was altered by an average of 4 ± 6.02°, and the median time from implantation to removal of the implant was 13 mo. Guzman *et al*[42] used ananatomical lateral femur distal Angle (aLDFA) as an evaluation index and compared the single plate with the double plate. The change rate of femoral aLDFA in the single plate group and the double plate group was 0.81° (3.3°/year) and 1.06° (4.2°/year) every 3 mo on average, respectively. The mean follow-up was 12.7 mo, and statistical analysis showed a correction rate of 0.96° every 3 mo. Popkov's report[43] also used the aLDFA as an evaluation indicator, stating that the treatment time from surgery to complete correction of the deformity and removal of the plate was 18 mo, with a correction rate of 0.61°/mo for the right tibia and 0.67°/mo for the left tibia. Danino *et al*[44] used the mMPTA to evaluate the efficacy. A total of 45 patients were included, with an average age of 9.5 years (1.6-14.8 years) at the time of surgery. The mean receiver operating characteristic curve for all follow-up periods was 1°/mo and the mean correction time was 24.5 mo.

EPIPHYSIODESIS IN SAGITTAL PLANE

Al-Aubaidi *et al*[45] included children with cerebral palsy and myelomeningocele in their study, and the correction evaluation index used was fixed flexion contracture Angle. 12 of them were treated with 8-figure plates, with an average age of 9.6 (7.5-5) years. The average initial deformity was about 20°, and the orthosis time was 20 mo with an average correction rate of 0.5°/mo. Klatt *et al*[46] treated 18 patients (29 sides) with steel plates for knee flexion deformity, with an average preoperative fixed flexion deformity of 23.4° (10-50°). The mean fixed flexion deformity was 8° (0-30°) at the last follow-up. One patient (single knee) relapsed 18 mo after surgery. Stiel *et al*[47] included a total of 73 cases in the study, of which 68 cases were treated with portal nails and 5 cases were treated with 8-figure plates. After exclusion, a total of 49 cases were included. 83 knees) with an average age of 12 years (6-20 years). Patients were divided into three groups based on diagnosis: Cerebral palsy, meningomyelocele, and other groups. The average follow-up after implant removal was 46 mo (12-78 mo). The average fixed knee flexion deformity was 21° (10°-60°) before surgery and improved to 8° (0°-50°) after surgery. Fixed knee flexion deformity at implant removal was corrected by an average of 13. The average correction rate was 0.44°/mo, and the implant was removed after an average of 32 mo (6-72 mo). The monthly correction rate was the highest in the other groups (0.60°), followed by the meningocele group (0.52°). Patients with cerebral palsy had the lowest monthly correction rate (0.20°). Stiel *et al*[47] proposes that improvement in flexion deformities decreases with age, and for patients with significant growth potential, minor overcorrection of fixed knee flexion deformities (about 5°) should be considered when removing implants to avoid recurrent knee flexion deformities.

In the study of Zaghloul *et al*[48], both distal anterior femur hemi-epiphyseal plate fixation and hamstring muscle release were used to treat children with neuromuscular diseases to evaluate the clinical and functional outcomes of patients with fixed knee flexion malformation. A total of 19 children were included, with an average age of 12 ± 2.1 years. There were 15 males and 4 females. The main diagnosis was cerebral palsy (16 cases). The mean follow-up time was 3.8 years (1.5-7 years), and the mean fixed knee flexion deformity improved from 28.9° to 13.4°, with a mean correction rate of 0.94°/mo. The mean preoperative popliteal Angle was 81.8°, the mean early postoperative Angle was 44.4°, and the mean last follow-up was 51.8°. The average correction time was 18.9 mo.

EPIPHYSIODESIS IN SPECIAL DISEASES

Baghdadi *et al*[49] studied 6 cases of congenital insensitivity to pain (CIP). The median age was 10 years (5-12 years). The mean follow-up was 31 mo (16-56 mo). The average preoperative mLDFA was 74.6°. The mean mLDFA at the last follow-up was 81° (76-84°), and the mean correction rate of femoral malformation was 0.28°/mo. They also noted in the study that children with CIP have lower growth rates and should therefore be given guided growth procedures earlier than non-CIP children.

Sağlam *et al*[50] studied 11 children with skeletal dysplasia combined with genu valva, with an average age of 10.5 years. The mean duration of treatment with the figure eight plate was 35 mo (12-60 mo). Two uncorrected patients were excluded from the correction rate assessment. The correction rates of distal femur aLDFA and mLDFA were 0.384 ± 0.5°/mo and 0.395 ± 0.39°/mo, respectively. The MPTA correction rate of proximal tibia was 0.297 ± 0.38°/mo.

EPIPHYSIODESIS IN ANKLE

In addition to the use of eight plates to correct the deformity of the knee valgus, there is another effective way to correct the malformations of the ankle valgus, namely the medial malleolar trans-epiphyseal plate screw (MMS). Most studies have also shown that MMS is an effective and safe correction method.

Driscoll *et al*[51] used tibial distance Angle as an evaluation index in the treatment of ankle valgus, and included a total of 42 patients with an average postoperative follow-up time of 34 mo. In 35 patients with mMMS, the tibial distance Angle was corrected from 77.1° before surgery to 87.8° after surgery, and the correction rate was 0.55°/mo. The Angle of 25 patients in TBP group ranged from 81.3° before surgery to 87.6° after surgery, and the correction rate was 0.36°/mo. Bayhan *et al*[52] used medial malleolar screw hemi-epiphysiodesis in the treatment of malleolar valgus in children with spina bifida, and retrospectively analyzed the clinical data of 10 patients (18 ankles) with malleolar valgus. The effect of correction was evaluated by measuring the tibial distance Angle. The mean age of the patients was 10.05 years. The mean follow-up was 15.33 mo (11-21 mo). The mean tibial distal Angle was improved from 16.27° before operation to 2.88° after operation. No serious complications occurred after operation. After summarizing the data from the study, the authors suggest that hemi-epiphysial arrest is a safe and effective method to correct malformations of ankle varus in children with spina bifida. Chang *et al*[53] studied and analyzed the clinical data of ankle valgus patients treated with MMS hemi-epiphysial arrest, including 16 males and 21 females (63 ankles), with an average age of 11.0 years (5.4-14.8 years). All patients had a mean postoperative follow-up of 1.6 years (0.4-4.9 years). The average time from screw insertion to screw removal was 1.4 years (0.4-5.2 years). The average correction rate of tibial distance Angle was 0.37 ± 0.04°/mo. Ankle valgus recurred in 18 of 22 ankles after screw removal. The average recurrence rate of screw removal patients was 0.28 ± 0.08°/mo. The study of Macneille *et al*[54] included a total of 22 patients (34 ankle). There were 11 males and 11 females. The mean follow-up time was 7.2 years (2-13 years). The mean age was 10.3 years (6.3-12.9 years). This study used lateral distal tibia angle (LDTA) as an evaluation index, with a mean preoperative LDTA of 79.2° (65-86°). The mean LDTA at the last follow-up was 88.1° (74-105°). The mean variation in LDTA is 8.9° (0-19°). The average correction rate is 0.4°/mo (0-1.4°). All 20 ankle joints were corrected to neutral position. Less than 10 sides were corrected, and 4 sides were over-corrected. The average age of the 4 over-corrected patients was 9.8 years, and the ankle LDTA was about 100 degrees. Trans-epiphyseal plate screws were removed in 12 patients (19 ankle). Screw removal time ranged from 30 to 214 wk (mean 81 wk). In the study population of van Oosterbos *et al*[55], children with inherited multiple exostoses were treated with an 8-figure plate to correct ankle varus deformity. A total of 18 children were included, including 10 males and 8 females, and the average age of the first operation was 12.6 years old (9.5-15 years old). The average follow-up was 22 mo (3-40 mo) until the implant was removed or the epiphysis closed completely. The mean preoperative LDTA was 76.9° (68.5-83.5°). The mean LDTA at implant removal or epiphyseal closure was 83.6° (76.5-90°). The average LDTA correction is 6.9° (1-16.5°). In this study, none of the patients had overcorrection of the varus deformity. After data analysis, the authors concluded that the correction of valgus deformity was significantly related to age at the time of hemi-epiphysial arrest, with the greatest correction in younger patients.

In the treatment of malformation of the ankle, Stevens *et al*[56] pointed out that due to the difficulty of screw extraction, the eight plate was selected for treatment. A total of 33 patients (57 ankle) were included, with an average age of 10.4 years (6.08-14.58 years) at the time of implantation, and an average postoperative follow-up of 27.12 mo (12-57.5 mo). The mean preoperative LDTA was 78.7° (68-85°). The average LDTA at removal is 90° (76-103°). The mean LDTA at the last follow-up was 88.2° (71-104°) and the mean correction rate was 0.6°/mo (0.15-1.6°/mo).

OTHER TREATMENT OPTIONS

The case report of Ghaffari *et al*[57] suggested that 3.5mm non-hollow screws and reconstruction plates should be used instead of the eight plate. They believed that the effect of reconstruction plates was as ideal as that of eight plates, and it was more cost-effective, accessible and suitable for young people. The duration of correction was 8 mo. Narayana Kurup *et al*[58] used 2-hole reconstruction plates, and they believed that 2-hole reconstruction plates and 8-figure plates had similar correction effects at the same time, without additional complications, and with lower cost and easy to obtain. A total of 23 patients were implanted with 2-hole reconstruction plates. The mean age at the time of surgery was 11.25 years. The mean postoperative follow-up was 36 mo, the mean correction time was 18.64 mo, and the mean mLDFA correction rate was 0.61/mo. Bakircioglu *et al*[59] used an 8-figure plate. However, the difference between the application of the 8-figure plate and the conventional 8-figure plate was that they compared the recurrence rate and fastening effect of the metaphysis screw extraction alone (sleeper plate technique) and the conventional full plate extraction. A total of 72 patients (107 Limbs) were enrolled, of whom only metaphyseal screws were removed in 25 patients (35 Limbs) and both screws and plates were removed in 47 patients (72 Limbs). The mean age of patients at the time of initial surgery was 97 mo (80-129 mo). After an average of 49 mo (16-86 mo), stable correction was expected in 17 Limbs (48.5%) of the screw removal group and 59 Limbs (72.2%) of the total removal group. The recurrence rate of screw removal group and total removal group was 34.3% and 27.8%, respectively, and the difference was not statistically significant. Metaphyseal screws were re-placed in 8 of the 12 Limbs, and the remaining 4 Limbs required further surgery. In the screw extraction group, 6 Limbs (17.3%) were tethered, 4 of which required further corrective surgery. The remaining two limbs are slightly tethered and require no further surgery. By comparing the above data, the authors concluded that the removal of metaphyseal screws alone would increase the risk of teaming. If only metaphyseal screws are removed, close follow-up is required. But Retzky[60] indicated that Sleeper plates technique should be avoided to use in patients with proximal tibia MHE, surgeons should be extreme caution when considering this technique.

REBOUND PHENOMENON

The correction effect of epiphysiodesis varies with age, disease nature, and nutritional status. When the temporary arrest is terminated, recurrence of the deformity is relatively common[61,62], which is called rebound phenomenon. Some studies[7,63-69] have advocated the use of mild overcorrection to compensate for the rebound that occurs after termination of treatment. It is recommended to follow up once every 3 mo after surgery and once a year after 1 year. If rebound is found, follow-up is continued for 3 mo until further surgery is required. For example, for patients with valgus malformations, some scholars[70,71] advocate excessive correction of 5° to 10° (mild varus) for children with risk factors (dysplasia, obesity, *etc*.) to prevent possible recurrence of malformations. Park *et al*[72] analyzed 37 Limbs of 34 children and measured mLDFA or MPTA to assess correction. Multiple logistic regression analysis showed that orthotic rate body mass index (BMI), age and initial valgus angle were significantly correlated with rebound. With respect to the magnitude of rebound Angle, the annual correction rate of 8.5° and BMI of 21 kg/m² were significant thresholds, and the authors divided them into three groups: Group A was children with a correction rate ≥ 8.5°/year; Group B was children with correction rate < 8.5°/year and BMI < 21 kg/m². Group C consisted of children with a correction rate < 8.5°/year and BMI ≥ 21 kg/m². A total of 14 Limbs were included in group A, and 11 Limbs showed rebound. In group B, 7 Limbs and 3 Limbs showed rebound. Group C has 16 Limbs, no rebound. The highest incidence of rebound occurred in children with rapid orthosis (79%), while the incidence of rebound was lower in children with slow orthosis at low BMI (43%), and no rebound occurred at BMI ≥ 21 kg/m². Choi *et al*[73] retrospectively analyzed 50 children with tension band plate hemi-epiphyseal plate fixation due to coronal angulation deformity of lower limbs, with an average age of 11.0 ± 2.5 years, and a total of 94 epiphyseal plates were included. mLDFA and mMPTA were measured to evaluate the effect of correction. The mean correction rate was 8.1 ± 4.7°/year for valgus deformity 66 and varus deformity 2. The rebound group was defined as the mLDFA or mMPTA returning more than 5° to the original deformity. The rebound group had 41 epiphyses and the non-rebound group 53 epiphyses. The correction rate is significantly associated with rebound phenomenon, and the risk of rebound phenomenon increases by 1.2 times when the correction rate increases by 1° per year. The critical correction rate between the two groups was 6.9°/year ($P < 0.001$). Compared with the non-rebound group (mean age 11.7 years, mean correction rate 6.5 ± 4.4°/year), the rebound group children were younger (mean 10.2 ± 2.5 years) and the correction rate was faster (10.2 ± 4.3°/year). The authors note that children with a faster rate of correction (> 7°/year) should be closely monitored after implant removal. Ko *et al*[74] reviewed 68 patients with idiopathic knee valgus treated with tension band plates (plate group) or trans-epiphyseal plate screws (screw group) and followed up until bone maturity. A total of 68 Limbs were treated in 68 patients. The mean hip - knee - ankle force line was -5.4° ± 1.8° (valgus) at temporary hemi-epiphysis fixation, 2.6° ± 2.1° at extraction and internal fixation, and 0.7° ± 2.6° at last follow-up. The rebound amplitude of the plate group (4.1° ± 1.9°) was greater than that of the screw group (1.1° ± 3.1°). By regression analysis, the authors suggest that the rebound phenomenon is positively associated with plate use and faster correction, but not with more severe deformity or greater Angle of correction before surgery.

CONCLUSION

Epiphysiodesis is an effective treatment for limb deformity in children with unclosed epiphyseal. Different techniques of epiphysiodesis and different age of correction bring different rate of deformity correction. While there is still debate about when to remove the implant after correction, children with risk factors can be overcorrected by 5 to 10, given the potential for rebound, and should be closely followed for optimal deformity correction.

FOOTNOTES

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MINIREVIEWS

Mechanisms of shoulder trauma: Current concepts

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Abstract

Acute traumatic injuries to the glenohumeral articulation are common. The types of injuries depend on age, muscle strength, bone density, and biomechanics of the traumatic event. Understanding the different mechanisms of trauma and how they affect the functional anatomical structures of the shoulder joint is crucial for the treatment of these lesions. Therefore, when clinicians have knowledge of these mechanisms they can accurately diagnose and treat shoulder pathology and predict distinct injury patterns. Here, we have described the fundamentals of the mechanisms of injury of the glenohumeral dislocation, dislocation with fracture of the humeral head, and the proximal humerus fracture. We have focused on common injury mechanisms and the correlation with radiological diagnostics. Radiological and laboratory findings of distinct types of injury were also discussed.

Key Words: Mechanism; Hill-Sachs; Shoulder dislocation; Proximal humerus fracture; Shoulder biomechanics

Core Tip: The biomechanics of shoulder trauma have not been fully investigated. In this review, we discuss the factors in addition to age, muscle strength, and bone density that play an important role in the development of different types of injury. Knowledge of specific injuries based on the mechanism of the injury will enable the clinician to diagnose and treat the injury even if radiological imaging must be delayed or if detailed radiological imaging is unavailable. In addition, knowledge of shoulder trauma mechanisms will enable clinicians to reduce the possibility of falsely omitting negative imaging findings.

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INTRODUCTION

Shoulder trauma can be caused directly or indirectly. A person can injure their shoulder directly by falling on their arm. Indirect mechanisms include falling on an outstretched hand with the upper extremity mounted at a different angle to the torso or when the arm is at a fixed point and the trunk is turned sharply. Shoulder injuries can produce different types of lesions including a simple dislocation (anterior, posterior, or inferior), a proximal humerus fracture, or a fracture dislocation. Fractures of the proximal humerus are classified as two-part, three-part, or four-part fractures according to Neer[1]. His classification system was based on an observation that all proximal humerus fractures were composed of four major segments: Lesser tuberosity; greater tuberosity; articular surface; and humeral shaft[2]. Neer[1] added categories for articular surface fractures and dislocations as he correctly observed these to be important prognostic factors. He enumerated the most common injury patterns and described how characteristic patterns of displacement occur with each fracture type. In addition, he explained how these fracture types result from the attached bone segments and the deforming forces generated by the rotator cuff.

Proximal humerus fractures are among the most frequent fractures in the elderly population[3]. Dislocations have a bimodal distribution as they most often occur in young male patients and females over 50 years of age[4]. Despite the frequency of shoulder trauma, little is understood about the pathobiomechanics. The purpose of this study was to investigate the literature on the mechanisms of shoulder injuries and to ascertain correlations between different types of lesions.

HISTORY

In 1938, Bankart[5] underlined the significance of the detachment of the capsule with or without the glenoid labrum from the anterior margin of the glenoid fossa. His theory of the mechanism of shoulder trauma became widely accepted. He considered that the detachment of the anterior capsule was responsible for the installation of the anterior instability of the shoulder. This explanation was founded upon surgical findings from 27 patients with recurrent shoulder dislocation. He also refuted the existing theories and proposed a refixation operation of the anterior capsule. In the novel approach used by Bankart[5], an osteotomy of the coracoid process is performed, and a cross-section of the subscapularis near its insertion is created for a wider view of the anterior glenohumeral ligaments. His technique has since been widely discussed and is still used today with some modifications. For example, anchors with strong non-absorbable sutures instead of catgut sutures and arthroscopy without incision on the subscapularis muscle and detaching the coracoid process are used. When there is a detachment of the labrum or a bone deficit in the anterior lower part of the glenoid fossa, they are referred to as a Bankart lesion and a bony Bankart lesion, respectively.

Shortly afterwards, radiologists Hill *et al*[6] examined compressive fractures in the posterolateral aspect of the humeral head, which is found after shoulder dislocations and is the typical defect. According to previous data, the force is transferred from the longitudinal axis to the humeral head when the hand is in abduction and turned outward. The humeral head is extruded out of the joint as it opposes the anterior edge of the glenoid fossa. Depending on the force applied, a greater tuberosity fracture of the neck of the humerus can be caused or the soft cancellous bone at the postero-lateral aspect of the humeral head can be compressed into the scapula, creating the typical defect. The study of Hill *et al*[6] revealed that this compression fracture in cases of habitual dislocation were found so frequently that they were described as the typical defect (Figure 1). They postulated that many of these defects are sustained at the time of the first dislocation, and they may be an etiologic factor of recurrence. The defect can be best visualized by anteroposterior radiograph with the arm adducted and internally rotated (Figure 2). A special sign of the Hill-Sachs lesion is sharp, vertical, and dense medial border of the groove known as the “line of condensation,” which is the length that correlates with the size of the defect.

In 1948, Palmer *et al*[7] presented their results obtained with 90 patients treated with a bone block procedure, also known as the Hybbinette-Eden procedure. The augmentation of the anterior glenoid with a graft from the iliac crest was placed in a periosteal pocket at the anterior glenoid rim. They postulated that the compression fracture of the postero-lateral aspect of the humerus was responsible for the development of recurrence, which was characterized as the essential lesion.

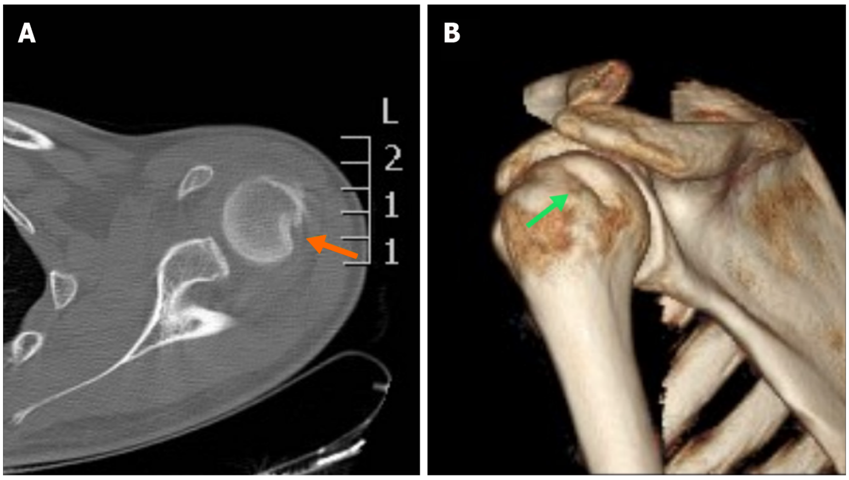

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Figure 1 A 20-year-old patient after a forced abduction and hyperextension injury of his left shoulder with no support of his hand. A: The computed tomography scan revealed an impaction fracture on the posterolateral part of the humeral head (orange arrow); B: A three-dimensional image in which the entire Hill-Sachs lesion was impressively displayed (green arrow).

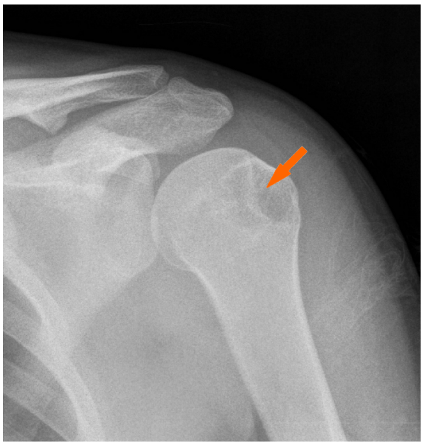

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Figure 2 Left shoulder of a patient in internal rotation immediately after reduction of an anterior dislocation. A large Hill-Sachs defect and a line of condensation was very obvious on this radiograph (orange arrow).

There are two theories that have become widely accepted to explain the development of instability. The first is detachment of the anterior capsule and the second is compression fracture in the posterolateral aspect of the humeral head. Other authors have attempted to investigate the role of different anatomical structures such as the anterior-medial glenohumeral ligament and the subscapularis muscle[8-10].

INCIDENCE OF SHOULDER TRAUMA

Most shoulder dislocations occur in males. The greatest incidence is observed in young and active patients, with the peak involving patients aged 16-20 years. In females, the prevalence increases after age 50, with the peak involving patients aged 61-70 years[4,11]. The risk of recurrence is lower if the primary reduction was performed by an orthopedic surgeon or was associated with a greater tuberosity fracture[12]. Older age and higher medical comorbidity score are also protective of recurrence.

About 95% of shoulder dislocations are anterior. The variants of the humeral head location after displacement are subglenoid, anterior or axillary, and subcoracoid[6]. Posterior glenohumeral dislocations represent approximately 2%-5% of all traumatic shoulder dislocations. A precise determination of the incidence remains difficult because of the frequency of undetected posterior dislocations[13].

Proximal humerus fractures account for almost 6% of all fractures in the Western world[3]. Following the fractures of the distal radius and spine fractures, it is the third most common osteoporotic fracture[14]. About 85% of these fractures occur in people over the age of 50, with the highest incidence occurring between the ages of 60 and 90 and with a female-to-male ratio of 70:30[3]. The most common fracture pattern according to the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification system is B1.1. This classification is valgus impacted and is found in 20% of cases[15]. AO types B1.1, A2.2, A3.2, and A1.2 represent over 50% of all proximal humeral fractures, while AO type C fractures occur in only 6% of cases[15].

MECHANISM OF SHOULDER DISLOCATION

Dislocations of the glenohumeral articulation and dislocations with a greater tuberosity fracture can be studied together due to similarity of the mechanism of the injuries. Gotzen *et al*[16] provided an alternative description for dislocations with great tuberosity fractures in their classification. In the most recent classification, Mutch *et al*[17] studied the morphology of these fractures and observed three fracture patterns, namely avulsion, split, and depression. These patterns may have practical implications in pathophysiology.

Symeonides[10] studied the etiology of shoulder instability and reproduced dislocations in fresh cadavers. He found that with the arm abducted, externally rotated, and extended, the posterior border of the greater tuberosity meets the posterior margin of the glenoid fossa. In this position the subscapularis muscle was in maximal tension. To permit dislocation, the subscapularis muscle had to be stretched or even partially ruptured; at the same time, the posterior border of the greater tuberosity was scratched while it was overriding the posterior margin of the glenoid. These data provided an explanation for the development of fracture dislocation of the shoulder, which is most referred to as a dislocation with greater tuberosity fracture.

When the head of the arm, which is located inside a very narrow pocket, meets the posterior margin of the glenoid fossa, creating an impression fracture on the posterolateral part of the humeral head, it was previously described as a Hill-Sachs lesion[6]. In other cases, a greater tuberosity fracture is created. In cases where the force continues without causing a fracture, the head collides with the anterior elements of the joints, which sometimes causes damage to the humerus, anterior glenoid labrum, cartilage, and subscapularis muscle. However, there is disagreement as to the part of the glenoid fossa where the collision with the humeral head takes place, with some authors suggesting the anterior margin[18,19] and others the posterior[10,20].

Bahrs *et al*[20] suggested that the common Hill-Sachs lesionwhich occurs in anterior shoulder dislocations and is defined as an impaction fracture at the posterolateral aspect of the proximal humeruspresents itself in its completed form as a greater tuberosity fracture. They divided their study population which consisted of patients with isolated great tuberosity fractures or dislocations with fractures into two mechanisms of injury: (1) Direct injury, sustained as a direct force or blow to the shoulder with the arm in adduction or a direct fall on the lateral aspect of the shoulder; and (2) Indirect injury, sustained as a fall on the extended arm or flexed elbow or abduction (external rotation trauma). They studied anteroposterior and axillary view radiographs before and after reduction, and they correlated the findings with the above mechanisms. Even though this study included a large number of patients, it referred to only two mechanisms of injury that led to either anterior dislocation or dislocation with greater tuberosity fracture. In addition, patients were evaluated with plain radiographs, which provide less diagnostic value than cross-sectional modalities such as computed tomography (CT) and magnetic resonance imaging (MRI). Nevertheless, the significance of this study lies in its strengthening of the theory of the mechanism of dislocation and fractures, as other authors before had suggested[6,10,21]. The important conclusion from this study was that dislocations with a greater tuberosity fracture almost never create instability as other authors had suggested[11,22]. This likely arises because the force of the impact transmitted from the humerus to the head is completely relieved in the greater tuberosity and is not enough to injure the anterior elements of the joint.

When there is a greater tuberosity fracture, the possibility of recurrence is low[11,22]. McLaughlin *et al*[22] postulated that recurrent and non-recurrent shoulder dislocations have little in common. They retrospectively reviewed two clinical samples to find a specific mechanism that led to instability. They observed that non-recurrent shoulder dislocations typically showed posterior joint support damage and that recurrent shoulder dislocations typically showed anterior joint support damage. It is worth noting that 5 of the patients required open reduction (all great tuberosity fractures), while 4 of the patients had dislocation of the long tendon of the biceps, which was interposed between the humerus and glenoid.

Age also plays an important role in the mechanism of shoulder injury[22-25]. In elderly patients, the posterior mechanism is predominant. The posterior elements, which consist of the rotator cuff muscles, are more prone to injury because of the weakening and degeneration associated with aging. As a result, young patients usually present with Bankart lesions, which are anterior inferior labral tears and are prone to dislocation. The rotator cuff plays a secondary role in the stability of the glenohumeral articulation. Therefore, only massive tears will increase the risk of recurrence[23] and specifically subscapularis tears[24]. In conclusion, younger patients show more shoulder instability than older patients[25].

IMAGING AFTER GLENOHUMERAL DISLOCATION

Plain anteroposterior radiographs before and after a dislocation are common practice. In most cases, anteroposterior radiographs are the only imaging conducted in an emergency. Axillary and/or transcapular projections are often performed when the direction of force producing the trauma is unknown, and there is a strong suspicion of posterior dislocation. Posterior dislocations can be missed up to 50% of the time on anteroposterior radiographs[26,27]. In the absence of other views there are several indications for diagnosis of posterior dislocation on the frontal view (Figure 3). The rim sign, which is a widening of the articular distance more than 6 mm, and the trough sign will appear on the

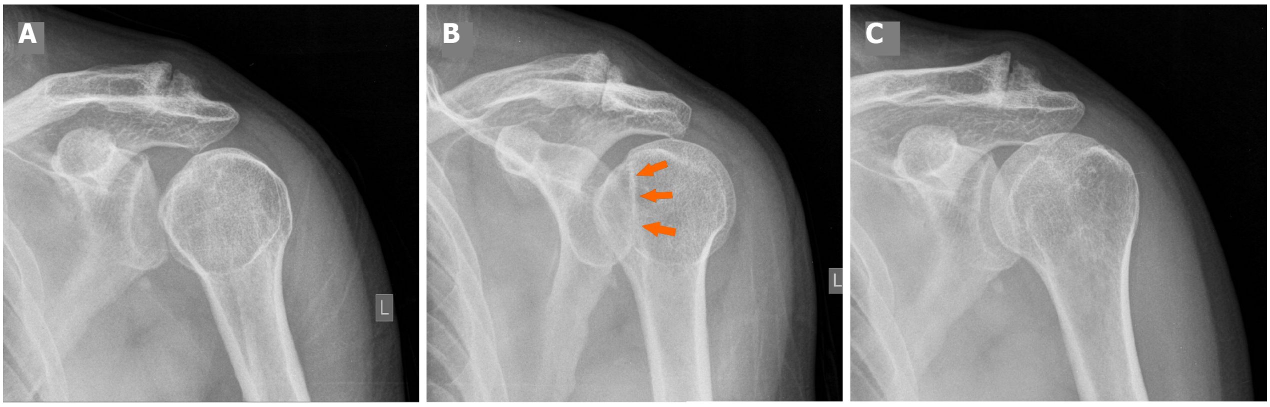

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Figure 3 Posterior shoulder dislocation. A: In the frontal view the distance of the medial cortical margin of the humeral head and the anterior glenoid rim was more than 6 mm, constituting a positive rim sign; B: A slightly oblique view with appreciable through sign (orange arrows). The humeral head was in internal rotation and hooked on the posterior rim of the glenoid fossa; C: The post reduction anteroposterior radiograph showed normal alignment and congruity of the glenohumeral articulation.

axillary view as a sclerotic line at the site of the impaction fracture on the anterior humeral head[26].

CT imaging is indicated in cases where the direction of force cannot be distinguished. In addition, it provides information regarding dislocation with a greater tuberosity fracture as well as bony-Bankart lesion (Figures 4 and 5). CT imaging is the most targeted examination for measuring the glenoid destruction with the best-fit circle technique used in the sagittal plane[28,29]. It is important to accurately diagnose glenoid bone loss as a defect of more than 20% of total glenoid surface or more than 7mm width, is very likely to lead to instability[18,26].

Imaging tests such as MRI are rarely considered necessary in patients with shoulder dislocation. MRI is often ordered after the early post-traumatic period, when soft tissue injury is suspected or joint instability develops. MRI is the most sensitive modality for diagnosis of soft tissue injuries such as rotator cuff ruptures, labral ruptures, and damage of the cartilage (Figure 6).

In a study by Atef *et al*[30], early findings after shoulder dislocation were investigated in 240 patients using MRI and ultrasonography (US) until the 1st wk after injury. The incidence of complications was significantly higher than in previous reports[31,32]. In that study, rotator cuff tears were found in a total of 27.9% of the population and were the most common injury. Greater tuberosity fractures were found in 15.4% of patients, and axillary nerve injuries were found in 15.3% of patients. Hill-Sachs and Bankart lesions were also observed[30]. The predominant age group with rotator cuff tears was females over age 45, which was similar to previous reports[33,34]. US is also an acceptable imaging modality when a rotator cuff tear is suspected. US has the advantages of speed and the ability to compare both shoulders at one time. However, the accuracy of US evaluation of the rotator cuff depends on the experience of the ultrasonographer[35]. Invasive modalities such as MRI and CT arthrography (Figure 7) are the best modalities to detect sports-related injuries like Bankart lesions, superior labral anterior posterior lesions, Perthes lesions, anterior labral periosteal sleeve avulsion lesions, and glenolabral articular disruption cartilage ruptures[36,37].

MECHANISM OF PROXIMAL HUMERUS FRACTURES

Little is understood about the pathobiomechanics that lead to proximal humerus fractures. Several theories include fractures transmitted through epiphyseal lines of the proximal humerus, deforming forces of the rotator cuff muscles on fracture fragments, and the arm position in relation to the torso at the time of impact[1,2,38]. Neer[1] refuted the existing theories of classification in proximal humerus fractures and emphasized the role of different arm rotations during injury. In addition, taking into account the size of the joint pocket that can fit up to two humeral heads when the tuberosities are detached, underlined that the articular surface of the humerus can easily be subluxated or rotated out of the glenoid fossa. To identify the role of muscle attachment on displaced fragments as well as the circulatory status and continuity of the articular surface, he adopted a classification system based on the four fracture segments (as described above)[2].

Most authors identify two mechanisms for the development of proximal humerus fractures, which can be divided into direct and indirect mechanisms. Direct fractures include a fall on the shoulder. This is represented by a direct impact of the head of the humerus on the scapula without the arm being loaded axially and is usually a high-energy injury[39,40]. Indirect fractures are usually caused by a fall onto an outstretched hand with the fracture point not directly impacted. The position of the hand can be different; sometimes it is in abduction and external rotation and sometimes in flexion and abduction. The indirect mechanism is also more frequent because the arm is subject to a large but relatively lower energy load compared to the direct mechanism[41-44]. Rare mechanisms that can cause a fracture include excessive muscle contraction by muscle groups around the shoulder, which can occur during seizures and electric shock[45].

In the indirect mechanism, the fracture is caused by an attempt to avoid an uncontrollable fall forward or sideways. Typically, a fall on an outstretched hand causes relative displacement or rotation of the trunk around the point of

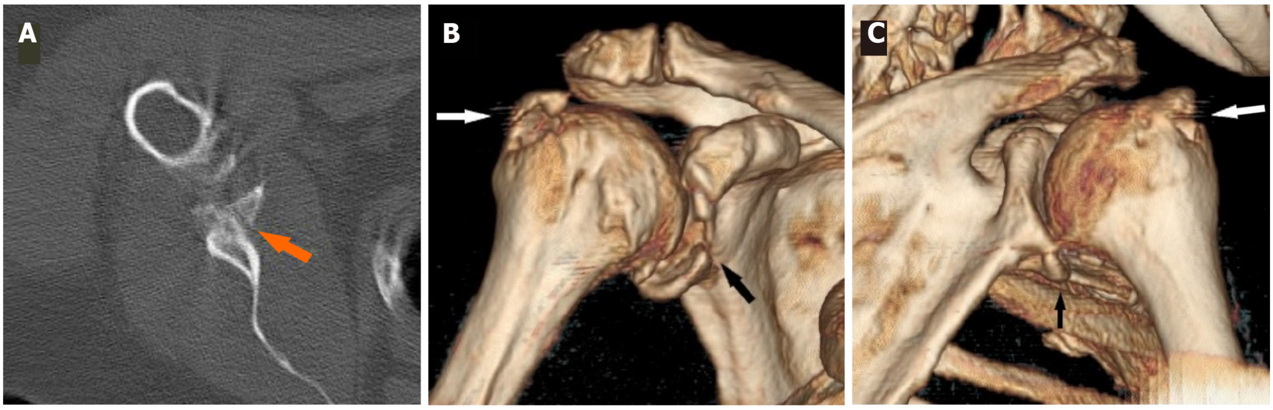

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Figure 4 A 58-year-old female after a forward fall with the arm in flexion resulted in anterior dislocation with a bony Bankart lesion and greater tuberosity fracture. A: The sagittal image illustrated a bony Bankart lesion (orange arrow); B: An anterior three-dimensional image on the same patient showed a large Bankart lesion (black arrow) and greater tuberosity fracture (white arrow); C: The absence of a Hill-Sachs lesion was evident on the posterior three-dimensional view.

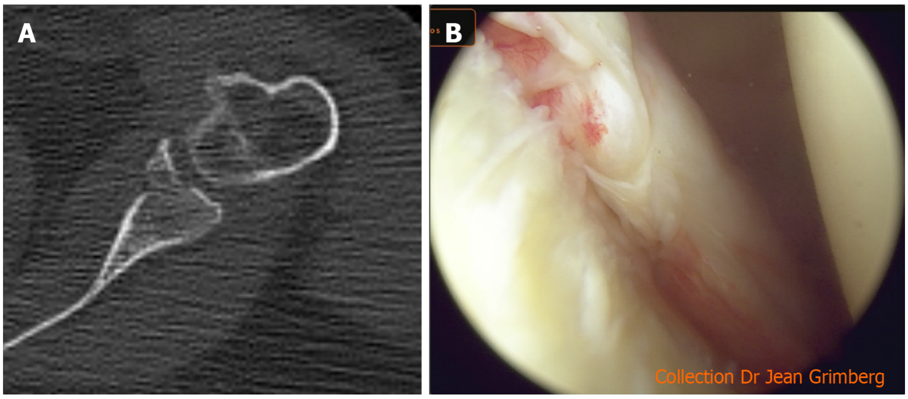
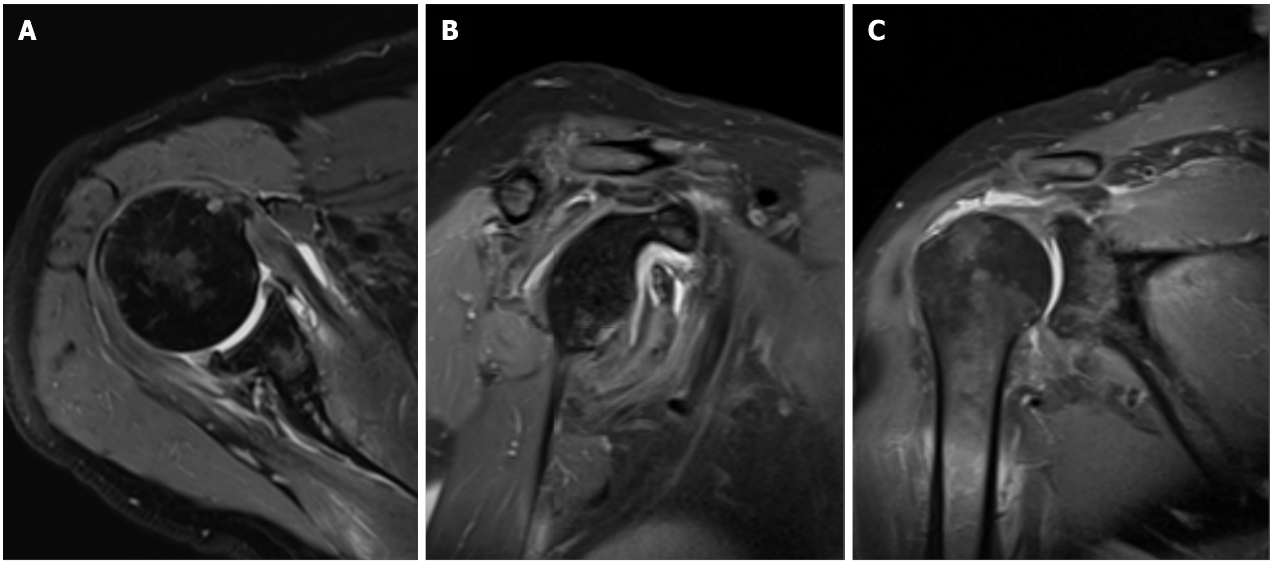


Figure 5 Bony Bankart lesion imaging. A: Computed tomography scan of a bony Bankart lesion on the sagittal view; B: Image during arthroscopy of a Bankart lesion.

rotation, producing an abduction or adduction motion to the proximal humerus[46-48]. Some authors have observed that anatomical neck fractures are associated with posterior dislocations, but the mechanism has not been fully established. Anterior dislocations can be associated with a greater tuberosity fracture or Hill-Sachs lesion.

Several studies investigating this type of injury have found that both greater tuberosity fractures and Hill-Sachs lesions may be the result of the same mechanism[10,20,41,47]. With the arm abducted, externally rotated, and extended, the posterior border of the greater tuberosity comes into contact with the posterior margin of the glenoid fossa. As a result, an impaction fracture in the posterolateral part of the humerus or a greater tuberosity fracture can occur[10,20]. Hyperabduction, with impaction of the humeral head to the acromion, can produce a valgus impacted two-part proximal humeral fracture or an inferior dislocation depending on the strength of the underlying ligaments[49]. Other mechanisms that can produce two-part proximal humeral fractures and humeral head split fractures with impaction of the humeral head onto the glenoid fossa have not been fully investigated[50,51].

There is no evidence of the biomechanics of proximal humerus fractures due to the lack of interest and absence of *in vivo* biomechanical data[52]. A study by Majed *et al*[53] investigated the mechanism of proximal humerus fractures by creating a biomechanical model to examine the effect of arm position at the point of impact. The mechanisms investigated were a direct impact onto the adducted shoulder in the neutral rotation (side impact simulation) and a fall onto an outstretched hand (parachute reflex)[38], which produced district fracture patterns. Both mechanisms were reproduced by a simulator. The side impact mechanism resulted in a simple head split, which also occupied the greater tuberosity and was accompanied by valgus impaction and relative valgus displacement of an intact articular head onto the shaft. The parachute reflex with the shoulder position in 70° abduction, 20° angulation in the sagittal plane, and 30° internal rotation[40] recreated the three main fracture types, namely an undisplaced greater tuberosity fracture, a shield-type fracture, and a head split. They also found that in shield type fractures the detached greater tuberosity segment extends to the sulcus of the biceps, thus creating a butterfly fragment. This is like the three-part fracture where the extension of the greater tuberosity is the point where the nutrient arteries enter the bone and provide perfusion to the arcuate vessels. This is an important inhibitory factor for the development of aseptic necrosis[1,2,38]. Despite the importance of this study, the authors did not account for the soft tissue attaching the head of the humerus that could affect fracture pattern.



DOI: 10.5312/wjo.v15.i1.11 **Copyright** ©The Author(s) 2024.

Figure 6 Magnetic resonance imaging of a 75-year-old male after a fall with forced abduction-hyperextension of the arm with support in the hand that resulted in anterior dislocation. A: Anterior labral tears are best detected on the sagittal view; B: Bone edema on the anteroposterior margin of the glenoid; C: Magnetic resonance imaging is the modality of choice in cases of suspected rotator cuff tears.

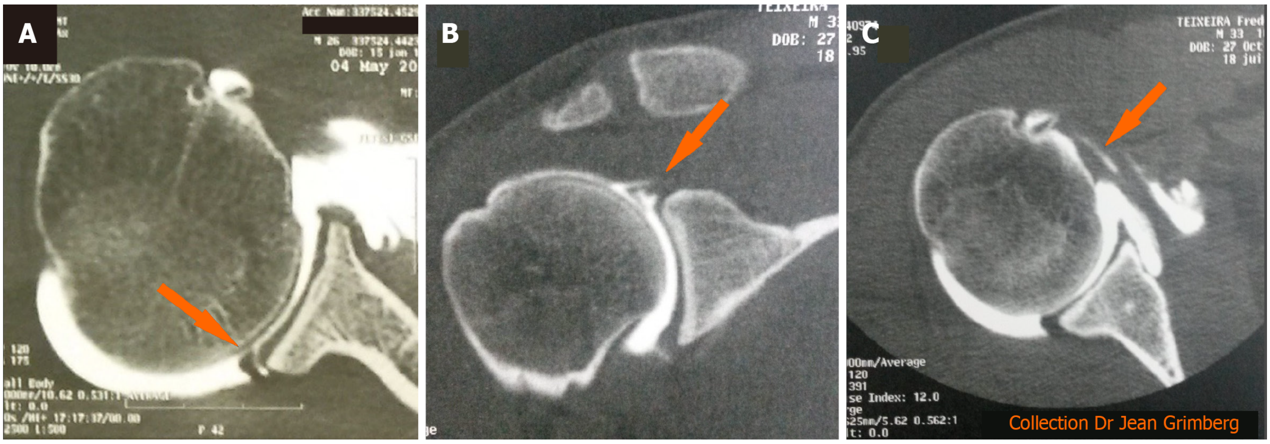


Figure 7 Computed tomography arthrography is useful in cases of false-negative magnetic resonance imaging results. A: Posterior labral tear on the sagittal view; B: Superior labral anterior posterior lesions are best detected on the coronal view; C: Computed tomography arthrogram is the modality of choice in cases of undetected subscapular tears. The sagittal view showed widening of the bicipital canal, which is an indirect sign of subscapularis rupture and delamination with penetration of contrast fluid into the tendon (orange arrow).

Furthermore, the mechanisms of the development of proximal humerus fractures, individual greater tuberosity fractures, and fracture dislocations could be more complex than the two mentioned above.

IMAGING AFTER PROXIMAL HUMERUS FRACTURES

Proximal humerus fracture imaging is carried out with the simplest tests due to the prevailing theory of independent fragments that are displaced by the rotator cuff muscles[1]. The anteroposterior view combined with the axillary view has been shown to be superior in terms of classification accuracy[20]. Existing classifications in use, like the Neer and the AO/Orthopedic Trauma Association classifications, have poor intraobserver and interobserver reliability despite the modality of imaging used[54]. Furthermore, CT and two-dimensional and three-dimensional CT are widely used by surgeons for the assessment of complex fracture patterns even though they do not offer improved interobserver and intraobserver agreement, as other authors have suggested[55,56]. Thus, even shoulder specialists fail to reconcile the classification and the appropriate imaging method for the best assessment of the fracture. In addition, the Neer classification of the four segments is not a radiographic classification. It is based on pathoanatomical classification by exacting roentgen studies, interpretation of the films, and occasionally intraoperative findings[57].

Other factors like the rotation of the segments, the impaction of the humeral head, and the separation of the articular surface seem to be more important and can be best evaluated by CT. The update of the Neer[57] classification in 2002 included a supplementary type for valgus-impacted four-part fracture underlined by valgus rotation of the humeral head among separated segments of the tuberosities. In these cases, the glenohumeral articular surface is preserved rather than dislocated, as seen with the classic four-part proximal humerus fracture. An intact medial calcar, where the nutrient arteries enter the bone and provide perfusion to the arcuate vessels, carries a lower risk of post-traumatic avascular necrosis and may be treated without surgery[29,58]. Consequently, this illustrative detail, that may change management and outcome, should be distinct.

MECHANISM OF SHOULDER TRAUMA IN SPORTS

Shoulder injuries are quite common in athletes, especially in high-energy contact sports such as rugby and hockey. Many studies have investigated the mechanisms of the repetitive movements of athletes in different sports that lead to aggravation of different anatomical structures, particularly the soft tissue around the shoulder joint. Other studies have investigated the diagnosis and treatment of these lesions. Two studies elucidated and described patterns of shoulder injury mechanisms in elite rugby players. The aims were to correlate injury-producing mechanisms with specific patterns of injury. Longo *et al*[59] used a video tape to analyze the mechanism of injury in four rugby players who sustained a shoulder dislocation. The authors observed abduction and external rotation as the accepted mechanism of anterior dislocation and suggested that rugby players are at risk of anterior dislocation by hyperflexion with internal rotation.

Crichton *et al*[60] identified three mechanisms of shoulder injury from a video analysis of 24 rugby players. They included the “Try-Scorer” (characterized by hyperflexion and axial load of the outstretched arm equally when an athlete falls to score), the “Tackler” (defined as forced abduction and extension of a non-fixed to the ground hand while tackling), and the “Direct Impact” (a direct fall on the shoulder with the arm adducted and representing direct impact of the head of the humerus on the scapula without axial load to the arm). The “Try-Scorer” and “Tackler” mechanisms predominantly resulted in shoulder dislocations with Bankart, reverse Bankart, and superior labrum anterior posterior tears. In addition, the “Try-Scorer” mechanism caused the majority (83%) of rotator cuff tears. The “Direct Impact” mechanism resulted in glenohumeral dislocation and labral injury in 37.5% of players and was the only mechanism that resulted in acromioclavicular joint dislocation and scapula fractures[60]. Limitations of the above investigation were the relatively small sample and the study population of athletes with a strong muscular system and increased bone density who are injured with significantly greater energy than the general population.

CONCLUSION

The mechanism of shoulder injury has been studied primarily in distinct injuries. Thus, possible mechanisms have been studied that lead to anterior dislocation of the shoulder and dislocation with concomitant greater tuberosity fractures. However, only two mechanisms of the proximal humerus dislocations have been succinctly reported.

The biomechanics of shoulder trauma have not been fully investigated, and it seems that other factors such as age, muscle strength, and bone density play an important role in the development of different lesions. Radiological and laboratory findings of distinct types, have been studied individually and fall under common mechanisms. To our knowledge, there are no recent studies linking the mechanism of shoulder dislocation and/or proximal humerus fracture injury to post-traumatic radiological findings. Knowledge of specific injuries based on the mechanism of the injury will enable the clinician to be suspicious when there is no capability for immediate radiological imaging, or when district patterns are not evident in a simple radiological examination. In addition they will help in the treatment plan that will be followed reducing the possibility of falsely omitting negative imaging findings.

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ORIGINAL ARTICLE

Retrospective Cohort Study

Complication rates after direct anterior *vs* posterior approach for hip hemiarthroplasty in elderly individuals with femoral neck fractures

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Abstract

BACKGROUND

Dislocation rates after hemiarthroplasty reportedly vary from 1% to 17%. This serious complication is associated with increased morbidity and mortality rates. Approaches to this surgery are still debated, with no consensus regarding the superiority of any single approach.

AIM

To compare early postoperative complications after implementing the direct anterior and posterior approaches (PL) for hip hemiarthroplasty after femoral neck fractures.

METHODS

This is a comparative, retrospective, single-center cohort study conducted at a university hospital. Between March 2008 and December 2018, 273 patients (a total of 280 hips) underwent bipolar hemiarthroplasties (n = 280) for displaced femoral neck fractures using either the PL (n = 171) or the minimally invasive direct anterior approach (DAA) (n = 109). The choice of approach was related to the surgeons' practices; the implant types were similar and unrelated to the approach. Dislocation rates and other complications were reviewed after a minimum follow-up of 6 mo.

RESULTS

Both treatment groups had similarly aged patients (mean age: 82 years), sex ratios, patient body mass indexes, and patient comorbidities. Surgical data (surgery delay time, operative time, and blood loss volume) did not differ significantly between the groups. The 30 d mortality rate was higher in the PL group (9.9%) than in the DAA group (3.7%), but the difference was not statistically significant (P = 0.052). Among the one-month survivors, a significantly higher rate of dislocation was observed in the PL group (14/154; 9.1%) than in the DAA group (0/105; 0%) (P = 0.002). Of the 14 patients with dislocation, 8 underwent revision surgery for recurrent instability (posterior group), and one of them had 2 additional procedures due to a deep infection. The rate of other complications (*e.g.*, perioperative and early postoperative periprosthetic fractures and infection-related complications) did not differ significantly between the groups.

CONCLUSION

These findings suggest that the DAA to bipolar hemiarthroplasty for patients with femoral neck fractures is associated with a lower dislocation rate (< 1%) than the PL.

Key Words: Hemiarthroplasty; Femoral neck fracture; Direct anterior approach; Posterior approach; Dislocation; Mortality

Core Tip: In this study, the posterior approach (PL) to bipolar hemiarthroplasty for femoral neck fractures was associated with a significantly higher complication rate (22.7%) than the direct anterior approach (DAA); 7.6% (P = 0.0013). This difference in complication rates probably reflects the significant difference in postoperative dislocation rates, as no dislocations were encountered in the DAA group compared to a dislocation rate of 9.1% in the PL group (P value = 0.0015).

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INTRODUCTION

Hip arthroplasty is often preferable to open reduction and internal fixation when treating displaced femoral neck fractures in geriatric patients because of its lower complication and reoperation rates[1]. Bipolar hemiarthroplasty (BHA) is associated with shorter operative times, less blood loss, decreased postoperative dislocation rates, lower costs, and fewer acetabular cup implantation complications than total hip arthroplasty (THA)[1-3]. Therefore, it is often the treatment of choice for frail older patients presenting with low physical demands[4].

Dislocation, one of the most common implant-related complications after BHA, is serious and associated with increased morbidity and higher reoperation rates[4-6]. Post-BHA dislocation rates between 1% and 17% have been reported[1]. Dislocation is usually associated with the posterior approach (PL) and generally occurs within the first six months after the intervention[4,5,7].

The minimally invasive direct anterior approach (DAA) has become increasingly popular for THA in patients presenting with hip osteoarthritis[3,8]. The DAA approach is associated with decreased soft tissue damage, which leads to faster postoperative rehabilitation, shorter hospital length of stay, and decreased dislocation rates[3,8]. Compared to the DAA approach, the PL approach is associated with shorter learning curves, fewer technical difficulties, and lower risks of perioperative greater trochanter fractures[8].

At our institution, surgeons use both the DAA and PL approaches regularly, depending on their preferences for and experience with treating displaced femoral neck fractures. In this study, we aimed to compare the DAA and PL approach complication rates in patients who underwent BHA for displaced femoral neck fractures. In particular, we analyzed the early postoperative dislocation rates and the possibly associated factors, such as the surgical approach and the surgeon's experience.

MATERIALS AND METHODS

This retrospective, single-center study reviews the clinical data of all the patients who underwent BHA between January 2008 and December 2018 with either a PL or a DAA approach. All displaced femoral neck fractures classified as 31B1.3 according to the Orthopedic Trauma Association classification[9], or Garden type III or IV[10] were eligible for inclusion. A minimum six-month postoperative follow-up period was needed because dislocation generally occurs within the first six months after hip hemiarthroplasty[1,4,5,7].

All patients underwent a preoperative X-ray (in bed) of the pelvis and contralateral healthy hip with the foot internally rotated (15 degrees) and a 28 mm diameter radiopaque ball to scale the X-ray to facilitate hemiarthroplasty planning using OrthoView™ (a computerized program) prior to surgery.

Either QUADRA® or AMIS® (Medacta®) femoral stems were used. The stems were cementless or cemented based on the surgeon's decision during preoperative planning or the intraoperative bone quality and ability to obtain sufficient press fit. The bipolar heads were steel on the outside and highly crosslinked polyethylene on the inside. The cobalt-chrome (Medacta®) femoral head was 28 mm in diameter.

In the absence of any perioperative complications (femoral fractures), full weight bearing was permitted in the immediate postoperative period. No mobility restrictions are needed following the DAA approach. After the PL approach, patients follow a rehabilitation protocol, including the use of an abduction cushion, toilet seat elevator, and early mobility restrictions on flexion and internal rotation.

This study's primary endpoints were early postoperative dislocation (within six months of surgery) and major postoperative complications-perioperative femoral fractures and/or surgical site infections.

DAA

The DAA approach is performed using a leg positioner, with the patient in the supine position on a traction table. The incision begins approximately 2 cm distally and 3 cm posterior to the anterior superior iliac spine (ASIS) and runs approximately 6 to 10 cm parallel to the line joining the ASIS and fibular head. After cutting the fascia lata, dissection occurs in the intermuscular plane between the tensor fascia lata laterally and the sartorius and rectus femoris muscles medially. The ascending branches of the medial femoral circumflex artery behind the innominate fascia are ligated. The iliocapsularis muscle is reflected medially from the capsule, followed by an L-shaped capsulotomy along the intertrochanteric line. The femoral head is extracted, and capsular release is performed prior to leg mobilization to allow femoral exposition. Capsular closure was systematically performed at the end of the intervention.

PL

The PL approach is performed in a lateral position. The curved incision is approximately 10 cm to 15 cm and centered around the tip of the greater trochanter. After cutting the fascia lata, the gluteus maximus muscle fibers were bluntly dissected. The hip is internally rotated to expose the posterior capsule and external rotator muscles. The external rotator tendons (the Gemini and obturator tendons) are then cut close to their insertion on the greater trochanter and reflected posteriorly to protect the sciatic nerve. A stitch is placed on the piriformis tendon prior to its incision close to its insertion into the greater trochanter. A T-shaped capsulotomy is then performed to expose the femoral neck fracture prior to femoral head extraction. At the end of the intervention, capsular closure is systematically associated with transosseous reinsertions of the external rotator tendons and the piriformis tendon.

Statistical analysis

A biomedical statistician performed all the statistical analyses. Both groups' demographic data were compared to check for similarities in sex, age, body mass index (BMI), and American Society of Anaesthesiologists (ASA) scores. The analyzed surgical data included time of delay to surgical intervention, intervention time, and blood loss volume. The analyzed postoperative data included complication (including postoperative infections, peri- and postoperative periprosthetic fractures, dislocation, reintervention, and 30 d mortality) rates. Particular attention was given to the relationship between dislocation rates and surgeons' experience levels to assess whether experience levels influenced dislocation rates.

Data are given as numbers and percentages (%) or as the mean ± SD. Categorical data were compared by chi-square or Fisher's exact tests. Continuous non-longitudinal variables were compared using a Mann-Whitney test. The association between surgical approach, ASA score, and death at one month was explored using log-linear models. The statistical significance of the inclusion of the surgical approach and the ASA score was assessed by a conditional goodness-of-fit test. This test was performed using the chi-square distribution for the difference between the likelihood ratios and the chi-square for two models with degrees of confidence equal to the difference in degree of freedom from the models.

Statistical analyses were performed using the NCSS 19.0.3 statistical package (NCSS, LLC; Kaysville, UT) and Systat v 5.0 for DOS (Systat Software, Inc., Chicago, IL, United States). A $P < 0.05$ was considered statistically significant for all tests. This study was approved by our institutional ethics committee (Comité d'éthique Erasme-ULB) under the following number: P2019/390.

RESULTS

Demographic data

Overall, 109 hip fractures were operated on using the DAA approach, and 171 hips were operated on using the PL approach. The mean patient age was 82.3 years in the DAA group and 82.6 years in the PL group. The DAA group was 73% female compared to 71% female in the PL group. Table 1 provides detailed ASA scores. No significant difference between groups was found regarding patient age, sex, BMI, or ASA score. Mean follow-up duration was 10 mo (1-48 mo) for the PL group and 9 mo (1-48 mo) for the DAA group (Table 1).

Surgical data

The mean delay time to surgery was 2.5 ± 3.3 d for the DAA group and 1.9 ± 2.9 d for the PL group ($P = 0.19$). The mean surgical time was 96.7 ± 33.6 min in the DAA group and 99.2 ± 30.4 min in the PL group ($P = 0.41$). The mean blood loss volume was 307 ± 184 mL in the DAA group and 359 ± 265 mL in the PL group ($P = 0.43$). Femoral stems were cemented in only 15 of 171 cases in the PL group (9%), compared to 25 of 109 cases in the DAA group (23%) (Table 2).

Mortality

The 30 d mortality rates were 3.7% ($n = 4$) in the DAA group and 9.9% ($n = 17$) in the PL group (Table 3). There was no statistically significant difference between the groups in terms of mortality at 30 d ($P = 0.052$). There was a statistically

Table 1 Demographic data, mean ± SD

	DAA (*n* = 109)	PL (*n* = 171)	*P* value
Age (yr)	82.3 ± 7.2	82.6 ± 8.2	0.72
Sex (M/F, %)	29 (27)/80 (73)	50 (29)/121 (71)	0.63
BMI (kg/m^2)	23.1 ± 5.4	23.6 ± 4.5	0.91
ASA Score (%)			0.87
ASA 1	0	0	
ASA 2	33 (30)	68 (40)	
ASA 3	69 (63)	90 (53)	
ASA 4	90 (53)	8 (5)	

ASA: American Society of Anaesthesiologists; BMI: Body mass index; DAA: Direct anterior approach; F: Female; M: Male; PL: Posterolateral approach.

Table 2 Surgical data, mean ± SD

	DAA	PL	*P* value
Delay to surgery (d)	2.5 ± 3.3	1.9 ± 2.9	0.19
Surgical time (min)	96.7 ± 33.6	99.2 ± 30.4	0.41
Blood loss (mL)	307 ± 184	359 ± 265	0.43

DAA: Direct anterior approach; PL: Posterolateral approach.

Table 3 Thirty-day mortality rates

	Anterior approach	Posterior approach
ASA 1 + ASA 2 (%)	0/33 (0)	5/68 (6.8)
ASA 3 + ASA 4	4/72 (5.3)	12/86 (12.2)
Log-linear model: Including approach, ASA score, and Death; Chi^2 = 12.93-*P* = 0.039, indicating statistically significant differences from the fitted model, showing that the model did not fit the observed data		
The interaction: Approach × Death: *P* = 0.06		
The interaction: ASA score × Death: *P* = 0.028		

ASA: American Society of Anaesthesiologists.

significant difference between the groups' ASA scores when the ASA 1 and 2 categories and ASA 3 and 4 categories were grouped (*P* = 0.039). However, this was further explored using a log-linear model, which produced no significant effect according to the surgical approach (*P* = 0.06) but was significantly affected according to the ASA score (*P* = 0.028).

Complication rates

Patients who died during the first postoperative month were not included in the postoperative complication and dislocation rate analyses (Table 4). The overall complication rates were 7.6% in the DAA group (*n* = 8) and 22.7% in the PL group (*n* = 35). The PL group showed significantly higher complication rates than the DAA group (*P* = 0.0013).

No patient in the DAA group presented with a BHA dislocation, and 14 patients in the PL group did. This difference was statistically significant (*P* = 0.0015). The risk ratio for BHA dislocation after PL compared to DAA was infinite since the DAA group had no dislocations. However, if we assumed 1 dislocation in the DAA group, the risk ratio was 9.55 [95% confidence interval (CI) (1.27-71.5), *P* = 0.028]. For the 14 BHA dislocations, 22 closed reductions were performed. Implant revisions for persistent instability were performed in 8 of the 14 BHA cases (5.2%). One patient underwent two revision surgeries for recurrent dislocations and periprosthetic fractures. The dislocation rates were analyzed by surgeon experience (Table 4). The dislocation rates were 7.9% when senior surgeons performed PL BHAs and, 9.5% when residents or trainees in orthopedic surgery performed BHA. The risk ratio for dislocation after a PL BHA performed by a resident or trainee compared to a senior surgeon was 1.20 [95%CI (0.35-4.18), *P* = 0.77].

Table 4 Complications, *n* (%)

	DAA (*n* = 105)	PL (*n* = 154)	*P* value
Fractures			0.87
Perioperative fracture	2 (1.9)	4 (2.6)	
Postoperative fracture	2 (1.9)	4 (2.6)	
Infection			0.96
Superficial	1 (1.0)	2 (1.3)	
Deep (implant retained)	1 (1.0)	1 (0.6)	
Deep (implant changed)	2 (1.9)	2 (1.3)	
Overall Dislocations	0	14 (9.1)	0.0015
Revision surgery for recurrent dislocation	0	8 (5.2)	0.018
Total hips operated (*n*) *vs* dislocated hips (Dis)			
n/Dis	105/0	154/14 (9.1)	
Senior surgeon			
n/Dis	60/0	38/3 (7.9)	
Resident surgeon			
n/Dis	32/0	77/6 (7.8)	
Trainee			
n/Dis	13/0	39/5 (12.8)	

DAA: Direct anterior approach, Dis: Dislocated hips, PL: Posterolateral approach.

Overall, four patients in the DAA group and eight patients in the PL group experienced fractures. This difference was not significant (*P* = 0.87). In the DAA group, two perioperative fractures were treated with cerclage wires during the same surgical time. The other two were traumatic postoperative fractures occurring on the 2nd and 27th days after BHA and were treated with revision BHA using cerclage wires and cerclage wires alone, respectively. In the PL group, there were three perioperative fractures, two metaphyseal fractures (treated with cerclage wires), and one fracture of the greater trochanter (treated nonoperatively). Three Vancouver B3-classified postoperative traumatic fractures were encountered between the 8th postoperative day and the 34th postoperative month. All were treated with long stem revisions and cerclage wires. One patient in the PL group presented with two consecutive fractures. This patient also presented with recurrent BHA instability. During an open surgical reduction for intraprosthetic dislocation 31 d after the index surgery, the patient presented with a perioperative periprosthetic fracture, for which long stem revision with cerclage wires was performed during the same surgical time. The same patient presented with persistent BHA instability and fracture extension to the greater trochanter on the 49th day after the index surgery. For this reason, a second revision surgery was performed using plate osteosynthesis.

Table 3 details the infection-related complications. There was no difference in the DAA and PL groups regarding infection-related complications (*P* = 0.96). Superficial surgical site infections were encountered in one patient in the DAA group and in two patients in the PL group. Deep infections were encountered in three patients each in the DAA and PL groups. In the DAA group, debridement antibiotics and implant retention (DAIR) were performed for two early postoperative deep infections, of which one failed to control infection, and a two-stage implant revision was performed. The third patient presented with a late postoperative infection, for which a two-stage implant revision was performed. In the PL group, two patients presented with early postoperative deep infections. DAIR was performed on both patients and failed in one of them. For this patient, a two-stage implant revision was performed at another institution. The third patient also presented with a late postoperative infection, for which a two-stage revision was planned.

Surgical revision was needed for 5.7% of patients in the DAA group (*n* = 6) and for 11% of patients in the PL group (*n* = 17). This difference was statistically insignificant (*P* = 0.14). The difference in the rate of revision surgeries needed for chronic instability between the DAA group (0%) and the PL group (5.2%) was statistically significant (*P* = 0.018). Anesthesia to manage complications was needed for 5.7% of patients in the DAA group (*n* = 6) and for 25.3% of patients in the PL group (*n* = 39). This difference was statistically significant (*P* < 0.0001).

DISCUSSION

Despite the abundant literature concerning hip replacement surgery approaches, no consensus has yet been reached regarding the superiority of one approach over the others. However, we feel that in this particularly frail population, the DAA approach might offer some useful advantages.

Post-BHA dislocation is a serious complication that is reportedly associated with higher six-month mortality rates, ranging between 65% and 73%[1,7,11]. Overall, post-BHA dislocation rates range from 3.2% to 16%[1,7], with a rate of recurrence over 60%[5]. When using the DAA approach, reduced dislocation rates of 0% to 2% have been described[12]. Our results further support the evidence supporting reduced post-BHA dislocation rates using the DAA approach. None of the patients in the DAA group experienced dislocations in this study. However, assuming that one dislocation occurred in the DAA group in our series, the overall risk for BHA dislocation using the PL approach was 9.5%.

Approximately 20% to 50% of patients admitted with hip fractures present with dementia or known cognitive impairment[13,14]. After hip fracture surgery, over half of patients present with postoperative delirium, with a prevalence of up to 89% in patients with known dementia[14]. In patients without dementia, the prevalence of postoperative delirium after hip fracture surgery ranges from 12% to 26%[14,15]. The presence of impaired cognitive function is in addition to neurological disorders, abductor muscle weakness, and hip joint deformities-another patient-related risk factor for dislocation[1]. Impaired cognitive function is also a limiting factor in compliance with the restrictive postoperative precautions needed after surgery using the PL approach[7]. Because the DAA approach is associated with lower dislocation rates than the PL approach and requires no postoperative mobility restrictions, this approach seems preferable for older adults with known dementia.

The DAA approach is a true intermuscular and inter-nervous muscle-preserving method[8] in that it preserves the hip abductor mechanism. Lateral approaches, in which the release of the gluteus minimus and part of the gluteus medius is described, can be associated with postoperative gluteal insufficiency and lateral thigh pain[16]. The risk of postoperative abductor weakness-a risk factor for dislocation-might, in our opinion, lead to the DAA being favored over direct lateral approaches. One meta-analysis described a nonsignificant difference between the dislocation rate of the anterolateral approach, which was slightly higher at 1.9%, and the DAA approach which was 0%[7]. In another meta-analysis, an odds ratio of 1.87 was calculated for post-BHA dislocation when using a lateral rather than a DAA approach[6]. Thus, post-BHA dislocation rates using a lateral approach are lower than those described when using a PL but are still slightly higher than those using the DAA approach. This is probably due to the true muscle-sparing benefit of the DAA approach. Even if these rates are not statistically significant, considering the morbidity associated with a closed reduction and poor functional results after recurrent dislocations[17], we question whether those rates can be considered of no clinical significance.

Mortality rates in our series align with the 10% 30 d mortality rates described in the literature[18]. Interestingly, 30 d mortality rates were slightly higher in the PL group than in the DAA group in our series, at 9.9% and 3.7%, respectively. Upon further analysis, patients' preoperative ASA scores affected mortality rates; however, this is expected because higher ASA scores are associated with higher mortality rates. A prediction model based on ASA scores that predict 30-d mortality rates after hip fractures has recently been validated[18].

The most important drawback of the DAA approach is its technical difficulty, which might be associated with more perioperative complications, such as implant malpositioning and perioperative fractures, due to limited visibility during surgery[8]. However, two meta-analyses showed no differences in peri or postoperative complication rates between the DAA approach and other methods[6,7]. We encountered slightly more perioperative fractures when using the PL in our series than when we used the DAA approach (2.6% and 1.9%, respectively). This difference was not statistically significant.

An important limiting factor for this study is the lack of long-term follow-up, which limits opportunities to evaluate functional results. However, since our interest was primarily in early postoperative dislocation rates, we feel that the follow-up duration in this series is sufficient but possibly missed a few late dislocations. We may have encountered a few perioperative complications because surgeons experienced in the DAA for hip arthroplasty or residents supervised by those surgeons performed the BHA using the DAA approach. Experienced hip surgeons performed some, but not all, of the BHAs, using the PL approach, thereby possibly introducing a surgical experience bias rather than an approach bias. However, we feel that this is more representative of a teaching hospital in which residents and orthopedic trainees are trained.

CONCLUSION

Treating femoral neck fractures with BHA using the DAA approach is associated with the lowest dislocation rates. Using the DAA approach for this specific frail patient population might offer advantages, specifically lower risks of dislocation-related morbidity and mortality and an economic advantage over the PL approach.

ARTICLE HIGHLIGHTS

Research background

Bipolar hip hemiarthroplasty, which presents few advantages compared to total hip replacement, is often considered the treatment of choice for frail older patients presenting with low physical demands. Reported dislocation rates after hip hemiarthroplasty vary between 1% and 17%. Dislocation represents a serious complication and is associated with increased morbidity and mortality after hip hemiarthroplasty.

Research motivation
Approaches for hip hemiarthroplasty are still debated. When considering elective total hip replacement, the direct anterior approach (DAA) is associated with the lowest dislocation rates. However, because of the difficulties associated with this approach, there are some drawbacks to using this approach for frail older patients for hip fracture surgery.

Research objectives
The aim of this study was to compare the direct anterior and posterior approach (PL) early complication rates in patients who underwent bipolar hemiarthroplasty (BHA) for displaced femoral neck fractures.

Research methods
This is a retrospective, single-center comparative cohort study conducted at a university hospital between March 2008 and December 2018. A total of 280 hips (273 patients) were analyzed, of which 171 hips were operated using the PL and 109 hips were operated using the DAA. All patients underwent preoperative X-rays of the pelvis and the healthy hip for preoperative planning purposes.

Research results
The PL for BHA for femoral neck fractures in the elderly was associated with significantly higher complication rates compared to the DAA, respectively 22.7% *vs* 7.6% (P = 0.0013). This difference probably reflects the significant difference in postoperative dislocation rates as no dislocations were encountered in the DAA group compared to a dislocation rate of 9.1% in the PL group (P = 0.0015). Dislocation rates were also analyzed according to the surgeon's experience. The risk ratio for dislocation after BHA through PL by a resident or trainee was 1.20 compared to BHA through PL by a senior surgeon.

Research conclusions
The DAA to BHA for patients with displaced femoral neck fractures is associated with lower dislocation rates compared to the PL. This approach might offer some other advantages, specifically lower risks of dislocation-related morbidity and mortality and possibly an economic advantage over the PL.

Research perspectives
Larger prospective randomized trials are needed in order to confirm the advantages of the DAA for hip fracture surgery.

FOOTNOTES

Author contributions: Jayankura M designed research; Jayankura M, Bloemers N, Kapanci B performed research; Jayankura M and Charles T analyzed data; Charles T drafted the manuscript; Charles T, Jayankura M, Kapanci B and Bloemers N proofread the manuscript.

Institutional review board statement: This study was reviewed and approved by the Ethics Committee of the HUB-Hospital Erasme.

Informed consent statement: All study participants or their closest family members provided informed written consent allowing the collection of personal and medical data prior to study enrolment. The need for informed consent was waived by the Ethics Committee in case of death of the patient or if a patient presented with cognitive impairment without known relatives.

Conflict-of-interest statement: All the Authors have no conflict of interest related to the manuscript.

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ORIGINAL ARTICLE

Retrospective Study

Health economics for intra-capsular hip fractures undertaking fixation

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Abstract

BACKGROUND

Hip fracture is a common musculoskeletal injury in the elderly requiring surgery worldwide. The operative mainstay of intra-capsular hip fractures is arthroplasty with a smaller proportion for fixation.

AIM

To determine the most beneficial method of fixation for patients with intra-capsular hip fractures.

METHODS

A registered audit from 2012-2018 was conducted on all intra-capsular hip fractures treated with 2 commonly used fixation methods. Patient notes, electronic records and clinical codes for cost benefit were evaluated. A validated quality of life measure was collected at least 1 year after surgery.

RESULTS

A total of 83 patients were identified with intra-capsular fractures undergoing fixation during the retrospective period. There were 47 cannulated cancellous screw and 36 sliding hip screw fixations with the case mix comparable for age, gender, co-morbidities and fracture configuration. There was no significant difference in blood loss, tip apex distance, radiation exposure, length of stay, radiological union time, collapse, avascular necrosis or re-operation between fixation methods. Logistic regression analysis demonstrated displaced intracapsular hip fractures correlated significantly with an undesirable outcome conferring a relative odds ratio of 7.25. There were 9 (19%) and 4 (11%) patients respectively, who required re-operation. There was no significant difference in health resource group tariff and implant cost with comparable EQ-5D and visual analogue scores.

CONCLUSION

No significant advantage was identified with differing fixation type, but irrespective there were a high number of patients requiring re-operation. This was predicted by initial fracture displacement and patient age. Arthroplasty may need to be carefully considered for health economics and patient benefit.

Key Words: Hip fracture; Fixation; Patient reported outcome measure; Cost

Core Tip: Both sliding and cannulated hip screws had undesirable outcomes in older patients with displaced fractures. More predictable methods of treatment such as hip arthroplasty should be considered for older patients with displaced fractures.

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INTRODUCTION

Hip fracture is the commonest musculoskeletal injury requiring surgery in the United Kingdom[1,2]. In 2017 alone, the national hip fracture database reported 65958 admissions with a 1 mo mortality of 6.9% and the disability leaving only half of patients returning to their premorbid state[3]. The total cost and burden to health and social services is over £1 billion per year along with 1.5 million National Health Service beds occupied annually[3-5]. A number that is set to rise with an aging population making health resource and provision allocation more important than ever[6].

Almost all hip fractures are managed surgically to enable early mobilisation, reducing complications associated with prolonged recumbency[7-9]. Surgical management is primarily dictated by fracture configuration and level, whilst also considering patient-specific factors such as physiological age, co-morbidities and pre-morbid function[10,11]. Specifically, operative management of intra-capsular fractures, which accounts for roughly 60% of all hip fractures, include a range of fixation and arthroplasty procedures[3,12]. Hip fixation whilst less successful than arthroplasty still comes as an attraction in order to maintain native anatomy and hip geometry whilst always having arthroplasty as a backup if it fails [12-14]. The evidence to date is equivocal for which fixation type is superior but a recent international multi-centre randomised controlled trial (FAITH) comparing standard cancellous and sliding hip screws found trends favouring sliding hip screws in certain subgroups of patients for reoperation rate[15]. With the cost implication to society of these fractures, health economics may play an important role in the decision making of fixation type to best manage them. This study therefore set out to determine the best fixation method routinely used for intra-capsular neck of femur fractures incorporating patient, surgeon and hospital metrics. The primary aim of this clinical practice study is to determine the most effective and beneficial way of treating these patients. The secondary aim is to determine which factors predispose to an undesirable fixation result. The null hypothesis was that no difference would be determined between fixation methods.

MATERIALS AND METHODS

A retrospective analysis was conducted on all skeletally mature patients who sustained a closed intra-capsular hip fracture treated with either cannulated cancellous screws (CCS) or 2-hole sliding hip screw (SHS) fixation during the period from October 2012 to October 2018 (Figure 1). The study was conducted at a single district general hospital which regularly treats hip fractures using both fixation types and having no preference for either, with the requirement to proceed having achieved good-closed reduction in all planes intraoperatively. Patients with malignancy associated, basi-cervical or intertrochanteric fractures were excluded. The service improvement project was registered locally to follow good clinical governance practice guidelines.

Patients and procedure

Over the audit period, 1751 patients were admitted with a hip fracture, of which 83 had intra-capsular hip fracture fixation (Table 1) which met the study criteria. Fixation was achieved with either three partially threaded cancellous screws (6.5 mm diameter with 16 mm thread length) arranged in a reverse triangular configuration or with a single 13 mm sliding hip screw with a 47 mm barrelled two hole side plate affixed with two 4.5 mm cortical screws +/- 6.5 mm anti-rotational screw. The time of surgery was defined as time from admission to the emergency department to the time

Table 1 Fracture configuration, *n* (%)

	Cannulated cancellous screw fixation	2-hole sliding hip screw fixation
Fixation group	47 (56.6)	36 (43.4)
Laterality		
Left	25 (53.2)	18 (50)
Right	22 (46.8)	18 (50)
Garden classification		
I	24 (51.1)	13 (36.1)
II	8 (17)	11 (30.6)
III	10 (21.3)	7 (19.4)
IV	5 (10.6)	5 (13.9)
Pauwels classification		
I	7 (14.9)	1 (2.8)
II	32 (68.1)	24 (66.7)
III	8 (17)	11 (30.6)

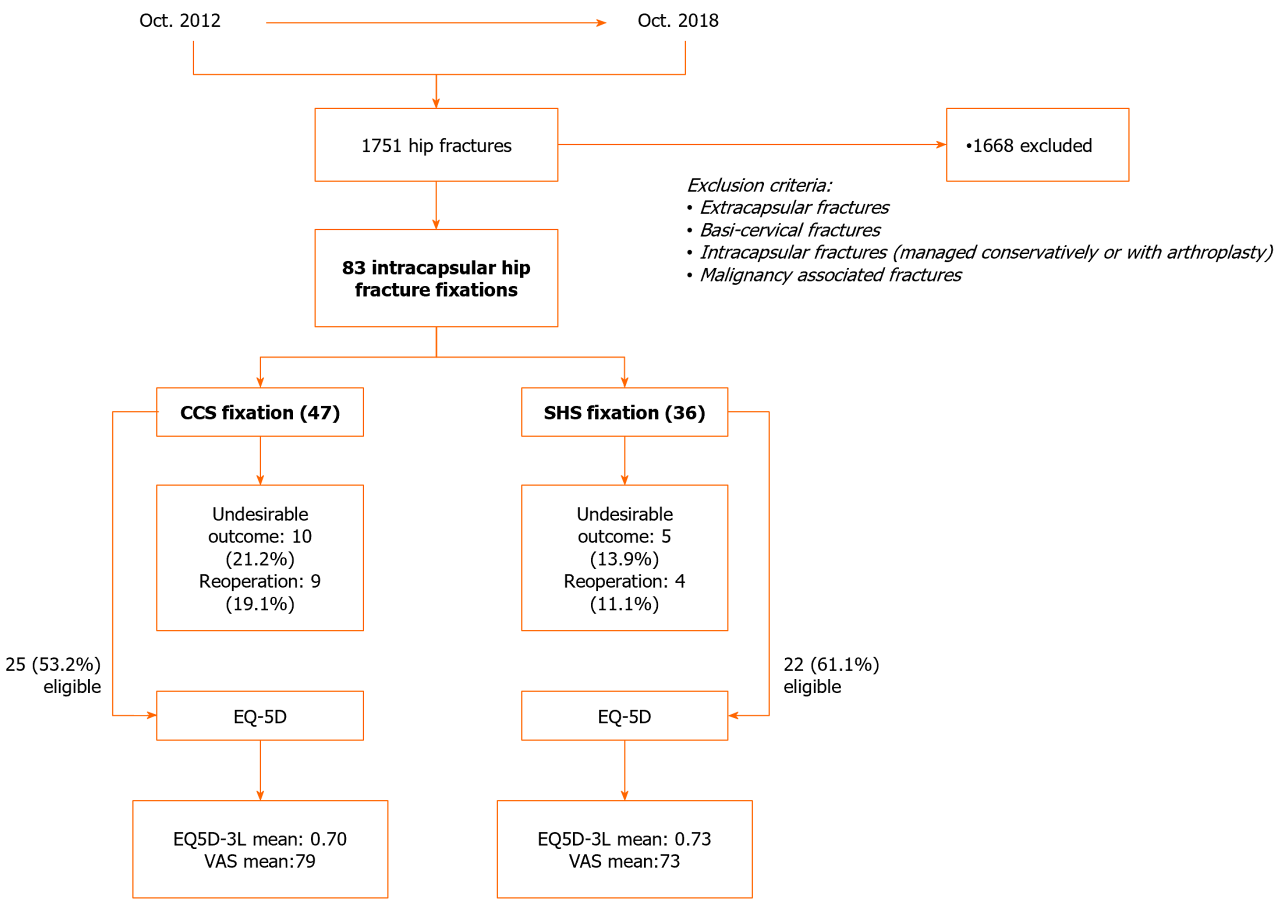

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Figure 1 Audit period flowchart for hip fractures. CCS: Cannulated cancellous screws; SHS: Sliding hip screw; VAS: Visual analogue score.

of surgery in theatres. All procedures were conducted by specialty trainee registrars with minimum 3 years' experience under the supervision of a consultant. The patient setup was identical for both using a standard hip traction table using routine manoeuvres such as gentle traction with internal rotation. All patients before having closed reduction with fixation under fluoroscopy guidance had a single dose of intravenous antibiotic. All patients had hospital guided prophylaxis low molecular weight heparin peri-operatively unless contra-indicated. Patients were all seen by physiotherapy department day 1 post-operatively with a standardised protocol encouraging early mobilisation.

Operative and post operative parameters

All clinical records were reviewed to determine age, sex, date of injury, date of surgery, pre-to-post operative haemoglobin count, post-operative weight bearing status and length of stay. Pre-operative imaging studies were reviewed to assess fracture configuration and displacement, classified according to the Pauwel and Garden classification systems, respectively with a simple modification (undisplaced or displaced) to the Garden classification for improved reliability[16,17]. Intra-operative imaging studies were reviewed to assess fixation type, reduction adequacy, fixation accuracy on the centre of the femoral head (tip-apex index) along with the radiation exposure time report, a surrogate for procedural complexity and radiation exposure. All available post-operative patient imaging studies were reviewed to assess fracture union time and the event of an undesirable outcome including significant collapse (> 5 mm), non-union, avascular necrosis (AVN) or implant failure. All images were accessed through the hospital electronic picture archiving and communication system and were reviewed by a senior surgeon. Follow up clinic letters were accessed using the electronic clinic letter system and reviewed further for an undesirable outcome.

Patient reported outcome measure

Patients not flagged as deceased by hospital records were contacted by a trauma coordinator a minimum of 1 year after surgery. Patients were asked if they were satisfied with their outcome and if further operations following hip fixation was required. A validated quality of life measure, the EuroQol-5 dimensions 3-level (EQ-5D- 3L) index score and visual analogue scale score were collected to provide a single index value for health status[18].

Cost analysis

Clinical coding data corresponding to the patients hip fracture hospital spell was obtained from the hospital clinical coding department. Data included international classification disease (ICD- version 10) diagnostic codes, OPCS-4 procedural codes and health resource group (HRG) coding records. Patient co-morbidity data was extracted and recorded based on number of chronic end-organ co-morbidities. HRG Codes were then converted into monetary tariffs based on service level agreements.

The current standard implants used for CCS and SHS fixation are the Stryker Asnis III and Omega 3 systems respectively (Mahwah, NJ, United States). The implant cost price for each procedure was obtained from the local procurement officer.

Statistical analysis

Statistical analysis was performed using SPSS (IBM SPSS Statistics, version 21) software. Normality was assessed using a Kolmogorov-Smirnov test. A Student-*t* and Mann-Whitney *U* test were used for parametric and non-parametric data. Fisher's exact test was used for categorical variables. Logistical regression analysis was conducted to analyse factors affecting an undesirable result. Significance was set at 0.05 throughout. Results are reported as mean (range) and number (percentage).

Ethical statement

Ethical approval was not sought nor required as it was part of a service evaluation project for the trauma and orthopaedic department. The service evaluation was registered (SUR.NP.19.003) with the local clinical governance team before the audit commencement to ensure hospital standard operating procedure adherence.

RESULTS

A total of 83 patients meeting the inclusion/exclusion criteria were evaluated. CCS fixation was utilised in 47 (57%) patients with 36 (43%) patients undergoing 2-hole SHS fixation. Fracture configuration was comparable between CCS and SHS groups, with undisplaced fractures (Garden I/II) 68.1% *vs* 66.7%, respectively and Pauwel type II the most common type representing 68.1% and 66.7% respectively. Fracture configuration for each fixation group is detailed in Table 1. The case mix was similar for age (65.7 *vs* 70.9 year), gender (66% *vs* 58.3% female) and end-organ co-morbidities (1.47 *vs* 1.42 mean). Patient demographics are summarised in Table 2.

Operative and post operative parameters

There was no significant difference in blood loss (1.8 *vs* 1.5 g/dL), blood transfusions (2 in each group), tip apex distance (20 mm *vs* 23 mm, length of stay (15 *vs* 17 d), total radiation exposure time (53 *vs* 47 sec.) or union time (5.1 *vs* 5.8 mo) respectively for CCS and SHS (Table 3). There was a clear difference in post operative weight bearing instructions following the fixation types (Table 3). Partial weight bearing was most common advice, 45% of the time, in CCS fixation and fully weight bearing, 44% of the time for the SHS fixation.

Complications

In total there were 15 undesirable events with no statistical difference between groups for avascular necrosis, significant collapse, non-union, and cut-out (Table 4). Furthermore there was no statistical difference in re-operation rate between the groups with 9 (19.1%) and 4 (11.1%) for the CCS and SHS groups respectively. Most reoperations were metal work

Table 2 Patient demographics, *n* (%)

	Cannulated cancellous screw fixation	2-hole sliding hip screw fixation
Mean age, yr (range)	66 (18-91)	71 (28-100)
Group by age		
< 50	7	6
> 50	40	30
Gender		
Male	16 (34)	15 (41.7)
Female	31 (66)	21 (58.3)
Number of organ co-morbidities		
0	13 (27.7)	11 (30.6)
1	13 (27.7)	9 (25)
2	11 (23.4)	8 (22.2)
3	6 (12.8)	6 (16.7)
4	4 (8.5)	2 (5.6)
Mean	1.5	1.4

Table 3 Peri-operative parameters, *n* (%)

	Cannulated cancellous screw fixation	2-hole sliding hip screw fixation
Time to surgery, h (range)	39 (6-168)	43 (7-408)
Tip-apex, mm (range)	20 (10-45)	23 (15-35)
Hb drop pre-op to post op, g/dL (range)	1.8 (0.1-5.0)	1.4 (0.3-4.2)
Radiation time, sec (range)	53 (7-127)	47 (35-75)
Length of stay, d (range)	15 (3-69)	17 (4-62)
Weight bearing status		
NWB	5 (10)	2 (6)
PWB	21 (45)	7 (19)
FWB	3 (6)	16 (44)
Unclear	18 (39)	11 (31)
Union time, mo (range)	5.1 (1-16)	5.8 (1-12)
Health resource group, £ (range)	5979 (517-11117)	6862 (639-14323)

NWB: Non weight bearing, PWB: Partial weight bearing, FWB: Full weight bearing; Hb: Haemoglobin.

removal due to significant collapse causing soft tissue irritation. Each group had 3 patients having undergone revision total hip replacement.

Subanalysis and regression analysis of all patients

In total there were 56 patients with undisplaced fractures and 27 with displaced fractures. With the undisplaced fractures only 9% (n = 5) resulted in an unsatisfactory outcome in comparison to 37% (n = 10) in the displaced group. When subdividing the patient by age, there were a total of 13 patients under the age of 50 with 5 having an undisplaced fracture and 8 having a displaced fracture. There were zero unsatisfactory results in the less than 50 years undisplaced fracture patients but 25% (n = 2) in the displaced fractures. When analysing patients over the age of 50 years, there were in total 70 patients with 51 undisplaced and 19 displaced fractures. Of the greater than 50 group with an undisplaced fracture, only 10% (n = 5) resulted in an unsatisfactory outcome as compared to 42% (n = 8) in the displaced group.

Binary logistic regression analysis of all characterisable variables showed that only a displaced (Garden 1-2 *vs* Garden 3-4) intracapsular hip fracture was a significant (P = 0.016) independent predictor of an unsatisfactory result. Hosmer-Lemeshow goodness of fit was P = 0.566 for the model and Nagelkerke R-Square was 0.287 with a classification accuracy

Table 4 Complications, *n* (%)

Undesirable outcomes	Cannulated cancellous screw fixation	2-hole SHS fixation
Avascular necrosis	1 (2.1)	3 (8.3)
Significant collapse	5 (10.6)	1 (2.7)
Non-union	3 (6.4)	0 (0)
Cut-out	1 (2.1)	1 (2.7)
Reoperation	9 (19.1)	4 (11.1)

SHS: Sliding hip screw.

of 82% and an odds ratio of 7.25 (CI: 1.45-36.31).

Patient related outcome measures

Of the 83 patients having undergone fixation only 47 (57%) were contactable or able to coherently converse for psychometric analysis. A breakdown of those included and reasons for exclusion are detailed in Table 5. Fixation groups were similar for the proportion valid to be included (74% *vs* 79%). There was no significant difference in EQ 5D-3L or VAS scores between fixation groups (0.70 *vs* 0.73 and 79 *vs* 73, respectively). Sub-analysis of all requiring revision total hip arthroplasty demonstrated a score of 0.62 and 69.

Cost analysis

Clinical coding demonstrated no significant difference in the actual tariff received with a mean value of £5979 and £6862 respectively. Total CCS implant cost was £259.35 incorporating Asnis III 6.5 mm cannulated cancellous screws (×3), washers (×3), guidewire and drill bit. Total SHS implant cost was £146.13 assimilating SHS plate, 13 mm lag screw, cortex screws (×2), guidewire and drill bit.

DISCUSSION

Whilst much research has focused on the clinical outcomes of intra-capsular hip fracture fixation considerably less work has examined the health economics on the quality of life and financial effect of differing fixation methods[19,20]. This retrospective study found no significant cost-saving difference between CCS and SHS fixation methods. Both groups had similar lengths of stay and intra-operative radiation exposure, a surrogate for the cost of time. The mean HRG, which is the currency that each patient event attracts, were not statistically dissimilar but favouring the SHS with a mean of £6862 when compared to the CCS with a mean of £5979. Additionally both fixation types had comparative quality of life indices with a mean EQ-5D score of 0.70 and 0.73 and EQ-VAS of 79 and 73for CCS and SHS respectively. These quality of life findings for economical appraisal terms signifies reasonable return of everyday health and function considering the average index and visual analogue score without injury in the United Kingdom is 0.78 and 77for individuals greater that 65[21].

In terms of the health impact to the patient, both methods had relatively high rates of undesirable outcomes (21.2% CCS *vs* 13.9% SHS group) resulting in reoperation rates of 19.1% and 11.1% respectively. With greater failures predicted by fracture displacement and patient age over 50 years which is consistent with a recent study looking at displaced fractures treated with fixation[22]. The reoperation rates, demonstrating a non-significant trend favouring SHS, are comparable with those demonstrated in the FAITH study, a multi-centre randomised controlled trial comparing CCS and SHS fixation in an elderly with low impact fractures[15]. As found in the FAITH trial, the rates of AVN also appear to be more frequent in the SHS group. This is contrary to a previous systematic review which suggested CCS were more likely to develop AVN than SHS[23]. Non-union on the contrary was found to be more common for the CCS group but not statistically dissimilar and were identical to the FAITH trial at 6%[15]. The latter observation may be accounted by a recent biomechanical cadaveric study that found significant superiority for prevention of implant migration, varus tilt, femoral neck and leg shortening with a SHS when compared to CCS[24].

Yet, the most compelling finding in this study was the significant correlation of the degree of fracture displacement with the risk of an undesirable outcome following any fixation procedure, which is not unsurprising biomechanically and has been previously reported[25-28]. Previous trials have indicated poor outcomes with internal fixation in displaced hip fractures with one study reporting fixation failure rates as high as 44%[29], which was marginally higher than the 42% found in this study for the greater than 50 age group. A meta-analysis comparing internal fixation and arthroplasty in displaced hip fractures found arthroplasty significantly reduces the need for further revision surgery at the expense of greater operative blood loss and surgery time[30]. A subsequent national registry study in patients with displaced hip fractures found that those treated with arthroplasty had significantly less reoperations, reported less pain and had a better quality of life[25,31]. Most literature to date suggest that arthroplasty should be more readily considered in those with displaced fractures, particularly in the elderly[12,32-34].

Table 5 EQ 5D and visual analogue score parameters, *n* (%)

	Cannulated cancellous screw fixation	2-hole sliding hip screw fixation
Successfully contacted patients, *n* (%)	25 (53.2)	22 (61.1)
Deceased	12 (25.5)	4 (11.1)
Moved abroad	2 (4.3)	1 (2.8)
Dementia	1 (2.1)	4 (11.1)
Unable to contact	7 (14.8)	5 (13.9)
Time from surgery to PROM, months (range)	42 (12-78)	46 (12-98)
Valid (*n*) to answer questionnaire	25/34 (74%)	22/28 (79%)
EQ 5D 3 level (range)	0.70 (0.07-1)	0.73 (0.22-1)
EQ 5D visual analogue score (range)	79 (40-100)	73 (10-100)

This study is limited by a variety of factors. The basic retrospective analysis intrinsically suffers bias and lends to a fall out rate for data collection. This was seen, as near 20% of patients had deceased before patient reported outcome measures were collected. Surprisingly, this was higher in the CCS group despite being 10% younger. There was also a noticeable difference in the post-operative weight bearing instructions between the two fixations in our study, which is consistent with a multi-national survey studying surgeon preferences for managing femoral neck fractures[35]. In this study, operating surgeons preferred partial or non-weight bearing following CCS fixation whereas SHS fixation was associated with more full weight bearing status. There is evidence to suggest that a restriction in weight bearing status can compromise functional levels up to a year following surgery[36]. In this respect arthroplasty has been shown to be advantageous given the lack of restriction and improved mobility[37]. Finally, the small nature of this series can lead to statistical errors, particularly false negatives, which limit the conclusion, so caution must be taken with these results.

CONCLUSION

In conclusion, no significant benefit was seen with differing fixation types for intra-capsular hip fractures. Nonetheless, younger patients and undisplaced fractures fared better. The significant rates of undesirable outcomes seen in displaced fractures for patients over the age of 50 years suggest hip arthroplasty should be considered.

ARTICLE HIGHLIGHTS

Research background

Hip fractures are common injuries requiring surgery.

Research motivation

Determining if there is an advantage between two common procedures for hip fracture fixation.

Research objectives

Identifying the best fixation method and identifying any patient factors which put them of a less desirable outcome.

Research methods

An audit was conducted to identify patients who had hip fracture fixation during a 6 year period followed by a quality of life questionnaire along with cost analysis of patient having undergone hip fracture fixation.

Research results

Older patients (> 50 years) and displaced fractures were risk factors for undesirable outcomes in hip fracture fixation.

Research conclusions

Alternatives from hip fracture fixation should be considered in displaced hip fractures and older patients requiring surgery.

Research perspectives

Further research should look into fixation constructs along with patient metabolomics.

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FOOTNOTES

Author contributions: Wiik AV designed the study; Wiik AV and Ashdown T collected the clinical data; Wiik AV and Ashdown T analysed the data; Wiik AV, Ashdown T and Holloway I interpreted and wrote the report.

Institutional review board statement: The study was a registered audit so no ethical approval was sought nor required. No individual patient or related identity information have been presented.

Informed consent statement: As a registered audit without any patient or related identity no consent was required.

Conflict-of-interest statement: All authors had no conflicts.

Data sharing statement: Raw data is not available freely for use as per National Health Service audit regulations.

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ORIGINAL ARTICLE

Retrospective Study

Acetabular cup size trends in total hip arthroplasty

Daniel Patrick McKenna, Alex Price, Timothy McAleese, Darren Dahly, Paul McKenna, May Cleary

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Abstract

BACKGROUND

Total hip arthroplasty (THA) is a common procedure for end stage osteoarthritis. The learning curve for THA is complex and challenging. One of the most difficult skills to master is acetabular reaming. We wish to identify if experience in arthroplasty leads to preservation of more bone stock.

AIM

To investigate if increasing surgeon experience will predict an ever decreasing acetabular cup size.

METHODS

A retrospective case series of four attending orthopaedic surgeons was completed. All uncemented elective total hip arthroplasties since appointment were selected for inclusion. The size of acetabular cup used was noted and logistic regression was used to identify if a trend to smaller cups existed.

RESULTS

A total of 1614 subjects were included with a mean age of 64 years. Overall cups were on average 0.18mm smaller per year (95% confidence interval -0.25 to -0.11, $P < 0.001$). Individual surgeon trends showed cup sizes to decrease 0.27 mm/year for surgeon A, 0.02 mm/year for surgeon B, 0.15 mm/year for surgeon C and 0.29 mm/year for surgeon D. Three of the four surgeons had a more pronounced trend to smaller cups for male subjects than their female counterparts.

CONCLUSION

We found increasing surgeon experience to be associated with an ever-decreasing acetabular cup size. Smaller acetabular cup size may act as a surrogate marker of surgical proficiency by virtue of decreased acetabular reaming.

Key Words: Hip; Arthroplasty; Acetabulum; Cup; Learning

Core Tip: The learning curve for total hip arthroplasty is complex and challenging. One of the most difficult skills to master is acetabular reaming. We hypothesise that with increasing surgeon experience there will be a trend to smaller acetabular cup sizes as a result of less acetabular reaming. A retrospective case series of four attending orthopaedic surgeons was completed. A total of 1,614 cups were analysed. Overall cups were on average 0.18mm smaller per year (95% confidence interval -0.25 to -0.11, $P < 0.001$). We found increasing surgeon experience to be associated with an ever decreasing acetabular cup size.

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INTRODUCTION

The incidence of hip osteoarthritis and its associated morbidity is an ever increasing global health burden[1]. Management can take numerous forms however total hip arthroplasty (THA) is oftentimes necessary[2]. Competency in elective hip arthroplasty is a skill derived from both knowledge of the procedure and surgeon experience.

In this study we hypothesise that acetabular cup size decreases in accordance with increasing THA experience. We propose that familiarity with the procedure will result in preservation of bone stock through decreased acetabular reaming. This trend may act as a surrogate marker of surgical competency and understanding of the procedure.

This case series of consultant arthroplasty surgeons practicing in the Republic of Ireland compares the cup sizes used with increasing experience. Our question is, does consultant experience predict an ever-decreasing acetabular cup size?

MATERIALS AND METHODS

Four consultant arthroplasty surgeons were selected for this case series. The practices of each surgeon were analysed by the size of the acetabular cup components used in their elective THAs. Theatre log books were analysed and cross referenced with the Irish National Orthopaedic Register[3].

All primary elective uncemented THAs performed under each consultant since appointment were selected. Baseline demographics and implant sizes were recorded. The manufacturer and product details for each cup used were noted. Linear regression analysis was used to examine for a statistically significant trend towards smaller acetabular cup size.

For the purposes of analysis each surgeon served as their own control. We acknowledge that individual surgeons prefer different cup sizes. The average size of cup that each surgeon chose when relatively inexperienced was deemed to be their baseline preference. It was the trend with time, regardless of whether the surgeon prefers large or small cups at baseline, that was of primary interest.

RESULTS

Consultant experience ranged from four to ten years. Cumulatively this data provided analysis for 30 years of practice. In total 1614 cases were completed between February 2012 and September 2022. Subjects had an average age of 64 years and a male preponderance of 51%.

Firstly the overall trend for uncemented acetabular components used against time was analysed. Year on year there was a statistically significant trend towards decreasing cup size. Cups were on average 0.18mm smaller per year (95% confidence interval -0.25 to -0.11, $P < 0.001$).

Individual consultant practices were then examined. For each surgeon there was a negative trend in acetabular cup size. The trend for surgeon A was -0.27 mm/year, surgeon B was - 0.02 mm/year, surgeon C was -0.15 mm/year and surgeon D had the most pronounced trend at -0.29 mm/year. Scatter plots were used to depict the trends for male and female cup sizes in Figure 1 respectively.

Finally the effect of gender was analysed. We found that for three of the surgeons the trend in decreasing cup size was more pronounced for male subjects. Relative to females, the trend for smaller cups was 0.1 mm/year greater in male subjects for surgeon A, 1.19 mm/year for surgeon B and 1.64 mm/year for surgeon C. Surgeon D had the opposite trend with their female subjects having greater decrease in cup size compared to males at 0.53 mm/year.

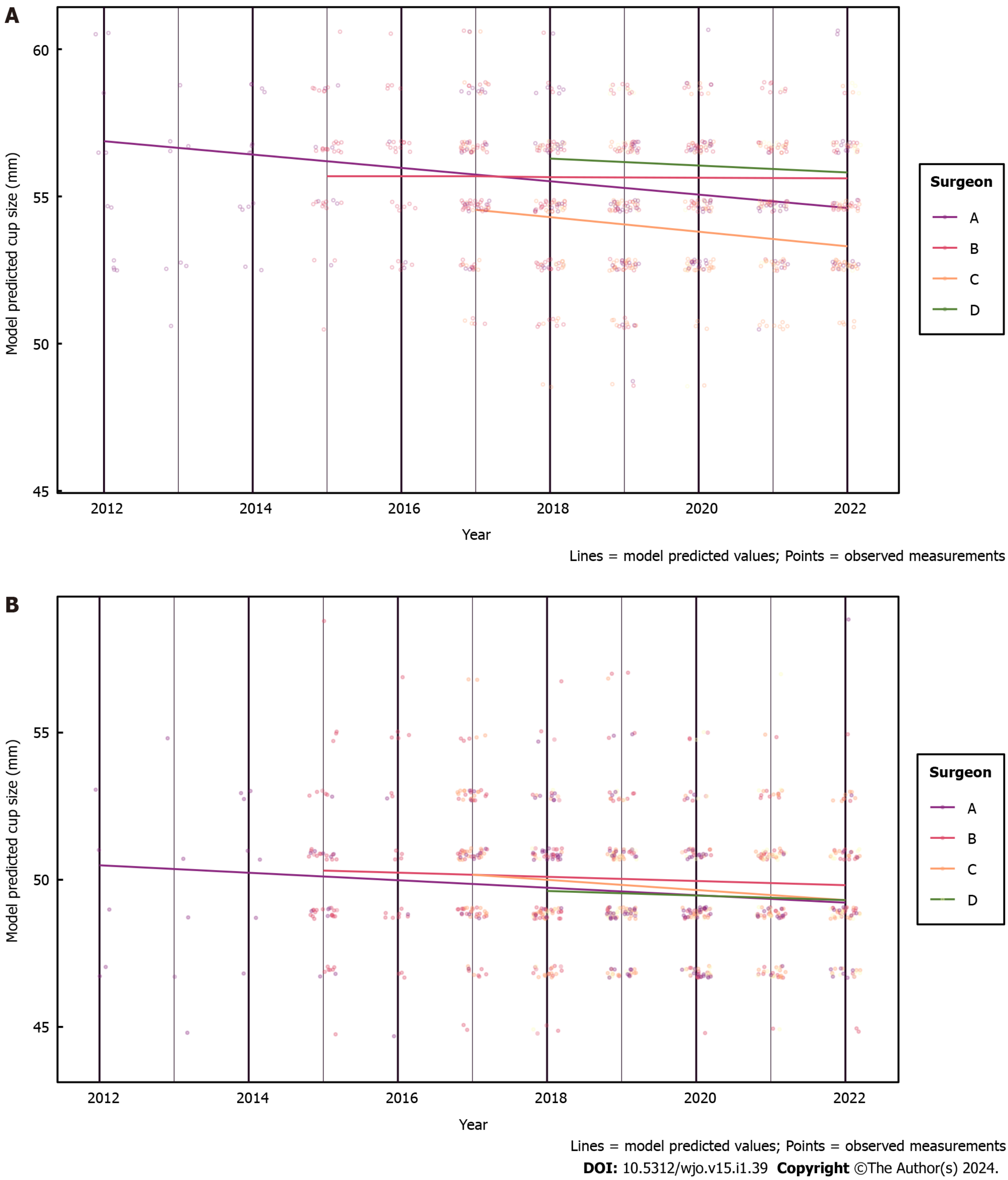

Figure 1 Cup size trends. A: Male; B: Female.

DISCUSSION

Training in orthopaedic surgery and the learning curve associated with individual procedures are ever evolving. Despite the virtues of simulation, apprenticeship learning still forms the basis of training[4]. However the definition of when a surgeon has become fully "trained" is not well-defined. Acetabular reaming is recognised as one of the most difficult skills in hip arthroplasty teaching[5]. Our findings were in keeping with our hypothesis that increasing experience would confer decreasing cup sizes. This is despite all of the operating surgeons completing arthroplasty fellowships prior to appointment as a consultant.

There is a paucity of evidence examining the trend for acetabular cup sizing in THA *vs* clinician experience. To our knowledge this case series is the first to investigate this theory. However one of the related skillsets needed for hip arthroplasty is proficiency in templating. It has been suggested that proficiency in cup size templating occurs at between 50 and

100 cases[6]. Given that templating is used to guide the ultimate acetabular component selected, one could expect the trend for cup size to remain static. Our findings identify that a trend towards smaller cup sizes exist, ever after performing more than 100 arthroplasties.

Interestingly 100 cases has been cited in other facets of hip arthroplasty as the critical volume needed to demonstrate competency. Recent interest in the direct anterior approach for hip arthroplasty has spawned a body of data examining the learning curve for this technique. A systematic review from Nairn *et al*[7] found that surrogate markers for competency such as intraoperative time and complication rates appear to plateau once a caseload of 100 cases has been reached. Perhaps acetabular reaming is a more subtle marker of competency in senior surgeons that can be used to assess familiarity with the procedure.

During our analysis we noted the following two cups systems to be in use; Trident Acetabular System (Stryker, Michigan, United Sates) and Pinnacle Hip Solutions (De Puy Synthes, Massachusetts, United States). These components were used by all four surgeons. None of the practices examined exclusively used one acetabular cup for the duration of the study. Even with this heterogenicity we found a significant trend to smaller cup sizes. For surgeons who are still acquiring arthroplasty skills and techniques, it should be noted that these uncemented cups ideally transmit forces through the acetabulum in a similar topographical distribution to the native hip joint[8]. Knowledge of these three load bearing surfaces should also for bone stock preservation and emphasises the need for intraoperative visual control.

The other finding of note from our study is that for three of the four consultant practices examined, the trend for decreasing cup size was more pronounced for male than female subjects. The size of reamer, depth of reaming and the angle subtended during the reaming process are all acknowledged to influence the volume of acetabular bone loss[9]. The reason for the male subjects having a more pronounced trend to smaller cups can only be speculated at this stage. It may be due to subconscious biases such as conservative reaming in osteoporotic acetabula which tend to be female. Our findings could present a target for future training if male subjects are found to be at risk of excess reaming and unnecessary bone loss.

Another hypothesis as to why the trend was more pronounced for males is the biomechanical properties of the pelvis that allow for press fit cup designs. *In vitro* testing has demonstrated that stable cup fixation is best achieved by buttressing against the three bones that comprise the acetabulum[10]. Female pelvises are known to be smaller and deeper than their male counterparts[11]. Given that the peripheral acetabular bone stock is of critical importance to stability, we speculate that the more inexperienced surgeon may use larger cups for male subjects in an effort to ensure adequate fixation in their shallower acetabula.

The main strengths of this case series are the number of subjects and the expertise of the fellowship trained arthroplasty surgeons. To the authors' knowledge it is the first descriptor of acetabular cup size trend *vs* surgeon experience. The main weaknesses are its inherently descriptive nature and the lack of an scientific explanation for the discrepancy in trends for male *vs* female subjects. We also acknowledge that a lack of data regarding the components used limits our results. Cup design is known to influence cup seating in THA[12]. This may in turn influence the degree of reaming required for different components.

Further studies examining surgeons of varying experience may show a more pronounced learning curve from larger to smaller cup sizes. We expect the decrease in cup size to be more evident with increasing surgeon experience. This in turn could be a marker of proficiency when gauging the abilities of an arthroplasty surgeon in training.

CONCLUSION

In our case series of four consultant hip arthroplasty surgeons, acetabular implant sizes continue to trend smaller with increasing experience in clinical practice. Fellowship trained arthroplasty surgeons continue to develop component sizing preferences even after their formalised training and this may serve as a surrogate marker of familiarity with the procedure and proficiency.

ARTICLE HIGHLIGHTS

Research background

To the authors knowledge this is the first study examining total hip arthoplasty experience and the relationship with acetabular cup size. Other facets of arthroplasty learning are documented however the trend towards ever decreasing cup sizes has not been previously described in the literature.

Research motivation

The motivation for this study was derived from noting a trend towards smaller acetabular cup sizes by one of the arthroplasty surgeons in our institution. We wanted to investigate if this observation was in fact correct and if so identify the underlying reasons.

Research objectives

The main objective was to record acetabular cup size used against time. This was completed by means of chart review. Future research by means of a prospective trial would benefit from standardization in cup size used.

Research methods

The log books from our elective theaters were cross checked with the national hip database. Acetabular cup sizes used were recorded for each surgeon. Logistic regression was then used to assess the trend against time.

Research results

We found experience in hip arthroplasty predicts an ever-decreasing acetabular cup size. The main unresolved question is why does this trend exists? This retrospective study also highlights that the trend for males appears to be more pronounced. This finding was unexpected and again the exact reason for this can only be speculated at this stage.

Research conclusions

This study proposes that even despite being fully trained in hip arthroplasty, a trend exists to ever decreasing acetabular cup sizes for arthroplasty surgeons.

Research perspectives

Future research should be targeted at investigating if these smaller acetabular cups result in improved clinical outcomes and also at the underlying reasons for this trend.

FOOTNOTES

Author contributions: All of the aforementioned authors contributed to this article; the study concept and design was devised by McKenna P and Cleary M; data collection was performed by McKenna DP and Price A; data analysis was completed by Dahly D; write up was completed by Mckenna DP with edits and proof reading provided by McAleese T, McKenna P and Cleary M.

Institutional review board statement: This study was classified as a service evaluation. In keeping with local guidelines and practice it did not require formal institutional board review.

Informed consent statement: Consent was not sought from subjects given its anonymised and retrospective nature.

Conflict-of-interest statement: The authors have no conflicts of interest to declare.

Data sharing statement: The dataset and statistical analysis information can be made available by the corresponding author upon request to danielmckenna21@rcsi.com. Consent was not sought from subjects given its anonymised and retrospective nature.

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ORIGINAL ARTICLE

Observational Study

Association between serum estradiol level and appendicular lean mass index in middle-aged postmenopausal women

Fang Jin, Yan-Fei Wang, Zhong-Xin Zhu

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Abstract

BACKGROUND

Previous studies investigating the association between loss of estrogen at menopause and skeletal muscle mass came to contradictory conclusions.

AIM

To evaluate the association between serum estradiol level and appendicular lean mass index in middle-aged postmenopausal women using population-based data.

METHODS

This study included 673 postmenopausal women, aged 40-59 years, from the National Health and Nutrition Examination Survey between 2013 and 2016. Weighted multivariable linear regression models were used to evaluate the association between serum E2 Level and appendicular lean mass index (ALMI). When non-linear associations were found by using weighted generalized additive model and smooth curve fitting, two-piecewise linear regression models were further applied to examine the threshold effects.

RESULTS

There was a positive association between serum E2 level and ALMI. Compared to individuals in quartile 1 group, those in other quartiles had higher ALMI levels. An inverted U-shaped curve relationship between serum E2 Level and ALMI was found on performing weighted generalized additive model and smooth curve fitting, and the inflection point was identified as a serum E2 level of 85 pg/mL.

CONCLUSION

Our results demonstrated an inverted U-shaped curve relationship between serum E2 levels and ALMI in middle-aged postmenopausal women, suggesting that low serum E2 levels play an important in the loss of muscle mass in middle-aged postmenopausal women.

Key Words: Estradiol; Skeletal muscle; Menopause; Health; The National Health and Nutrition Examination Survey

Core Tip: This paper evaluated the association between serum E2 level and appendicular lean mass index in middle-aged postmenopausal women from the National Health and Nutrition Examination Survey between 2013 and 2016, and found an inverted U-shaped curve relationship between them, with the point of inflection at a serum E2 level of 85 pg/mL.

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INTRODUCTION

Most women experience menopausal transition in middle age, when aging-related hormonal changes accelerate[1]. The onset of sarcopenia, a multifactorial condition related to the loss of muscle mass and quality, has been intimately linked to menopause[2,3].

Compared with the anabolic effects of androgens on the skeletal muscle mass in men[4,5], the effects of estrogens on the skeletal muscle mass in women are less clearly understood[6]. Moreover, previous studies on the association between the loss of estrogen at menopause and skeletal muscle mass or function came to contradictory conclusions[7]. As the most potent estrogen hormone, estradiol (E2) is responsible for the maintenance of sexual characteristics and muscle health[8]. Thus, we aimed to evaluate the association between serum E2 level and appendicular lean mass index (ALMI) in middle-aged postmenopausal women using population-based data.

MATERIALS AND METHODS

Data source and study population

The National Health and Nutrition Examination Survey (NHANES) is a large, ongoing cross-sectional survey conducted annually in a nationally representative sample of the non-institutionalized United States population. Data for this study were pooled from the NHANES between 2013 and 2016. The study population was restricted to postmenopausal women aged 40-59 years. Individuals with a regular period in the past 12 mo (n = 840), or with an unrecorded menopausal status (n = 287), as well as those with missing serum E2 Levels (n = 69) or ALMI data (n = 171) were excluded. Finally, 673 women were included in the analysis.

Written informed consent was obtained from all participants and the Institutional Review Board of the National Center for Health Statistics (NCHS) approved the survey protocols (Protocol #2011-17).

Study variables

The exposure variable was the serum E2 level, which was measured based on the reference method of the National Institute for Standards and Technology, using isotope dilution liquid chromatography tandem mass spectrometry. The outcome variable was ALMI, which was measured by dual-energy X-ray absorptiometry whole-body scans and calculated as the appendicular lean mass (kg) divided by height squared (m^2). The covariates included in this study were age, race, educational level, body mass index (BMI), ratio of family income to poverty, moderate activities, total protein, blood urea nitrogen, and serum uric acid and calcium levels. Detailed information on these variables can be found on the NHANES website (https://www.cdc.gov/nchs/nhanes/).

Statistical analyses

All estimates were applied with weights, in accordance with the guidelines edited by the NCHS[9], to account for the NHANES sampling method. All analyses were performed using EmpowerStats software (http://www.empowerstats.com) and R software (version 3.4.3). The statistical significance was set at P < 0.05. Weighted multivariable linear regression models were used to evaluate the association between serum E2 level and ALMI. Following the Strengthening the Reporting of Observational Studies in Epidemiology statement[10], we constructed three models: Model 1, no covariates were adjusted; Model 2, age and race were adjusted; and Model 3, all covariates presented in Table 1 were adjusted. When non-linear associations were found by using weighted generalized additive model and smooth curve fitting, two-piecewise linear regression models were further applied to examine the threshold effects.

Table 1 Weighted characteristics of study population based on serum estradiol level quartiles

Serum estradiol level (pg/mL)	Q1 (≤ 3.80)	Q2 (3.88-7.42)	Q3 (7.45-17.50)	Q4 (≥ 17.60)	*P* value
Age (yr)	54.4 ± 4.1	53.6 ± 4.0	52.9 ± 4.8	49.6 ± 4.9	< 0.001
Race/Ethnicity (%)					0.584
Non-Hispanic White	70.9	68.3	70.1	73.6	
Non-Hispanic Black	7.8	14.1	10.9	10.4	
Mexican American	6.1	8.3	8.3	6.3	
Other race/ethnicity	15.2	9.3	10.7	9.7	
Education level (%)					0.520
Less than high school	13.3	14.1	12.7	10.1	
High school	24.5	19.2	24.9	19.0	
More than high school	62.2	66.6	62.3	71.0	
Body mass index (kg/m^2)	25.6 ± 4.7	28.8 ± 4.8	32.2 ± 5.9	32.0 ± 8.3	< 0.001
Income to poverty ratio	3.0 ± 1.8	3.3 ± 1.7	3.1 ± 1.5	3.4 ± 1.6	0.143
Moderate activities (%)					0.965
Yes	49.1	47.2	49.7	49.8	
No	50.9	52.8	50.3	50.2	
Total protein (g/L)	69.9 ± 4.6	70.5 ± 4.1	71.1 ± 4.0	70.0 ± 3.4	0.022
Blood urea nitrogen (mg/dL)	5.0 ± 1.6	4.8 ± 1.6	4.8 ± 1.8	4.6 ± 1.2	0.076
Serum uric acid (umol/L)	263.8 ± 57.0	287.1 ± 69.7	302.9 ± 68.2	286.6 ± 67.6	< 0.001
Serum calcium (mg/dL)	2.4 ± 0.1	2.4 ± 0.1	2.4 ± 0.1	2.3 ± 0.1	0.092
Appendicular lean mass index (kg/m^2)	6.1 ± 1.0	6.8 ± 1.0	7.3 ± 1.1	7.5 ± 1.4	< 0.001

mean ± SD for continuous variables: *P* value was calculated by weighted linear regression model. "%" for categorical variables: *P* value was calculated by weighted chi-square test.

RESULTS

Demographic characteristics of the participants subclassified based on the serum E2 level quartiles (Q1: ≤ 3.80 pg/mL; Q2: 3.88-7.42 pg/mL; Q3: 7.45-17.50 pg/mL; and Q4: ≥ 17.60 pg/mL) are shown in Table 1. Compared with the Q1 group, individuals in other groups were younger, and had lower levels of blood urea nitrogen, and higher levels of income to poverty ratio, BMI, total protein, serum uric acid, and ALMI.

The association between serum E2 level and ALMI was positive in each model, with a significant P for trend among the different serum E2 level quartile groups (Table 2). In the subgroup analysis stratified by BMI and race, this positive association was significant in the group with BMI < 25 kg/m^2 (Table 3).

An inverted U-shaped curve relationship between serum E2 level and ALMI was found, as shown in Figure 1, and the inflection point was identified at a serum E2 level of 85 pg/mL (Table 4).

DISCUSSION

This study evaluated the association between serum E2 level and ALMI in middle-aged postmenopausal women, and found an inverted U-shaped curve relationship between them, with the point of inflection at a serum E2 level of 85 pg/mL.

Estrogens, especially E2, are known to play an important role in the preservation of muscle health. Several studies have investigated the effects of hormone replacement therapy (HRT) and found that it has a positive and measurable impact on muscle function[11,12]. Conversely, other studies found that HRT does not protect against muscle loss[13,14]. Moreover, it was reported that menopausal HRT was associated with an increased risk of adverse events, such as dementia[15], stroke[16], and breast cancer[17]. Therefore, it is important to balance the potential benefits against risks. Our results revealed an inverted U-shaped curve relationship between serum E2 level and ALMI, suggesting that adequate E2 supplementation may be a useful adjunct therapy for individuals with a low serum E2 level.

Table 2 Association between serum estradiol level (pg/mL) and appendicular lean mass index (kg/m²)

	Model 1 β (95%CI)	Model 2 β (95%CI)	Model 3 β (95%CI)
Serum estradiol level	0.004 (0.002, 0.007)[a]	0.003 (0.001, 0.005)[a]	0.001 (0.000, 0.002)[b]
Serum estradiol level categories			
Q1	Reference	Reference	Reference
Q2	0.665 (0.406, 0.924)	0.607 (0.356, 0.859)	0.090 (-0.036, 0.216)
Q3	1.222 (0.969, 1.475)	1.199 (0.953, 1.445)	0.128 (-0.002, 0.258)
Q4	1.369 (1.126, 1.612)	1.385 (1.133, 1.637)	0.268 (0.133, 0.402)
P value	< 0.001	< 0.001	< 0.001

[a]$P < 0.001$.
[b]$P < 0.01$.
Model 1: No covariates were adjusted. Model 2: Age and race were adjusted. Model 3: Age, race, educational level, body mass index, ratio of family income to poverty, moderate activities, total protein, blood urea nitrogen, serum uric acid, and serum calcium were adjusted.

Table 3 Association between serum estradiol level (pg/mL) and appendicular lean mass index (kg/m²), stratified by body mass index and race

	Model 1 β (95%CI)	Model 2 β (95%CI)	Model 3 β (95%CI)
Stratified by BMI			
BMI (< 25 kg/m^2)	0.002 (-0.000, 0.004)	0.001 (-0.001, 0.004)	0.002 (0.000, 0.003)[a]
BMI (25-29.9 kg/m^2)	0.003 (0.001, 0.005)[b]	0.002 (0.000, 0.004)[a]	0.001 (-0.001, 0.003)
BMI (≥ 30 kg/m^2)	0.006 (0.004, 0.009)[c]	0.005 (0.002, 0.008)[a]	0.001 (-0.001, 0.003)
Stratified by race			
Non-Hispanic White	0.003 (-0.000, 0.007)	0.002 (-0.002, 0.006)	0.002 (-0.000, 0.004)
Non-Hispanic Black	0.004 (0.000, 0.007)[a]	0.004 (-0.000, 0.007)	0.001 (-0.000, 0.003)
Mexican American	0.003 (-0.002, 0.008)	0.003 (-0.002, 0.008)	-0.003 (-0.005, 0.000)
Other race	0.015 (0.009, 0.022)[c]	0.013 (0.007, 0.020)[c]	0.002 (-0.001, 0.006)

[a]$P < 0.05$.
[b]$P < 0.01$.
[c]$P < 0.001$.
Model 1: No covariates were adjusted. Model 2: Age, and race were adjusted. Model 3: Age, race, educational level, body mass index, ratio of family income to poverty, moderate activities, total protein, blood urea nitrogen, serum uric acid, and serum calcium were adjusted. BMI: Body mass index.

The exact mechanism underlying the effects of E2 on skeletal muscle remains unclear. A possible explanation for the potentially beneficial effect is that E2 can stimulate the proliferative activity of the muscle satellite cells (stem cells) that are responsible for muscle tissue maintenance[18,19]. Another possible explanation is that estrogen deficiency results in the loss of muscle mass through apoptotic mechanisms[20,21]. Despite these possibilities, the molecular mechanism of the impact of E2 on muscle function needs to be further explored.

Data from the NHANES surveys were acquired following standard protocols, which ensured that the data were accurate and consistent. However, the limitations of this study should also be noted. First, a causal relationship between serum E2 level and ALMI in middle-aged postmenopausal women could not be determined due to the cross-sectional design of the NHANES surveys. Second, biases caused by unmeasured confounding factors cannot be excluded. Third, the conclusion cannot be generalized to older women because the population of this study was restricted to middle-aged postmenopausal women.

CONCLUSION

Overall, this study showed an inverted U-shaped curve relationship between serum E2 levels and ALMI in middle-aged postmenopausal women, suggesting that low serum E2 levels play a crucial role in the loss of muscle mass in middle-aged postmenopausal women.

Table 4 Threshold effect analysis of serum estradiol level on appendicular lean mass index using two-piecewise linear regression model

Appendicular lean mass index	Adjusted β (95%CI), *P* value
Serum estradiol level	
Fitting by standard linear model	0.001 (0.000, 0.002), 0.006
Fitting by two-piecewise linear model	
Inflection point	85 (pg/mL)
Serum estradiol level < 85 (pg/mL)	0.004 (0.002, 0.007), < 0.001
Serum estradiol level > 85 (pg/mL)	-0.001 (-0.003, 0.001), 0.280
Log likelihood ratio	0.003

Age, race, educational level, body mass index, ratio of family income to poverty, moderate activities, total protein, blood urea nitrogen, serum uric acid, and serum calcium were adjusted.

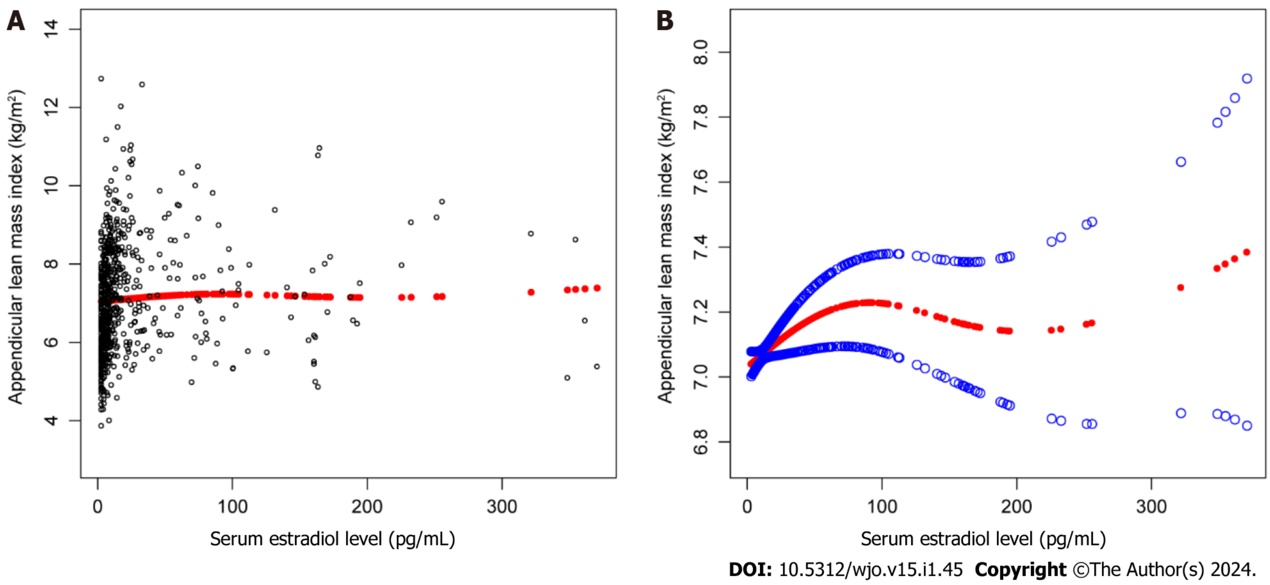

Figure 1 The association between serum estradiol level and appendicular lean mass index. A: Each black point represents a sample; B: Solid red line represents the smooth curve fit between variables.

ARTICLE HIGHLIGHTS

Research background

The onset of sarcopenia, a multifactorial condition related to the loss of muscle mass and quality, has been intimately linked to menopause.

Research motivation

Compared with the anabolic effects of androgens on the skeletal muscle mass in men, the effects of estrogens on the skeletal muscle mass in women are less clearly understood. Moreover, previous studies on the association between the loss of estrogen at menopause and skeletal muscle mass or function came to contradictory conclusions.

Research objectives

We aimed to evaluate the association between serum E2 level and appendicular lean mass index (ALMI) in middle-aged postmenopausal women using population-based data.

Research methods

This study included 673 postmenopausal women, aged 40-59 years, from the National Health and Nutrition Examination Survey between 2013 and 2016. Weighted multivariable linear regression models were used and when non-linear associations were found by using weighted generalized additive model and smooth curve fitting, two-piecewise linear regression models were further applied to examine the threshold effects.

Research results

There was a positive association between serum E2 level and ALMI. Compared to individuals in quartile 1 group, those in other quartiles had higher ALMI levels. An inverted U-shaped curve relationship between serum E2 level and ALMI was found on performing weighted generalized additive model and smooth curve fitting, and the inflection point was identified as a serum E2 Level of 85 pg/mL.

Research conclusions

Our results demonstrated an inverted U-shaped curve relationship between serum E2 levels and ALMI in middle-aged postmenopausal women, suggesting that low serum E2 Levels play an important in the loss of muscle mass in middle-aged postmenopausal women.

Research perspectives

The molecular mechanism of the impact of E2 on muscle function needs to be further explored.

FOOTNOTES

Author contributions: Jin F, Wang YF, and Zhu ZX contributed to data collection, analysis and writing of the manuscript; Zhu ZX contributed to study design and editing of the manuscript.

Institutional review board statement: The Institutional Review Board of the National Center for Health Statistics (NCHS) approved the survey protocols (Protocol #2011-17).

Informed consent statement: The datasets analysed during the current study are available at NHANES website. In accordance with ethical guidelines and research standards, informed consent was not required for this database-based study.

Conflict-of-interest statement: All the authors declare that they have no competing interests.

Data sharing statement: The datasets analysed during the current study are available at NHANES website (https://www.cdc.gov/nchs/nhanes/index.htm).

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ORIGINAL ARTICLE

Observational Study

Epidemiologic investigation of pediatric distal humerus fractures: An American insurance claims database study

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Abstract

BACKGROUND

Distal humerus elbow fractures are one of the most common traumatic fractures seen in pediatric patients and present as three main types: Supracondylar (SC), lateral condyle (LC), and medial epicondyle (ME) fractures.

AIM

To evaluate the epidemiology of pediatric distal humerus fractures (SC, LC, and ME) from an American insurance claims database.

METHODS

A retrospective review was performed on patients 17 years and younger with the ICD 9 and 10 codes for SC, LC and ME fractures based on the IBM Truven MarketScan® Commercial and IBM Truven MarketScan Medicare Supplemental databases. Patients from 2015 to 2020 were queried for treatments, patient age, sex, length of hospitalization, and comorbidities.

RESULTS

A total of 1133 SC, 154 LC, and 124 ME fractures were identified. SC fractures had the highest percentage of operation at 83%, followed by LC (78%) and ME fractures (41%). Male patients were, on average, older than female patients for both SC and ME fractures.

CONCLUSION

In the insurance claims databases used, SC fractures were the most reported, followed by LC fractures, and finally ME fractures. Age was identified to be a factor for how a pediatric distal humerus fractures, with patients with SC and LC fractures being younger than those with ME fractures. The peak age per injury per sex was similar to reported historic central tendencies, despite reported trends for younger physiologic development.

Key Words: Supracondylar humerus fracture; Lateral condyle fracture; Medial epicondyle fracture; Pediatric elbow; Truven; Epidemiology

Core Tip: In this insurance claims databases used, supracondylar (SC) fractures were the most reported, followed by lateral condyle (LC) and finally medial epicondyle (ME) fractures. Age was identified to be a factor for how a pediatric distal humerus fractures, with patients with SC and LC fractures being younger than those with ME fractures. The peak age per injury per sex was similar to reported historic central tendencies, despite reported trends for younger physiologic development.

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INTRODUCTION

Distal humerus fractures are one of the most common traumatic fractures seen in pediatric patients and present as three main types: Supracondylar (SC), lateral condyle (LC), and medial epicondyle (ME) fractures[1]. Historically, SC fractures are the most common with LC and ME fractures trailing after in incidence[1-3].

The pattern in which the pediatric distal humerus fractures is heavily influenced by both the force vector of injury as well as the remaining unfused ossification centers at the elbow[4,5]. SC fractures typically occur in children aged 5-10 years and are the result of a fall onto an outstretched arm[3-6]. LC fractures typically occur in children aged 4-10 years and are the result of a varus or valgus applied force to the elbow in extension[7]. ME fractures typically present in an older age group at 9-14 years[1,2,8-10]. Etiology consists of either trauma or an avulsion type injury from an overpull of the flexor-pronator mass[8-10].

The ossification centers and fusion at the elbow follow a very predictable sequential pattern[4,5]. Factors that influence the timing of ossification center fusion include injury across the physis, systemic diseases such as diabetes and hypothyroidism, endogenous stress hormones, and elevated estrogen at puberty[11]. Earlier ages of puberty have been observed in American children over the past three decades[12-14]. This phenomenon has implications for the age and injury pattern seen in American children now, in comparison with historic epidemiologic data.

The purpose of this study was to identify current epidemiologic data for pediatric distal humerus fractures between 2015-2020 in two insurance claims databases. The goal was to distinguish possible anthropometric differences with historic data. We hypothesized an overall younger central tendency for each of these injuries as compared to historic data, with a larger effect in females when compared with male patients. The clinical application of this investigation is intended to better predict injury patterns and counsel patients on modes of treatment.

MATERIALS AND METHODS

Population

From January 2015 to December 2020, we identified 1411 patients with an ICD 9 or 10 code designating them as having a SC, LC, or ME fracture. We included the ICD 9 codes 812.41 and 812.51 as well as the ICD 10 codes S42.41 and S42.42 (SC fractures). Also, ICD 9 codes 812.42 and 812.52 as well as ICD 10 code S42.45 (LC fractures) were included. Finally, we included ICD 9 codes 812.43 and 812.53 as well as ICD 10 code S42.44 (ME fractures). Selected patients were queried for CPT code treatments, patient age, sex, length of hospitalization, and comorbidities.

The patients were identified in the IBM Truven MarketScan® Commercial and IBM Truven MarketScan Medicare Supplemental databases. These databases contain de-identified, integrated, person-specific claim data. They are a conglomerate of three separate patient populations. The largest segment contains health information from participating large company employer-based health insurance, the second contains Medicare beneficiaries with supplemental

Table 1 Supracondylar fracture patient demographics

Treatment	Number of patients	Age (yr)	Male (%)
All SC patients	1133	6.76 ± 3.31	52
SC non-operative	194	8.86 ± 4.53	54
SC operative	939	6.32 ± 2.81	52
SC non-operative *vs* operative		P < 0.0001	P = 0.61
SC male	588	7.04 ± 3.56	100
SC female	545	6.45 ± 2.98	0
SC male *vs* female		P = 0.002	

SC: Supracondylar.

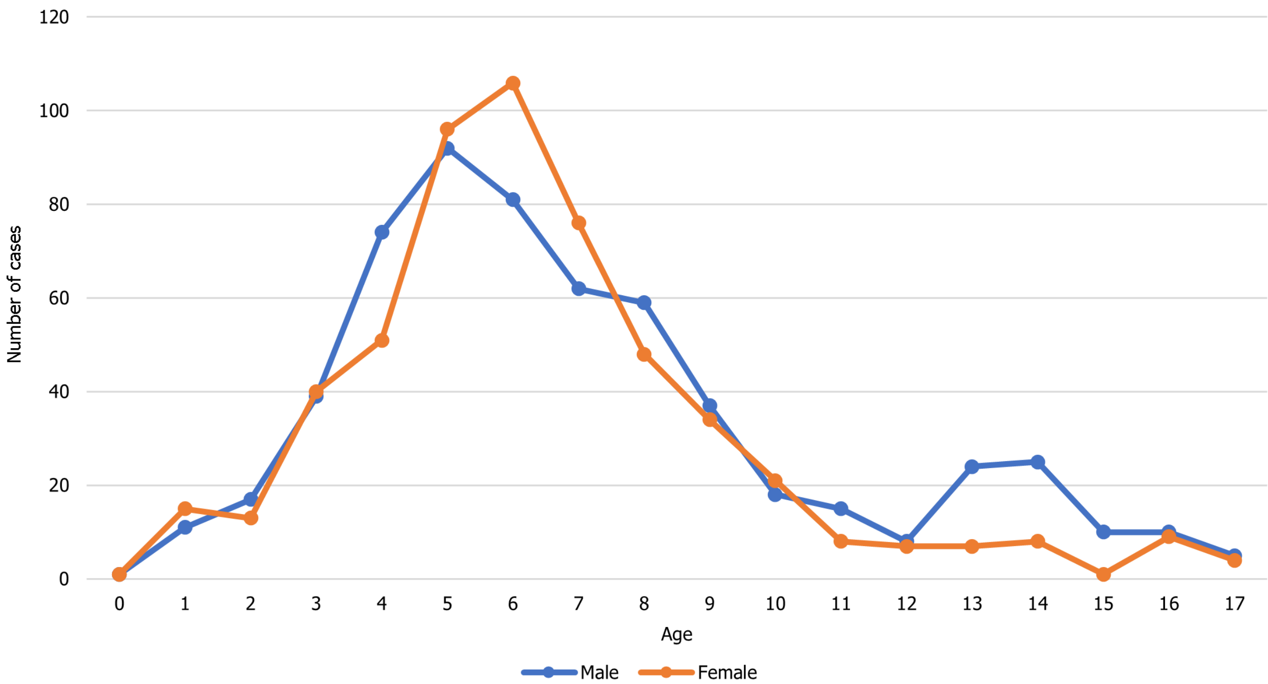

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Figure 1 Supracondylar male and female cases per age.

insurance provided by their employer, and the third includes 11 contributing state's Medicaid health information.

Statistical analysis

Data was organized by injury, patient age, and sex. Central tendency was calculated between the 25th and 75th percentiles. The distribution of continuous variables was assessed by the Kolmogorov-Smirnov test, and those with a normal distribution were analyzed by the unpaired t-test. Ordinal data was analyzed by the Chi-Square test or one-way analysis of variance for multiple variables. The comparison of proportions test was utilized for percentage analysis. Data entries were considered statistically significant if $P < 0.05$.

RESULTS

There were a total of 1133 patients with SC fractures at an average age of 6.76 ± 3.31 years, and 52% were male. There were 939 operative patients, 54% of which were male. Operative SC fracture patients were younger than nonoperative patients (6.32 ± 2.81 years *vs* 8.86 ± 4.53 years, $P < 0.0001$). The average age of male patients with SC fractures was 7.04 ± 3.56 years, with 50% having a fall between the ages of 5 and 9 years. The average age of female patients with SC fractures was 6.45 ± 2.98 years, with 50% having a fall between the ages of 5 and 7 years. Male patients were older than female patients (7.04 ± 3.56 years *vs* 6.45 ± 2.98 years, P =0.002) (Table 1, Figure 1).

Table 2 Lateral condyle fracture patient demographics

Treatment	Number of patients	Age (yr)	Male (%)
All LC patients	154	7.75 ± 4.2	64
LC non-operative	34	7.22 ± 3.81	65
LC operative	120	9.62 ± 4.91	63
LC non-operative *vs* operative		*P* = 0.009	*P* = 0.83
LC male	98	7.84 ± 4.1	100
LC female	56	7.59 ± 4.38	0
LC male *vs* female		*P* = 0.72	

LC: Lateral condyle.

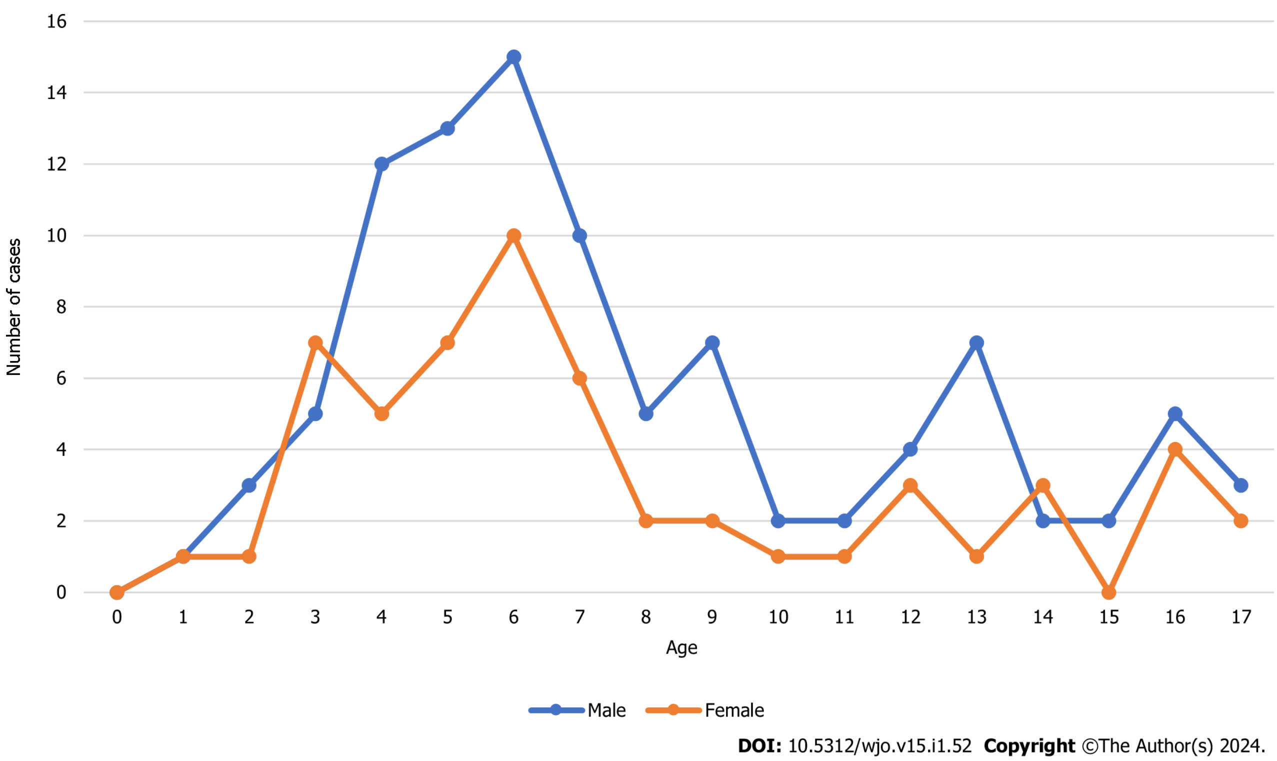

Figure 2 Lateral condyle male and female cases per age.

There were a total of 154 patients with LC fractures with an average age of 7.75 ± 4.2 years, and 64% were male. There were 120 operative patients, 63% of which were male. Operative LC fracture patients were older than nonoperative patients (9.62 ± 4.91 years *vs* 7.22 ± 3.81 years, P = 0.009). The average age of male patients with LC fractures was 7.84 ± 4.1 years, with 50% having a fall between the ages of 5 and 10 years. The average age of female patients with LC fractures was 7.59 ± 4.38 years, with 50% having a fall between the ages of 4 and 10 years (Table 2, Figure 2).

There were a total of 124 patients with ME fractures with an average age of 11 ± 3.86 years, and 47% were male. There were 51 operative patients, 45% of which were male. Operative ME fracture patients were older than nonoperative patients (12 ± 2.58 years *vs* 10 ± 4.43 years, P = 0.0045). The average age of male patients with ME fractures was 12.62 ± 3.67 years, with 50% having a fall between the ages of 10 and 15 years. The average age of female patients with ME fractures was 9.62 ± 3.52 years, with 50% having a fall between the ages of 7 and 12 years. Male patients were older than female patients (12 ± 3.67 years *vs* 9.62 ± 3.52 years, $P < 0.0001$) (Table 3, Figure 3).

When comparing across injury types, there was a statistically significant difference in the percentage of operative patients between SC and ME (83% *vs* 41%, $P < 0.0001$), and between LC and ME (78% *vs* 41%, $P < 0.0001$). Operative SC fracture patients were younger than those with LC (6.32 ± 2.81 years *vs* 9.62 ± 4.91 years, $P < 0.0001$) as well as ME fractures (6.32 ± 2.81 years *vs* 12 ± 2.58 years, $P < 0.0001$). Operative LC fracture patients were younger than those with ME fractures (9.62 ± 4.91 years *vs* 12 ± 2.58 years, P = 0.001). There was a statistical difference in sex among operative patients with SC (52% male), LC (63% male), and ME fractures (45% male) ($P < 0.05$; Table 4).

Table 3 Medial epicondyle fracture patient demographics

Treatment	Number of patients	Age (yr)	Male (%)
All ME patients	124	11 ± 3.86	47
ME non-operative	73	10 ± 4.43	48
ME operative	51	12 ± 2.58	45
ME non-operative *vs* operative		$P = 0.0045$	$P = 0.74$
ME male	58	12.62 ± 3.67	100
ME female	66	9.62 ± 3.52	0
ME male *vs* female		$P \leq 0.0001$	

ME: Medial epicondyle.

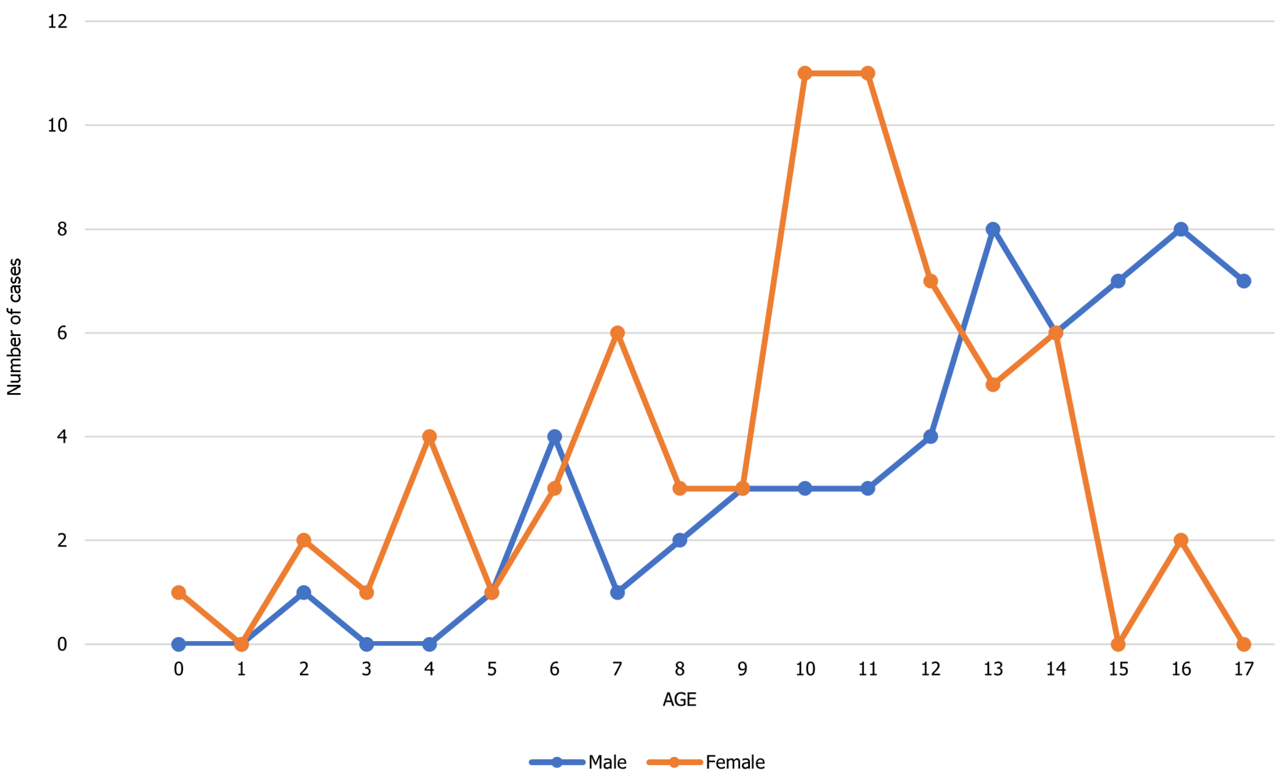

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Figure 3 Medial epicondyle male and female cases per age.

DISCUSSION

Pediatric distal humerus fractures are commonly encountered and therefore warrant continued epidemiologic investigation. SC fractures were the most represented in this study, followed by LC and finally ME fractures. American children may be undergoing developmental changes at earlier timepoints than in previous generations or in non-Western countries. This study identified differences in age and sex among the three injury types as well as in operative rate among injury types, with ME fractures having the lowest and SC fractures the highest operative rate.

Multiple contemporary studies have identified younger ages at which American female children and, to a lesser extent, male children undergo puberty[12-14]. A leading theory is directly linked with the simultaneous youth obesity epidemic in America[15-17]. Adiposity increases circulating estrogen and not only can initiate puberty, but it also has been found to directly close the physis[11,17-20]. Despite these population-wide trends, the effect on the distal humerus physis has not been shown in the orthopaedic literature. Peering back on previously published epidemiologic studies provides a comparison to our current landscape. One of the earliest pediatric elbow fracture epidemiologic studies collected the data from 1950-1979 in Sweden and found the average age of patients to be 7.4 ± 3.1 years for SC, 8.7 ± 3.9 years for LC, and ME 12 ± 2.3 years for ME fractures[21]. More recently, a Canadian study published results from 2002-2010 and found an

Table 4 Treatment comparison

Treatment	Total	Percentage of total (%)	Age (yr)	Male (%)
Operative SC	939	83	6.32 ± 2.81	52
Operative LC	120	78	9.62 ± 4.91	63
Operative ME	51	41	12 ± 2.58	45
Operative SC *vs* LC		$P = 0.13$	$P < 0.0001$	$P = 0.03$
Operative SC *vs* ME		$P < 0.0001$	$P < 0.0001$	$P = 0.01$
Operative LC *vs* ME		$P < 0.0001$	$P = 0.001$	$P = 0.002$

SC: Supracondylar; LC: Lateral condyle; ME: Medial epicondyle.

interquartile range of 3 to 6 years for all SC fractures[22]. Epidemiologic data has been published on non-Western populations with lower childhood obesity rates[23,24]. A 2013 Iranian study identified 8.1 ± 2.31 years old as the average age for all pediatric elbow fractures[25]. Similarly, an Indonesian study collecting data between 2009 to 2018 found the average age for all pediatric elbow fractures at 7.3 years[26]. In the American patient databases used, we did not observe any large age shifts from previous generations or for non-Western countries. Additional comparison studies can be found in Supplementary material[5,20-22,27-52].

Our study identified differences in patient sex distribution across the various fracture types. The 1998 study by Cheng *et al*[5] identified the sequence for the six pediatric elbow ossification centers and demonstrated that males lag about two years behind females. Our data coincides with the sex differences in ossification centers and physeal maturation, with male patients being older than female patients on average in SC and ME fractures[4,5]. The highest percentage of operative male patients was noted in those with LC fractures, while the lowest percent operative males was seen in those with ME fractures. In previous studies, ME fractures occur more frequently in a male population, likely due to mismatch between muscular strength and ME fusion site[7-9]. Our study identified more female ME fracture patients, possibly due to the increase in overall ligamentous laxity, larger elbow carrying angle, and continued increased involvement of women in overhead athletics[53-58].

Limits of the study

There were several limitations to this study. The data is retrospective in nature and were collected from de-identified insurance claims databases, so we were unable to read operative notes, review radiology exams, and analyze patient factors such as mode of injury, time from injury, body mass index, and follow-up. We also could only compare chronologic age and not bone age, which may be a better metric for this age group.

CONCLUSION

In the insurance claims databases used, SC fractures were the most reported, followed by LC and finally ME fractures. Age was identified to be a factor for how a pediatric distal humerus fractures, with SC and LC fracture patients being younger than ME fracture patients. The peak age per injury per sex is similar to reported historic central tendencies, despite reported trends for younger physiologic development. These results will help more accurately predict the type and treatment of distal humerus fractures in the American pediatric population.

ARTICLE HIGHLIGHTS

Research background

Distal humerus fractures are one of the most common traumatic fractures seen in pediatric patients and present as three main types: Supracondylar (SC), lateral condyle (LC), and medial epicondyle (ME) fractures and as such warrant continued, updated epidemiological evaluation.

Research motivation

The American pediatric population may be physiologically maturing at younger ages as compared to previous generations. This study aimed to look at common pediatric elbow injuries in relation to age and sex.

Research objectives

To explore patient age, sex, injury type, and treatment type for three common distal humerus fractures.

Research methods

A retrospective database review was performed.

Research results

SC fractures were the most reported, followed by LC and finally ME fractures.

Research conclusions

Age is a factor for how a pediatric distal humerus fractures, with patients with SC and LC fractures being younger than those with ME fractures.

Research perspectives

The peak age per injury per sex is similar to reported historic central tendencies, despite reported trends for younger physiologic development.

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FOOTNOTES

Author contributions: Klahs KJ wrote the manuscript and designed the project; Dertinger JE and Mello GT sorted and analyzed the data, and performed the literature review; Thapa K sorted and analyzed the data; Sandler AB assisted with manuscript formatting and edits; Garcia EJJ and Parnes N provided vision and direction, along with edits.

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ORIGINAL ARTICLE

Randomized Clinical Trial

Scoliocorrector Fatma-UI for correction of adolescent idiopathic scoliosis: Development, effectivity, safety and functional outcome

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Abstract

BACKGROUND

Adolescent idiopathic scoliosis remains a major problem due to its high incidence, high risk, and high cost. One of the aims of the management in scoliosis is to correct the deformity. Many techniques are available to correct scoliosis deformity; however, they are all far from ideal to achieve three-dimensional correction in scoliosis.

AIM

To develop a set of tools named Scoliocorrector Fatma-UI (SCFUI) to aid three-dimensional correction and to evaluate the efficacy, safety, and functional outcome.

METHODS
This study consists of two stages. In the first stage, we developed the SCFUI and tested it in finite element and biomechanical tests. The second stage was a single-blinded randomized clinical trial to evaluate the SCFUI compared to direct vertebral rotation (DVR). Forty-four subjects with adolescent idiopathic scoliosis were randomly allocated into the DVR group (n = 23) and SCFUI group (n = 21). Radiological, neurological, and functional outcome was compared between the groups.

RESULTS
Finite element revealed the maximum stress of the SCFUI components to be between 31.2 - 252 MPa. Biomechanical analysis revealed the modulus elasticity of SCFUI was 9561324 ± 633277 MPa. Both groups showed improvement in Cobb angle and sagittal profile, however the rotation angle was lower in the SCFUI group (11.59 ± 7.46 *vs* 18.23 ± 6.39, P = 0.001). Neurological and functional outcome were comparable in both groups.

CONCLUSION
We concluded that SCFUI developed in this study resulted in similar coronal and sagittal but better rotational correction compared to DVR. The safety and functional outcomes were also similar to DVR.

Key Words: Adolescent idiopathic scoliosis; Scoliocorrector Fatma-UI; Scoliosis surgery; Posteromedial translation; Direct vertebral rotation

Core Tip: We developed a novel set of tools to aid in the three-dimensional correction of adolescent idiopathic scoliosis. We performed finite element and biomechanical tests on the tools and evaluated its radiological, neurological and functional outcomes in a randomized clinical trial to ensure its efficacy and safety.

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INTRODUCTION

Adolescent idiopathic scoliosis (AIS) remains a major problem due to its high incidence, high risk, and high cost. The incidence of AIS is as high as 13%[1]. The management of AIS is also subject to a high risk of complications such as death, pseudoarthrosis, infection, neurological deficits, and pedicle screw misplacements[2]. The cost needed to manage AIS reached USD 55.000 in 1997 and USD 177.000 in 2012 and continues to increase[3].

One of the aims of management in adolescent idiopathic scoliosis is to correct the deformity. While coronal correction remains the major aim, corrections in sagittal and axial planes are also necessary. Both sagittal and axial plane deformity are associated with a decrease in lung function[4,5].

Many techniques are available to correct scoliosis deformities. However, all of them are far from ideal to achieve three-dimensional correction in scoliosis[6]. Direct vertebral rotation (DVR) gives excellent coronal and rotational correction but causes thoracic hypokyphosis[7]. Its safety is also questioned[8]. Posteromedial translation is reported to result in good coronal and sagittal correction but its rotational correction is questioned[6]. Sublaminar fixation point in posteromedial translation is located posterior to the rotational axis in scoliosis and may affect the axial correction[9]. Posteromedial translation also requires a universal clamp and sublaminar band, which are not available in many countries.

The aim of this study is to develop a set of tools named Scoliocorrector Fatma-UI (SCFUI) to aid three-dimensional scoliosis correction and to evaluate the efficacy, safety, and functional outcome of the tools in AIS surgery.

MATERIALS AND METHODS

This study consists of two stages. The first stage was the development of the SCFUI, as well as finite element and biomechanical analysis to evaluate the validity and safety of the SCFUI. The second stage was a single-blinded randomized clinical trial to evaluate the effectivity, safety, and functional outcome of the SCFUI compared to DVR.

SCFUI development

Development of SCFUI started in January to May 2020 in the Integrated Creative Learning Laboratory, Faculty of Technics, University of Indonesia. We listed anticipated benefits of the tools as well as ways to achieve them and formulated them in conceptual design. The conceptual design was subsequently developed into a technical design with an initial size complying with pedicle screws available in the market. Technical design was developed in Solidworks v.2017 software. The design was tested in finite element analysis using ANSYS v.2020 software. We tested the design by static structural method, no separation contact, automatic mesh, and stainless-steel 316L material with a testing force of 800N. We modified the size and design until the stress was lower than the yield strength of stainless steel 316L. Using Ultimaker Cura v.11, we modified the size and orientation of the SCFUI design to comply with the building machine. SCFUI was built using CNC milling Harford 1000 × 500 × 500 dan CNC Milling Eccoca 1050 × 550 × 500. The prototype was then tested using Universal Testing Machine Tensilon RTF 2350. Four hundred Newton force was used to pull SCFUI with a speed of 50 mm/s ten times, and the modulus of elasticity was recorded. The stress-strain curve was also generated. The prototype was pulled until the failure point to measure the maximum force and the response at the failure point.

Clinical trials

The second stage of the study was conducted in Fatmawati General Hospital from June 2020 to June 2021. The inclusion criteria were adolescent patients aged 11 to 18 with Lenke 1 idiopathic scoliosis 40-100 degrees without a history of previous spinal surgery. Forty-four subjects were randomized into the intervention group (SCFUI, n = 21) and control group (DVR, n = 23) using Randlist® software. The subject was blinded to the randomization. Ethical clearances from the Faculty of Medicine University of Indonesia number 615/UN2.F1/ETIK/PPM.00.02/2020 and Fatmawati General Hospital number DM01.01/VIII.2/294/2020 were obtained before the study.

Under general anesthetic and intraoperative neuromonitoring, the subject was put prone on two bolsters in the chest and pelvis region and fixed to the surgical table. The spine was exposed from the upper to lower instrumented vertebra (LIV). The upper instrumented vertebra (UIV) was the neutral vertebra cranial to upper-end vertebra while LIV was the last significantly touched vertebra. Screws were inserted into UIV, 1 level distal to UIV, apical vertebra, 1 level proximal and 1 level distal to apical vertebra, 1 level proximal to LIV and LIV. Whenever there were more than three subsequent vertebrae to UIV or LIV, additional screws were placed until there were no more than three instrumented subsequent vertebrae. The screws were inserted free hand without any specific attempt to hit the cortical bone in front of the vertical body, as it would increase risk of injury. A correction was performed according to the group allocation, and the wound was closed layer by layer.

For the intervention group, five pulleys were attached to the apical, one level above and below the apical screw, and to the closest screw proximal and distal to the apical screws. The correction board was attached to the surgical table on the concave side. Five correction screws and their housing were assembled and attached to the correction board according to the normal sagittal profile and intended direction of pulling. The lowest screw housing should be at least 5 cm higher than the most prominent point of the curve. Five wires were fixed to the correction screws and housings and circled to the pulleys to form moveable pulleys. A correction was achieved by gradually and alternately rotating the correction screws to pull the moveable pulleys. The pull was stopped when correction was achieved, screw rotation was maximized, or whenever there was a screw pullout. The convex rod was attached and secured with set screws. Pulleys were removed, and the concave rod was attached and secured with set screws.

For the control group, both rods were inserted and loosely secured with set screws. Tubes were inserted into the screws closest to the apical vertebrae. The vertebrae were rotated as neutral as possible and set screws were tightened. Other tubes were inserted into apical dan periapical screws and rotated while counter-rotation was performed on the distal neutral tubes. All set screws were tightened.

For radiological outcome, the coronal cobb angle and T5-12 kyphosis angle were measured from a standing radiograph, and rotational angle (RaSag) of the apical vertebra was measured from computed tomography (CT) scan. The radiograph and CT scan were obtained preoperatively and within 10 d after surgery. Intraoperative motor evoked potential, somatosensory evoked potential, and electromyography as well as post-operative motor power of the lower extremity were also recorded. Functional outcome was also measured using the SRS-22 questionnaire. The data were compared between groups, and statistical analysis was performed using STATA v. 14.

RESULTS

SCFUI development

We first identified the needs and then the principles and methods to fulfill the needs. The concept is shown in Table 1. Based on the concept, we developed a set of tools consisting of a correction board, correction screw, and its housing, wire, and pulley. The pulley is attached to pedicle screws and pulled toward correction screws secured by screw housing on the correction board (Figure 1).

From the finite element analysis, the maximum stress of the correction board, correction screw, screw housing, and wire were 126.5 MPa, 31.2 MPa, 92.1 MPa, and 252 MPa, respectively (Figure 2). Passing finite element analysis, the SCFUI prototype was built (Figure 3). Biomechanical analysis revealed the modulus elasticity of SCFUI to be 9561324 ± 633277 MPa. The stress-strain curve is shown in Figure 4. Failure of SCFUI was observed at 800 Nm as detachment of wire from correction screw.

Clinical study

Baseline characteristics of research subjects are shown in Table 2, while corrections using intervention and control groups are in Figure 5. Body weight, coronal curve, and rotational angle in the control group were higher than in the intervention

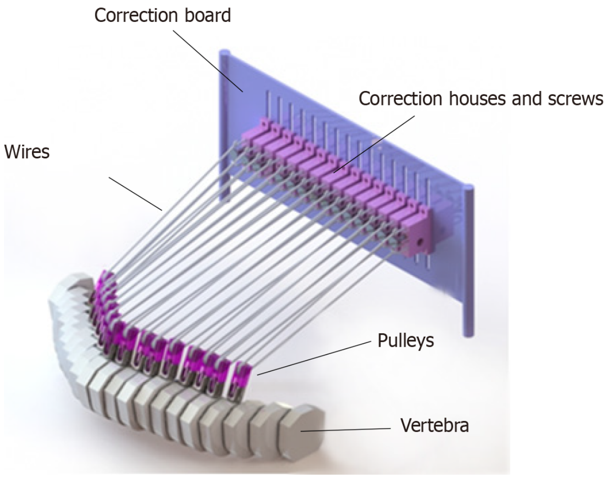

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Figure 1 Three-dimensional design of Scoliocorrector Fatma-UI. Scoliocorrector Fatma-UI consists of a board, pulling screws, screw housings, pulleys, and wire.

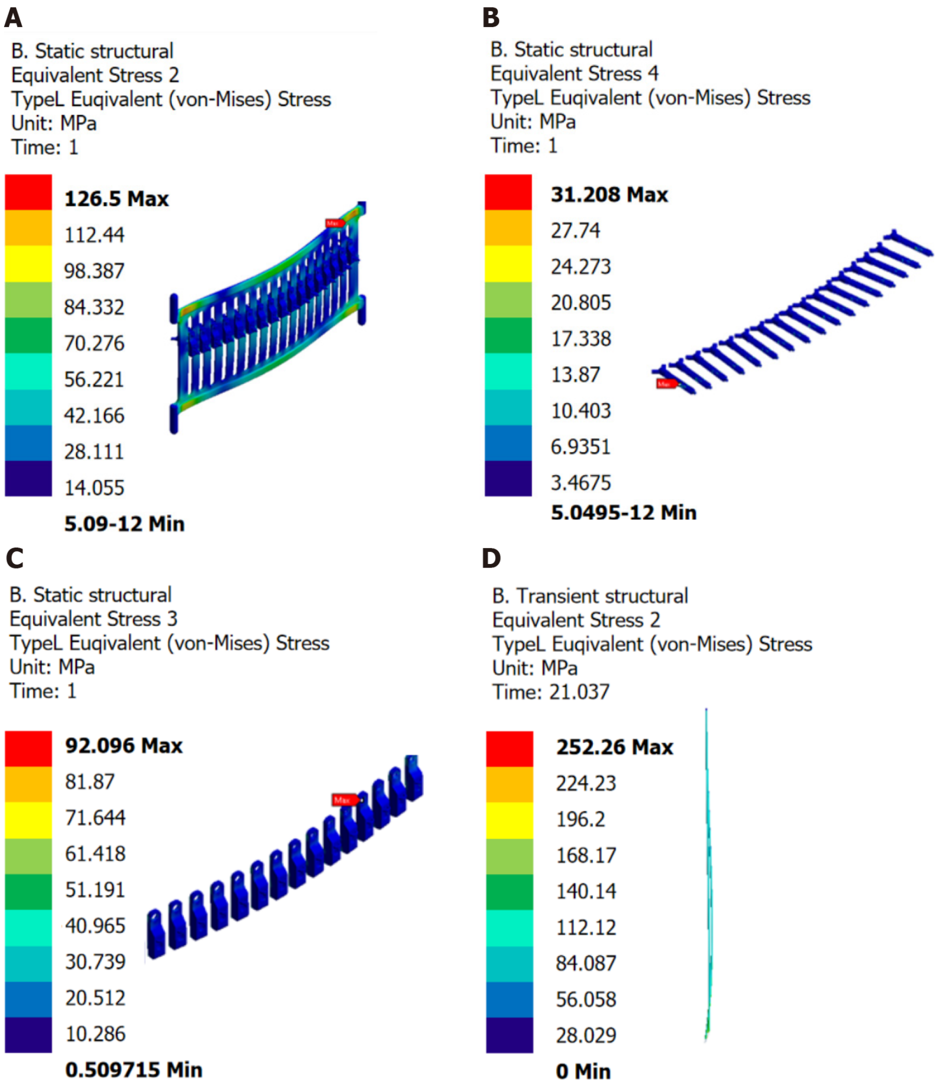

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Figure 2 Finite element analysis of Scoliocorrector Fatma-UI components. A: Correction board; B: Correction screw; C: Correction house; D: Wire. No deformation was observed in any of the components.

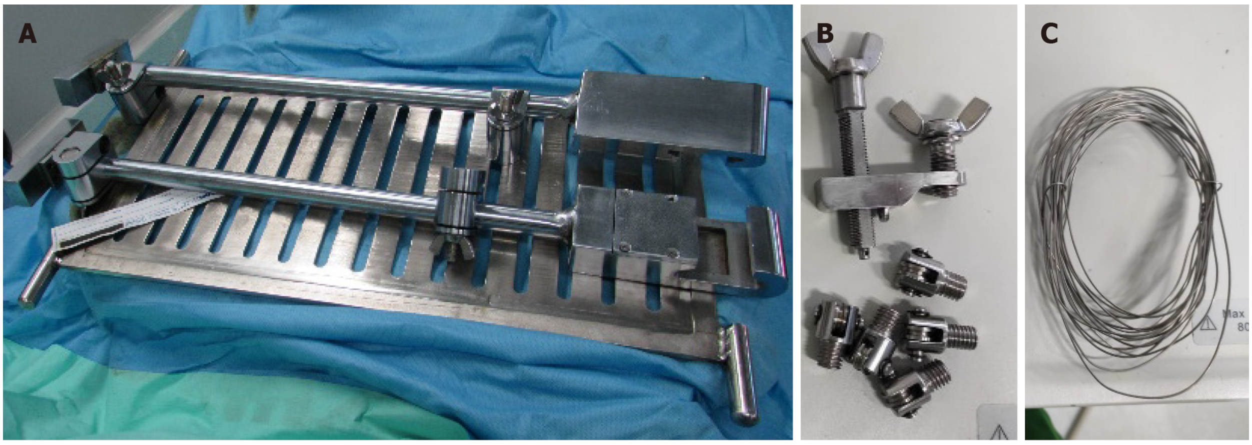

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Figure 3 Prototype of Scoliocorrector Fatma-UI. A: Correction board; B: Pulleys, correction house and correction screws; C: Wire.

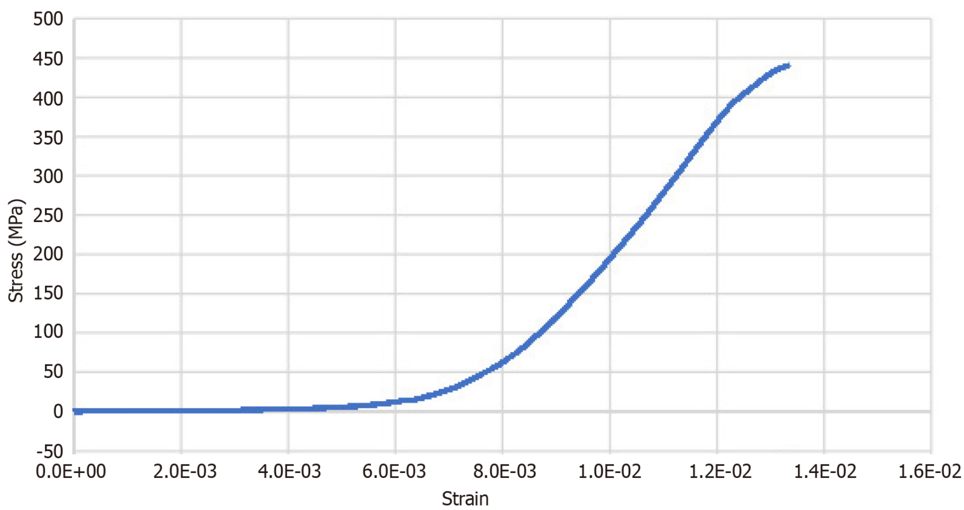

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Figure 4 Stress-strain curve of Scoliocorrector Fatma-UI. No breaking point was observed in this curve.

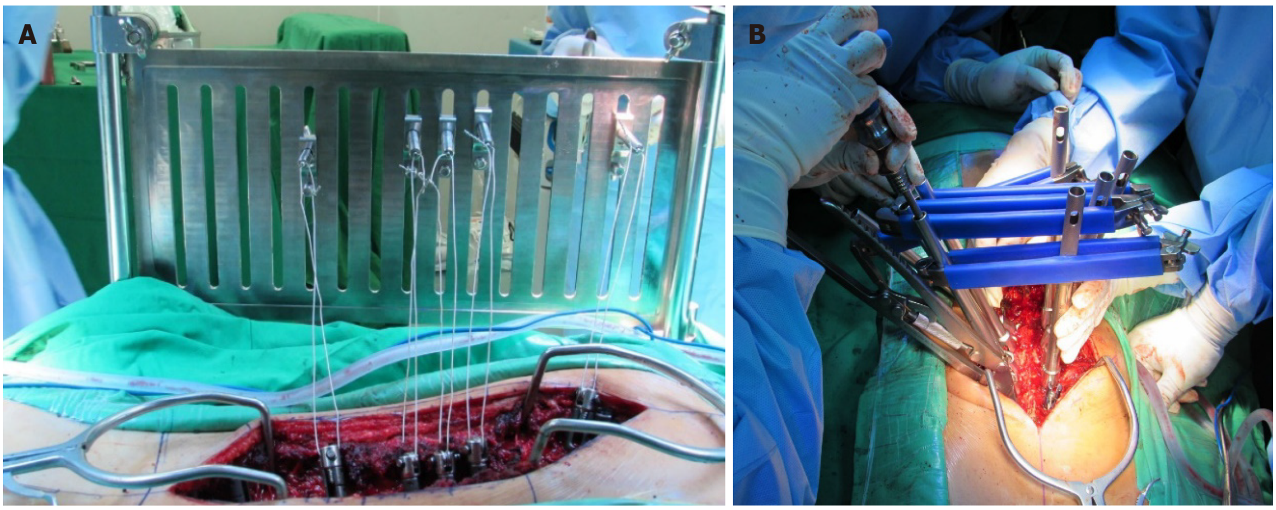

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Figure 5 Deformity correction using Scoliocorrector Fatma-UI and direct vertebral rotation. A: Scoliocorrector Fatma-UI (SCFUI); B: Direct vertebral rotation. Correction using SCFUI was done gradually.

Table 1 Concept of developing Scoliocorrector Fatma-UI

Need	Principle	Method
High failure load	Fixation of vertebrae using gold standard in spine surgery	Pedicle screw fixation
Good coronal correction	Long medial translation	Wire pulls from outside of the body
Good rotational correction	The correction axis should be anterior to the rotational axis of scoliosis	Pedicle screw fixation as it reaches to anterior corpus
	Long posteromedial translation	Wire pulls from outside of the body
Good sagittal correction	The pulling point height can be adjusted to a normal sagittal profile	Pulling board to accommodate height adjustment of pulling point
	Long posterior translation	Wire pulls from outside of the body
Low correction force	Mechanical advantages	Moveable pulley
Optimal pulling vector	The pulling vector could be adjusted	Moveable pulley
Controllable correction	Gradual correction	Screw threads to control gradual correction
Efficient	Correction could be maintained	Screw threads to maintain correction
Low risk of neurological injury due to sublaminar fixation	Others fixation anchor	Pedicle screw fixation
Low risk of neurological injury due to medial breaching	Avoid derotation of screws toward spinal canal	Wire pulls to the lateral vertebral canal
No risk of foreign body reaction	No extra implant	Removal of tools after correction is achieved

group.

Postoperatively, only rotational angle in the control group was higher than the intervention group (Table 3 and Figure 6). No abnormality of motor-evoked potential, somatosensory-evoked potential, or neurotonic discharge was found during surgery in either group (Figure 7). Postoperatively, no motor deficit was found in any group. During the study, no adverse event, screw pullout, or wire breakage was observed.

DISCUSSION

In the development of SCFUI, stainless-steel 316L was used as the material. Stainless-steel 316L is strong, stain-resistant, low maintenance, and economical[10]. It is also one of the most used alloys for spinal implants[11,12].

In finite element analysis, the highest stress was observed in the wire. However, the stress was lower than the yield strength and ultimate strength of stainless steel 316L[13]. It indicates that SCFUI is in the elastic phase, meaning that it can withstand force without any change in shape or failure[10,13]. During the analysis, the force used is far higher than the force required in clinical application or the force to cause screw pullout[13]. Moveable pulley configuration in SCFUI also gives a mechanical advantage to lower the force needed to correct the deformity up to 200%[14]. Biomechanical studies validated the finding of finite element analysis. The modulus elasticity of SCFUI is lower than the modulus elasticity of stainless-steel 316L and the stress-strain curve is proportional[13]. Hooke law describes that if the stress is proportional to the strain, a material is in the elastic condition; thus it will return to its initial shape whenever the force is removed[15].

At the point of failure, the wire attachment to the correction screw will be detached. The detachment occurs slowly and can be observed with the naked eye. The finding emphasizes the safety of SCFUI, as in the event of failure, it will not endanger the patient.

The SCFUI is therefore compliant with the ASTM F2193 standard[16]. ASTM F2193 is the international standard for the development of surgical instruments for spinal surgery. It included the design, strength, and safety of the instrument.

Coronal correction is important in the evaluation of surgery outcomes. For patients, coronal correction is the main indicator of the success of surgery. Medically, coronal correction is correlated to functional outcome[17]. In SCFUI, pedicle screw fixation is the use of higher force for correction. Moreover, the moveable pulley increases the force acting on the spine twofold. It also optimized the vector of pull.

Our coronal correction is similar to correction using posteromedial translation by Mazda *et al*[6]. They reported coronal correction of 66% ± 13%. A meta-analysis reported the coronal correction of scoliosis surgery was 60%-80% regardless of technique used for correction[18].

Evaluation of the sagittal profile is also important. An imbalance of the sagittal profile will result in poor pulmonary function and increased complications[19]. In our study, both techniques gave a good sagittal profile. The reported hypokyphosis due to DVR was not observed in our study.

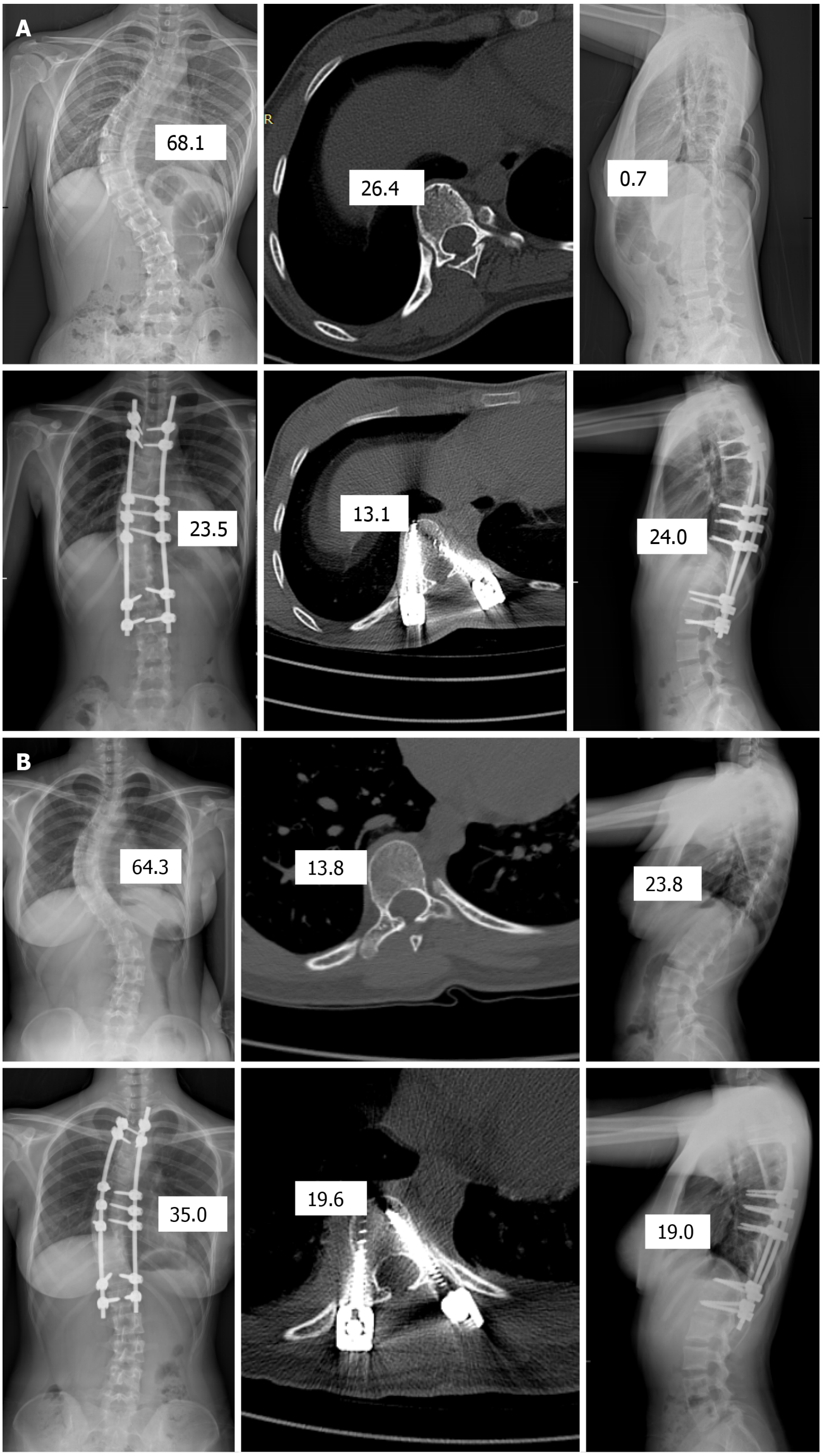

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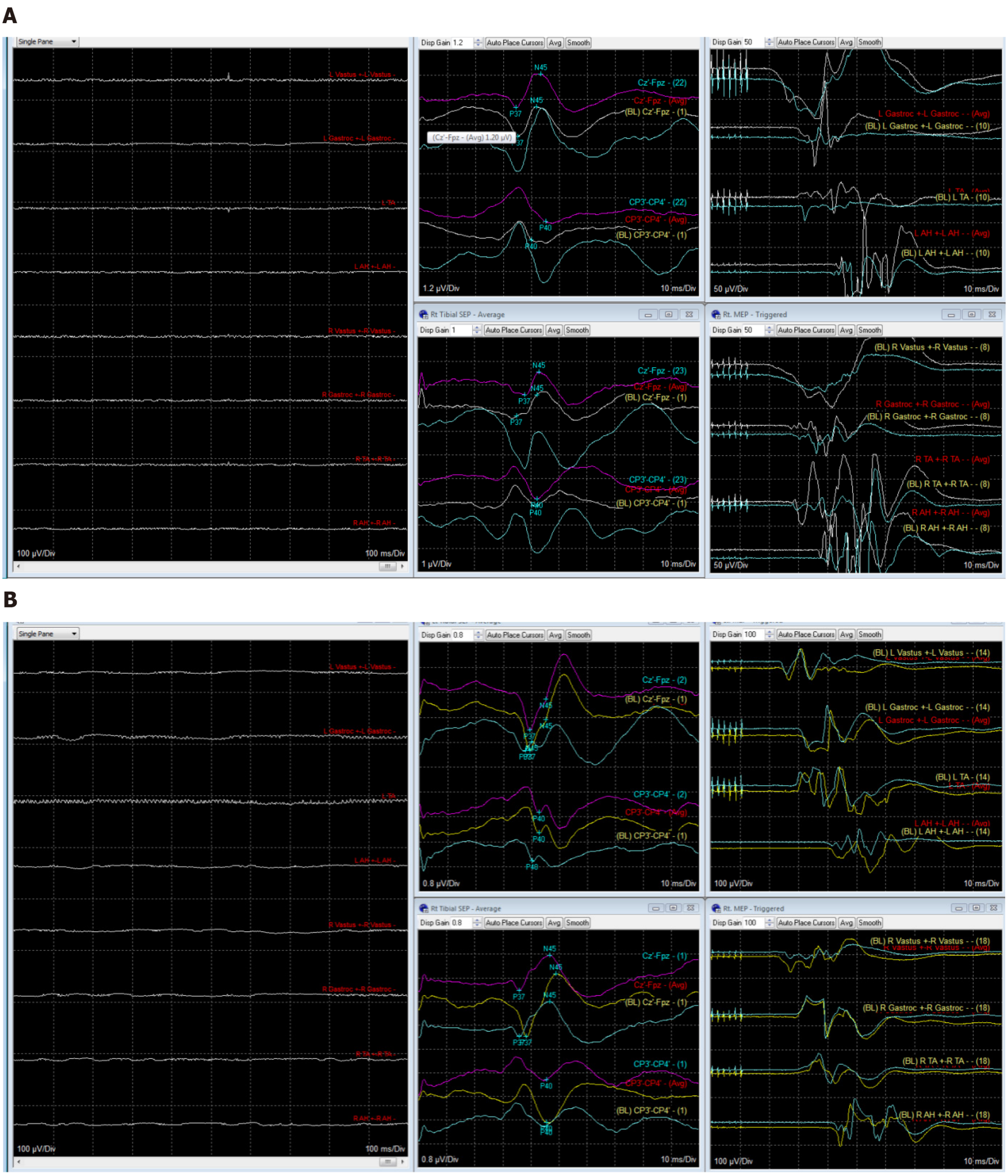
Figure 6 Radiographical finding of intervention and control group. A: Intervention group; B: Control group. Both groups improved in coronal, rotational, and sagittal angles although they were more profound in the intervention group.

A

B



DOI: 10.5312/wjo.v15.i1.61

Figure 7 Intraoperative neuromonitoring finding in intervention and control group patient. A: Intervention group patient; B: Control group patient. Blue graph indicated baseline recording and magenta graph indicated after correction recording. There was not any significant change of somatosensory evoked potential and motor-evoked potential during surgery in both groups.

SFCUI uses the correction board as the pulling point for translation. It allows a longer distance of posteromedial translation. However, the advantage of SCFUI over DVR for sagittal correction was not proven in our study. The advantage of SCFUI for sagittal correction is negated by the use of pedicle screws, which can also cause hypokyphosis. Moreover, the DVR in our study resulted in good sagittal correction.

Rotational correction is also emphasized in scoliosis correction[20]. Poor rotation will result in rib cage asymmetry and decreased respiratory function[21,22]. In our study, a better rotation correction was achieved by SCFUI. SCFUI utilized pedicle screw fixation that penetrate the vertebral body, thus allowing a fixation axis anterior to the rotation axis in scoliosis. Fixation points anterior to the rotational axis is mandatory to achieve adequate torsion for vertebra derotation [9]. However, it should be noted that our result is subject to bias, as a bigger rotational angle was found in the control

Table 2 Baseline charactersitics of the subjects

Characteristic	Intervention group, *n* = 21	Control group, *n* = 23	*P* value
Clinical			
Age - yr, mean (SD)	15.92 (0.35)	15.73 (1.51)	0.33[1]
Sex			
Male	2 (9.52)	4 (17.39)	0.67[2]
Female	19 (90.48)	19 (82.61)	
Body height - cm, mean (SD)	155.24 (7.52)	157.48 (6.1)	0.14[1]
Body weight - kg, mean (SD)	44.11 (5.66)	47.95 (6.78)	0.02[1]
Radiological			
Cobb angle - degree, mean (SD)	57.19 (6.78)	62.58 (8.51)	0.01[1]
Sagittal angle - degree, mean (SD)	17.7 (6.7)	20.08 (9.71)	0.18[1]
Rotational angle - degree, mean (SD)	14.76 (6.73)	19.42 (7.81)	0.02[1]
Sagittal profile			
Hypokyphosis	14 (66.67)	12 (52.17)	0.33[2]
Normokyphosis	7 (33.33)	11 (47.83)	
Functional			
SRS score - 22, mean (SD)	70.14 (6.81)	68.61 (6.85)	0.23[1]
Function domain, mean (SD)	4.13 (0.29)	4 (0.47)	0.13[1]
Pain domain, mean (SD)	3.55 (0.54)	3.61 (0.64)	0.38[1]
Self-image domain, mean (SD)	2.47 (0.6)	2.42 (0.59)	0.37[1]
Mental health domain, median (range)	4 (3-5)	3.6 (3-4.6)	0.41[3]

Data are , *n* (%) unless otherwise indicated.
[1]Unpaired t-test.
[2]Fischer test.
[3]Mann - Whitney test.
SD: Standard deviation.

Table 3 Postoperative characteristics of subjects

Characteristic	Intervention group, *n* = 21	Control group, *n* = 23	*P* value
Clinical			
Body height - cm, mean (SD)	159.28 (7.73)	161.13 (6)	0.19[1]
Body weight - kg, mean (SD)	44.19 (5.1)	48 (6.86)	0.02[1]
Radiological			
Cobb angle - degree, mean (SD)	16.28 (10.36)	20.79 (8.72)	0.06[1]
Coronal correction - percent, mean (SD)	71.92 (17.55)	67.39 (17.55)	0.16[1]
Sagittal angle - degree, mean (SD)	20.16 (4.75)	20.32 (6.63)	0.53[1]
Rotational angle - degree, mean (SD)	11.59 ± 7.46	18.23 ± 6.39	0.001[1]
Sagittal profile			
Hypokyphosis	11 (52.38)	10 (43.49)	0.56[2]
Normokyphosis	10 (47.62)	13 (56.52)	
Functional			
SRS-22 score, median (range)	63 (50-84)	68 (43-79)	0.62[3]

Function domain, mean (SD)	1.81 (0.41)	1.94 (0.42)	0.17[1]
Pain domain, mean (SD)	2.68 (0.56)	2.67 (0.58)	0.48[1]
Self-image domain, median (range)	3.4 (2.4-4.6)	3.6 (1.8-4.4)	0.83[3]
Mental health domain, mean (SD)	3.21 (0.68)	3.37 (0.74)	0.23[1]
Satisfaction, median (range)	4.5 (4-5)	4.5 (3-5)	0.4[3]

Data are , *n* (%) unless otherwise indicated.
[1]Unpaired t-test.
[2]Fischer test.
[3]Mann - Whitney test.
SD: Standard deviation.

group before the study.

We did not find any neurological deficits in our study. It might indicate that both techniques were safe. Nevertheless, scoliosis in our study was limited to a mild curve in which the incidence of neurological deficit is quite low[23]. The incidence of the neurological deficit will increase by the severity of the curve and the presence of hyperkyphosis[23,24]. None of the subjects in our study had hyperkyphosis.

SCFUI was developed with a novel design and complied with the international standard for spinal instruments[16]. The efficacy, safety, and functional outcomes had also been evaluated in the clinical study. However, our study was subject to several limitations. We did not measure the duration needed to assemble the correction tools until the correction was performed, nor whether bleeding occurred during the period. SCFUI is quite heavy and its assembly takes time. Further study is necessary to simplify the assembly and to reduce the size and weight. Scoliosis evaluated in this study was also very narrow, limited to Lenke type 1 curve only. Further study involving wider Lenke criteria should be performed.

CONCLUSION

We concluded that SCFUI developed in this study comply with the international standard for spinal instrument. It resulted in similar coronal and sagittal but potentially better rotational correction compared to DVR. The safety and functional outcomes were also similar to DVR.

ARTICLE HIGHLIGHTS

Research background

Adolescent idiopathic scoliosis remains a main problem in orthopedics due to its high incidence, high risk, and high cost.

Research motivation

Ideal correction of scoliosis should be three-dimensional. However, many techniques failed to achieve three-dimensional correction.

Research objectives

We developed a novel set of tools to aid three-dimensional correction of adolescent idiopathic scoliosis.

Research methods

We performed finite element and biomechanical test for the tools, and evaluated its radiological, neurological and functional outcomes in a randomized clinical trial to ensure its efficacy and safety.

Research results

The tools developed passed the finite element analysis and biomechanical test as well as clinical study.

Research conclusions

We developed a novel set of tools to aid three-dimensional correction of adolescent idiopathic scoliosis.

Research perspectives

A simplification of the tools.

FOOTNOTES

Author contributions: Phedy P contributed to the concepts, design, studies, data acquisition, data analysis, statistical analysis, manuscript preparation and review; Dilogo IH contributed to the design, studies, manuscript preparation and review; Indriatmi W contributed to the data analysis, statistical analysis, manuscript preparation and review; Supriadi S, Prasetyo M, and Octaviana F contributed equal contributions to study conception and design, data acquisition, data analysis, manuscript preparation and review; Noor Z contributed to the design, concept, clinical study, manuscript preparation and review.

Institutional review board statement: The study was reviewed and approved by the Ethical Committee Faculty of Medicine, University of Indonesia (Approval No. KET-615/UN2.F1/ETIK/PPM.00.02/2020) and Ethical Committee of Fatmawati General Hospital (Approval No. DM 01.01/VIII.2/1294/2020).

Clinical trial registration statement: This study was not registered on clinicaltrial.gov but it was registered with the University's ethical committee and hospital ethical committee prior to the study.

Informed consent statement: Informed consent was obtained prior to the study. The inform consent form was approved by the Ethical Committee Faculty of Medicine, University of Indonesia (Approval No. KET-615/UN2.F1/ETIK/PPM.00.02/2020).

Conflict-of-interest statement: The authors declare that they have no conflicts of interest.

Data sharing statement: Technical appendix, statistical code, and dataset available from the corresponding author at phedy.phe@gmail.com.

CONSORT 2010 statement: The authors have read the CONSORT 2010 statement, and the manuscript was prepared and revised according to the CONSORT 2010 statement.

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META-ANALYSIS

Which approach of total hip arthroplasty is the best efficacy and least complication?

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Abstract

BACKGROUND

Total hip arthroplasty is as an effective intervention to relieve pain and improve hip function. Approaches of the hip have been exhaustively explored about pros and cons. The efficacy and the complications of hip approaches remains inconclusive. This study conducted an umbrella review to systematically appraise previous meta-analysis (MAs) including conventional posterior approach (PA), and minimally invasive surgeries as the lateral approach (LA), direct anterior approach (DAA), 2-incisions method, mini-lateral approach and the newest technique direct superior approach (DSA) or supercapsular percutaneously-assisted total hip (SuperPath).

AIM

To compare the efficacy and complications of hip approaches that have been published in all MAs and randomized controlled trials (RCTs).

METHODS

MAs were identified from MEDLINE and Scopus from inception until 2023. RCTs were then updated from the latest MA to September 2023. This study included studies which compared hip approaches and reported at least one outcome such as Harris Hip Score (HHS), dislocation, intra-operative fracture, wound complication, nerve injury, operative time, operative blood loss, length of hospital stay, incision length and VAS pain. Data were independently selected, extracted and assessed by two reviewers. Network MA and cluster rank and surface under the cumulative ranking curve (SUCRA) were estimated for treatment efficacy and safety.

RESULTS

Finally, twenty-eight MAs (40 RCTs), and 13 RCTs were retrieved. In total 47 RCTs were included for reanalysis. The results of corrected covered area showed high degree (13.80%). Among 47 RCTs, most of the studies were low risk of bias in part of random process and outcome reporting, while other domains were medium to high risk of bias. DAA significantly provided higher HHS at three months than PA [pooled unstandardized mean difference (USMD): 3.49, 95% confidence interval (CI): 0.98, 6.00 with SUCRA: 85.9], followed by DSA/SuperPath (USMD: 1.57, 95%CI: -1.55, 4.69 with SUCRA: 57.6). All approaches had indifferent dislocation and intraoperative fracture rates. SUCRA comparing early functional outcome and composite complications (dislocation, intra-operative fracture, wound complication, and nerve injury) found DAA was the best approach followed by DSA/SuperPath.

CONCLUSION

DSA/SuperPath had better earlier functional outcome than PA, but still could not overcome the result of DAA. This technique might be the other preferred option with acceptable complications.

Key Words: Total hip arthroplasty; Total hip replacement; Approach; Supercapsular percutaneously-assisted total hip; Harris Hip Score; Intra-operative fracture

Core Tip: Total hip arthroplasty (THA) is as an effective intervention to relieve pain and improve hip function. Many minimally invasive surgeries have been proposed to preserve soft tissue and promote early recovery. Direct anterior approach and direct superior approach, the most popular and the newest technique, respectively have been explored about pros and cons to compare with previous conventional techniques. The results are still inconclusive. This is the first umbrella review that has included all systematic reviews and meta-analysis comparing the efficacy and complications among approaches of THA for patients in term of post-operative functional score and post-operative complications.

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INTRODUCTION

Total hip arthroplasty (THA) is an effective intervention for improvement of pain and hip function[1-4]. More than 1.4 million hip replacements are annually performed worldwide. Hip prosthesis has been established since 1950s[5]. Porous structure or bottom profile dimples of the ball type promote longevity, osteointegration and medullary revascularization [6-9]. Various bearing surfaces (*i.e.*, titanium on polyethylene, cobalt chromium molybdenum, ceramic, and polycrystalline diamond[10]), have been applied to optimize corrosive quality, stress reduction, contact pressure[11] and prevent osteolysis[2-4]. Survival of total hip replacement is not only influenced by deformation of prosthesis[2], acetabular cup inclination, body mass index (BMI)[3] and effects of pressure during walking[12,13], but it also depends on surgical approaches to the hip joint. Meanwhile, bleeding, wound problems, abductor muscle disruption and dislocation/instability were considered as common complications[7].

Approaches of the hip have been exhaustively explored about pros and cons. A conventional technique is the posterior approach (PA) by cutting short external rotator muscles. This technique provides a good exposure, but increases risk of hip dislocation[14]. Many minimally invasive surgeries (MIS) have been proposed to preserve soft tissue; promote early recovery, and lessen complications[6]. Direct lateral approach (LA) preserves posterior joint capsule, but may jeopardize superior gluteal nerve. Direct anterior approach (DAA) through an intermuscular plane[14] is the most popular, and preferred technique. Two-incision method combined anterior, to allow the acetabular cup placement, and posterior directions[15]. Mini-lateral approach (LMIS) can be performed with a shorter oblique skin incision without splitting or detaching muscle. Recently, direct superior approach (DSA) and supercapsular percutaneously-assisted total hip (SuperPath) are the newest MIS technique for PA by sparing the iliotibial band, obturator externus and quadratus femoris muscle[16,17]. An evidence from a randomized controlled trial (RCT) indicated that DSA was preferred to the postero-lateral approach in terms of blood loss, gait, and muscle strength[18]. SuperPath technique allowed shorter incision length[19], and early mobilization[17].

Many systematic reviews and meta-analysis (MA) of THA[6,20-46] showed that DAA could be beneficial for early hip function, and post-operative pain than other techniques[6,23,28,30,34-36,42,44,45]. Contradictory, it came up with a higher incidence of nerve injury[28,32,42,45,47], and inconsistent issues of other complications[6,31,37,39,44]. PA may be inferior to DAA, and other various hip approaches including DSA/SuperPath. A recent network MA reported conventional PA contributed to poorer hip function, insignificant complications, but had the advantage in shorter operative time when compared to DAA, DSA/SuperPath, MIS direct LA/anterolateral/PA[48]. Nevertheless, clinical important outcomes including hip dislocation, intra-operative fracture and wound complications were not considered. A comprehensive review of relevant MAs should lead to properly identify the best hip approach. This study hypothesized that various hip approaches provide different results. Therefore, an umbrella review was aimed to systematically appraise the quality of previous evidences and re-estimate the treatment effects and complication rates among THA approaches by re-pooling data. Update searching was filtered by the last search of when the previous MA was done, and at least 13 RCTs were recently added. A risk-benefit assessment (RBA) was also performed.

MATERIALS AND METHODS

An umbrella review of MAs was conducted with the following guidelines in the Preferred Reporting Items for Systematic Reviews and MA (PRISMA)[49]. The review protocol was registered in the international prospective register of systematic reviews; PROSPERO (CRD42017072580).

Located studies and study selection

PubMed and Scopus databases were used to identify data from an inception to the date of September 2023. Search terms were constructed according to patients (P), interventions (I), comparators (C), and outcomes (O), see Supplementary Table 1.

This study was divided into two parts, previous MAs exploration and update searching. First, previous MAs were explored and RCTs in those studies were retrieved. Previous MAs were eligible if they met the following criteria: systematic reviews of RCTs, use MA to obtain pooled effect size for outcomes that we are interested in among PA, LA, DAA, 2-incisions, LMIS, and DSA/SuperPath. One reviewer selected studies by titles and abstracts and another reviewer randomly checked about the accuracy. If a decision could not be made, the full texts were retrieved and reviewed. Any disagreement was resolved by discussion with a supervisor.

Second, updated searching was done and filtered from the last search of previous MA. Eligible RCTs were published in English language, studied in patients who underwent primary THA, compared with any pair among the hip approaches and reported at least one of the interested outcomes; Harris Hip Score (HHS), dislocation, intra-operative fracture, operative time, length of hospital stays, incision length, operative blood loss, wound complication, nerve injury, and visual analog scale (VAS). Studies were excluded if patients underwent bilateral THAs, or revision THA; had severe soft tissue damage; fracture or severe acetabular bone loss; computer navigation or robotic assisted surgery; modified techniques of each interested approach, *i.e.*, mini-posterior, modified PA; learning curve of surgeon; reported only long term outcomes; RCTs with randomization of other interventions rather than interested hip approaches, RCTs with randomization only of intervention groups comparing with one control group; and multiple publications.

Intervention and outcome of interests

The interested interventions were PA, LA, DAA, 2-incisions, LMIS, and DSA/SuperPath. The primary outcomes were HHS, dislocation, and intra-operative fracture. HHS ranged from 0 to 100, at follow up time of ≤ three months, six months, and one year[50]. Dislocation was diagnosed if a femoral head was not in the acetabular cup within the six-month post-operative period. Intra-operative fracture was defined as any fracture which occurred in the operative field.

The secondary outcomes were operative time (time at incision to the last stitch of wound closure, minutes), length of hospital stay (d), incision length (cm), operative blood loss (mL), wound complication (dehiscence, infection), nerve injury and VAS (0-10).

Risk of bias assessment

Risk of bias assessment was performed using a Risk of Bias Assessment Tool for Systematic Reviews (ROBIS)[51], which comprises three phases. Phase I assessed whether a systematic review/MA clearly stated their PICOS. Phase II assessed bias in the review process of study eligible criteria, identification and study selection, data collection and study appraisal and synthesis/finding. They were rated as low, high or unclear. The last phase was an overall judgement.

For each RCT, study quality was evaluated using The Cochrane Collaboration's tool for assessing risk of bias in randomized trials[52] This includes random sequence allocation, allocation concealment, blinding patients and assessors, blinding outcome assessment, incomplete outcome data management, and selective outcome reporting.

Data extraction

Characteristics of MAs were extracted including, databases used, last search date, number of included studies, type of intervention (PA, LA, DAA, 2-incisions, LMIS, and DSA/SuperPath), risk of bias assessment and outcomes of interest. Specific methods and findings were also extracted including pooled effect size along with 95% confidence interval (CI), pooling methods (fixed and random effects), heterogeneity assessment (*i.e.*, I^2 and Cochran Q test) and publication bias.

Furthermore, characteristics of the individual RCTs included in MA were also extracted to re-pool with updated RCTs beyond the last searching of previous MAs. Data was extracted including with general characteristics of study, patients and intervention-outcomes. Additionally, contingency data of interventions and outcomes were extracted for pooling dichotomous outcomes. Number of patients and mean value along with standard deviation were retrieved for pooling with continuous data.

The data extraction was independently performed by two reviewers. Disagreement was resolved by discussion with a supervisor.

Statistical analysis

The statistical methods of this study were reviewed by Sasivimol Rattanasiri, PhD, Associate Professor from the Department of Clinical Epidemiology and Biostatistics, Faculty of Medicine Ramathibodi Hospital, Mahidol University. Characteristics, results and risk of bias of MAs were summarized by using descriptive analysis. Overlapping studies were assessed using corrected covered area (CCA) to detect that previous individual RCTs were not included in previous MAs more than once. The citation matrix was constructed which assigned previous MAs in the first column and included individual RCTs in rows. The CCA was then classified as slight, moderate, high, and very high overlap if the CCA was 0% to 5%, 6% to 10%, 11% to 15%, and > 15%, respectively. Higher CCA reflects lower additional information across MAs.

This study also re-estimated the pooled effect size [*e.g.*, risk ratio (RR) or unstandardized mean difference (USMD)] using the data from individual RCTs that were included in these MAs and adding more studies by updating from the last search in the year 2019 from previous MAs. A fixed-effects model was used, if there was no evidence of heterogeneity, otherwise, the random-effects model was applied. Heterogeneity was present if P value for Q test was < 0.100 and I^2 was 25% or higher. Publication bias was determined by asymmetrical funnel plots and significant Egger's test. Constructed contour-enhanced funnel plots were further performed to distinguish between heterogeneity and publication bias.

A network MA (NMA) was conducted in the re-pooling process to estimate the mixed relative intervention effects by a two-stage approach. Six interventions (PA, reference, LA, DAA, 2-incisions, LMIS, and DSA/SuperPath) were coded as one, two, three, four, five, and six. Regression analysis with logit-link for dichotomous and identity-link for continuous outcomes was applied for each study. The coefficients and variance-covariance were then pooled using a multivariate MA with a consistency model, and estimated relative treatment effects. Inconsistency assumption was checked using a global Chi-square test. An adjusted funnel plot was constructed for publication bias assessment. Probability of being the best intervention was estimated and ranked using surface under cumulative ranking curve (SUCRA). All analyses were performed using STATA version 17.0, StataCorp, College Station, Texas, United States. P value < 0.05 was considered statistical significance.

RESULTS

For the first part, 28 MAs[6,20-46] were identified from PubMed and Scopus according to PICOS, including 61 RCTs. Finally, 40 RCTs were retrieved from previous MAs after screening for the eligible criteria and removing duplicated studies. For the second part, a total number of 85 and 101 studies were identified from PubMed and Scopus according to PICO. Thirteen RCTs met the inclusion criteria, and six duplicated studies were found. Finally, 47 RCTs[18,19,53-97] from both parts were included (Figure 1). The results of estimated CCA showed high degree (13.80%) of overlapping of individual RCTs among previous MAs (Supplementary Table 2).

Characteristics of eligible studies

The characteristics of 28 MAs are described in Table 1. Seventeen MAs included only RCTs. Twelve MAs including both RCTs and observational studies. These studies were published between the year 2014 and 2023 and had total sample sizes which ranged from 475 to 283036.

Flow chart of excluded studies with explanations according to PRISMA guidelines was constructed. Most studies were from USA, Europe and China. The numbers of included studies were thirteen PA *vs* DAA[53,54,56-58,69,75,84,85,87,88,94,96], thirteen LA *vs* DAA[55,59,61,67,71,74,76,77,79,81,82,86,97], seven PA *vs* LA[63,65,83,90-92,95], one PA *vs* two-incision [60], one PA *vs* LA *vs* two-incision[72], three LMIS *vs* LA[66,70,80], seven DSA/SuperPath *vs* PA[18,19,64,68,73,78,93] and two DSA/SuperPath *vs* LA[62,89]. The mean age was 51 to 76 years, BMI 21-31 kg/m^2, 13%-65% male and 20%-100% had hip osteoarthritis (Table 2).

Risk of bias assessment

Among 47 RCTs, most studies were low risk of bias for random sequence generation (89.4%), allocation concealment (36.2%), blinding of participants (29.8%), blinding outcome assessment (46.8%), incomplete outcome of data (40.4%), and selective outcome reporting (85.1%) (Figure 2, Supplementary Table 3). The ROBIS results from multiple reviews is shown in Figure 3.

Direct MA

Primary outcomes: According to functional outcomes, DAA significantly yielded the highest HHS at three months when compared with PA and LA (USMD: 2.79, 95%CI: 1.03, 4.55; and USMD: 3.76, 95%CI: 1.67, 5.85, respectively). There was no clinically significant difference of HHS at six months (DAA *vs* LA) and one year (DAA *vs* PA, DAA *vs* LA). All pairwise comparisons between hip approaches revealed no statistically significant dislocation and intraoperative fracture rate (Supplementary Tables 4 and 5).

Table 1 Characteristics of the 28 included meta-analysis studies

Ref.	Last search	Study design	Number of included studies	Sample size	Intervention	Reference	Outcome
Putananon *et al* [37], 2018	February, 2017	RCT	14	1201	PA/LA/DAA/PA2	PA	HHS, VAS, complications
Higgins *et al*[6], 2015	February, 2014	RCT & nRCT	17	2302	PA/DAA	PA	HHS, VAS, blood loss, intra-operative fracture, operative time, length of hospital stay, dislocation
Miller *et al*[34], 2018	June, 2017	RCT & nRCT	13	1044	PA/DAA	PA	HHS, dislocation, intra-operative fracture, wound infection
Wang *et al*[44], 2018	June, 2018	RCT	9	754	PA/DAA	PA	HHS, VAS, incision length, operative time, length of hospital stay, operative blood loss, intra-operative fracture, dislocation
Miller *et al*[35], 2018	June, 2017	RCT	7	609	PA/DAA	PA	Incision length, length of hospital stay, operative time, operative blood loss, pain score, complication
Kucukdurmaz *et al*[30], 2019	January, 2018	RCT & nRCT	17/1	1543	PA/LA/DAA	PA	HHS, operative time, incision length, VAS, neurapraxia, intra-operative fracture, wound infection, dislocation
Jia *et al*[28], 2019	August, 2016	RCT & nRCT	4/16	7377	PA/DAA	PA	HHS, length of hospital stay, operative time, VAS, dislocation, neurapraxia, intra-operative fracture
Wang *et al*[43], 2019	October, 2018	RCT	5	475	LA/DAA	LA	HHS, VAS, operative time, operative blood loss, length of hospital stay, complication
Migliorini *et al* [32], 2021	September, 2019	RCT & nRCT	20/39	10675	PA/LA/DAA	PA	Dislocation, nerve injury, revision
Migliorini *et al* [33], 2020	October, 2019	RCT & nRCT	13/23	4383	PA/LA/DAA	PA	Length of hospital stay, operative time, operative blood loss
Cha *et al*[22], 2020	October, 2019	RCT	8	673	PA/LA/DAA	PA	Operative time, Operative blood loss
Peng *et al*[36], 2020	November, 2019	RCT	7	600	PA/DAA	PA	HHS, VAS, operative time, operative blood loss, length of hospital stay, incision length
Docter *et al*[24], 2020	June, 2019	RCT & nRCT	19/50	283036	PA/LA/DAA	PA	Dislocation, intra-operative fracture, infection
Yang *et al*[45], 2020	June, 2019	RCT	11	932	PA/DAA	PA	VAS, neurapraxia, intra-operative fracture, infection, dislocation, operative time, operative blood loss, length of hospital stay
Chen *et al*[23], 2020	2020	RCT & nRCT	4 /14	34873	PA/DAA	PA	HHS, VAS, operative time, operative blood loss, length of hospital stay, dislocation, intra-operative fracture
Sun *et al*[42], 2021	June, 2019	RCT & nRCT	3 /6	22698	PA/DAA	PA	HHS, operative time, operative blood loss, length of hospital stay, complication
Awad *et al*[21], 2021	2021	RCT & nRCT	7/22	8576	PA/DAA	PA	HHS, operative time, operative blood loss, length of hospital stay, complication
Huerfano *et al* [27], 2021	2021	RCT & nRCT	5/20	7172	PA/DAA/	PA	Dislocation

Gazendam *et al* [25], 2022	2021	RCT	25	2339	PA/LA/ALA/DAA	PA	HHS, VAS, length of hospital stay, complication
Ge *et al*[26], 2021	2021	RCT & nRCT	3/3	526	DSA/SuperPath/PA	PA	HHS, operative time, operative blood loss, incision length, VAS, length of hospital stay
Joseph *et al*[29], 2023	2022	RCT	7	730	DSA/SuperPath/PA	PA	HHS, operative time, operative blood loss, incision length, VAS, length of hospital stay, complication
Lazaru *et al*[31], 2021	2021	RCT	9	998	DAA/PA	PA	HHS, operative time, operative blood loss, incision length, VAS
O'connor *et al* [105], 2021	2021	No RCT	15	1872	DAA/non-DAA	PA, ALA, LA	Infection
Ramadanov *et al* [39], 2021	2021	RCT	16	1392	DSA/SuperPath/DAA/PA	PA	HHS, operative time, operative blood loss, incision length, VAS
Ramadanov *et al* [40], 2021	2021	RCT	24	2074	DSA/SuperPath/DAA/PA	PA	HHS, operative time, operative blood loss, incision length, VAS, complication
Ramadanov *et al* [41], 2022	2022	RCT	20	1501	SuperPath/DAA/PA	PA	HHS, operative time, operative blood loss, incision length
Ramadanov *et al* [38], 2022	2022	RCT	14	1021	SuperPath/PA	PA	HHS, operative time, operative blood loss, incision length, VAS, complication
Zhou *et al*[46], 2022	2022	RCT	15	1450	DAA/PA/LA	PA, LA	HHS, operative time, length of hospital stay, complication
Ang *et al*[20], 2023	2023	RCT	24	2010	DAA/LA/PA	PA	HHS, operative time, length of hospital stay, complication

RCT: Randomized controlled trial; nRCT: Not randomized controlled trial; HHS: Harris hip score; VAS: Visual analog scale; PA: Posterior approach; LA: Lateral approach; DAA: Direct anterior approach; 2-incision: 2 incisions approach; LMIS: Mini-lateral approach; ALA: Anterolateral approach; DSA/SuperPath: Direct superior approach or Supercapsular percutaneously-assisted total hip.

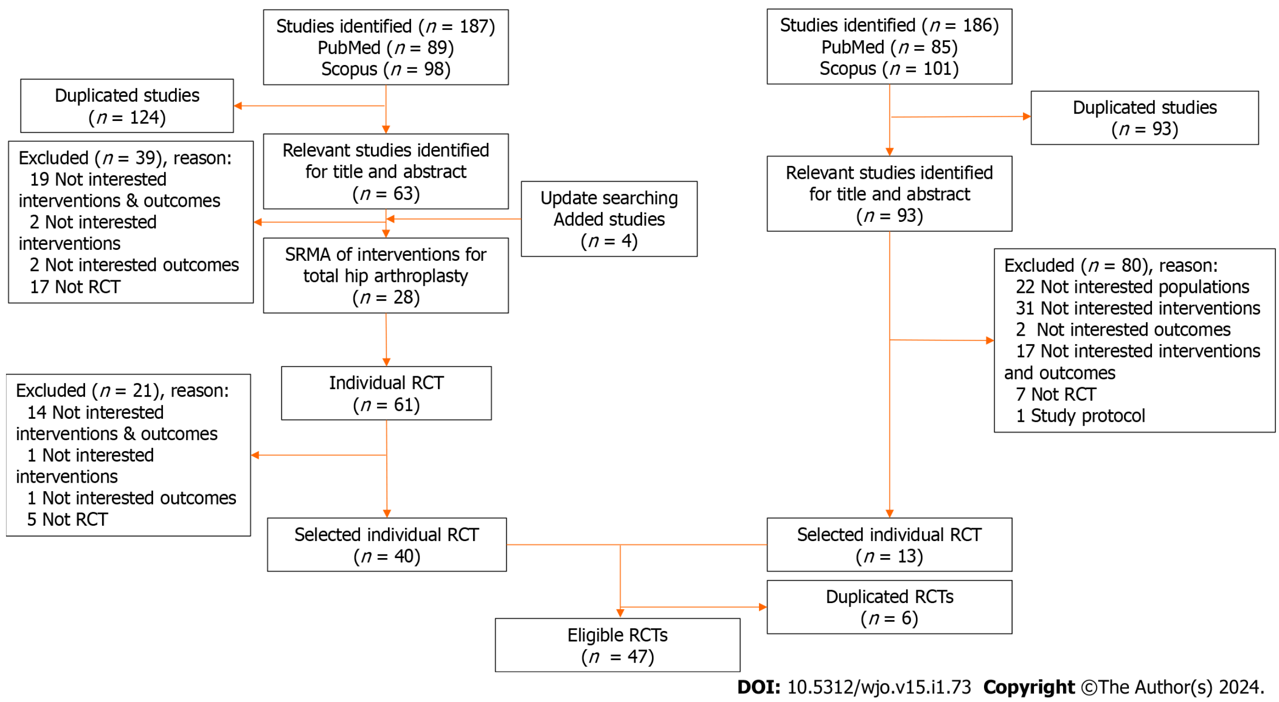


Figure 1 PRISMA flow diagram of the included studies. RCT: Randomized controlled trial.

Table 2 Characteristics of included 47 randomized controlled trials

Ref.	Country	Mean age	BMI	Male (%)	ASA	F/U (wk)	Diagnosis (% OA)	Intervention
Li *et al*[68], 2021	China	76.35	22.85	53.13	NR	NR	NR	DSA/SuperPath *vs* PA
Ulivi *et al*[18], 2021	Italy	72.98	23.51	37.78	NR	26	NR	DSA/SuperPath *vs* PA
Meng *et al*[19], 2021	China	64.90	23.09	42.50	2.35	52	NR	DSA/SuperPath *vs* PA
Rykov *et al*[84], 2021	Netherlands	62.50	28.20	41.30	1.59	52	NR	DAA *vs* PA
Cao *et al*[56], 2020	China	61.90	24.90	42.31	NR	26	NR	DAA *vs* PA
Nistor *et al*[76], 2020	Romania	62.63	28.15	41.07	NR	52	NR	DAA *vs* LA
Meng *et al*[73], 2019	China	51.00	21.49	100.00	1.66	52	NR	DSA/SuperPath *vs* PA
Wang *et al*[91], 2019	China	55.39	23.09	59.26	NR	52	100.00	LA *vs* PA
Moerenhout *et al*[75], 2020	Switzerland	69.66	27.10	52.73	1.90	260	NR	DAA *vs* PA
Li *et al*[67], 2019	China	62.00	23.26	73.33	NR	26	42.00	DAA *vs* LA
Bon *et al*[54], 2019	France	68.12	26.58	44.00	NR	NR	100.00	DAA *vs* PA
Ouyang *et al*[78], 2018	China	56.00	23.19	70.83	2.21	NR	20.83	DSA/SuperPath *vs* PA
Zomar *et al*[97], 2018	Canada	60.11	29.73	52.56	NR	12	100.00	DAA *vs* LA
Taunton *et al*[88], 2018	United States	64.51	29.48	51.00	NR	52	100.00	DAA *vs* PA
Brismar *et al*[55], 2018	Sweden	66.75	26.88	35.00	1.61	NR	51.00	DAA *vs* LA
Reichert *et al*[81], 2018	Germany	62.58	28.20	NR	NR	NR	100.00	DAA *vs* LA
Takada *et al*[86], 2018	Japan	62.60	24.40	13.33	NR	NR	100.00	DAA *vs* LA
Xie *et al*[93], 2017	China	65.54	23.84	66.30	NR	52	100.00	DSA/SuperPath *vs* PA
Cheng *et al*[57], 2017	Australia	61.28	28.01	45.20	1.96	12	100.00	DAA *vs* PA
Xu *et al*[94], 2017	China	58.27	24.49	60.92	NR	NR	NR	DAA *vs* PA
Nistor *et al*[77], 2017	Romania	63.75	28.04	40.00	NR	NR	100.00	DAA *vs* LA
Rosenlund *et al*[83], 2017	Denmark	61.03	27.51	65.00	1.32	52	NR	LA *vs* PA
Rykov *et al*[85], 2017	Netherlands	NR	NR	NR	NR	NR	84.80	DAA *vs* PA
Zhao *et al*[96], 2017	China	63.53	NR	NR	NR	NR	NR	DAA *vs* PA
Anta-Díaz *et al*[59], 2016	Spain	64.14	26.75	52.52	NR	52	100.00	DAA *vs* LA
Parvizi *et al*[79], 2016	United States	NR	NR	NR	NR	NR	100.00	DAA *vs* LA
Luo *et al*[69], 2016	China	NR	NR	NR	NR	NR	NR	LA *vs* PA
Christensen *et al*[58], 2015	United States	64.71	30.78	47.10	NR	NR	NR	DAA *vs* PA
Mjaaland *et al*[74], 2015	Norway	66.42	27.65	33.50	1.85	NR	100.00	DAA *vs* LA
Vicente *et al*[90], 2015	Brazil	55.94	27.38	55.36	NR	24	52.68	LA *vs* PA
Dienstknecht *et al*[61], 2014	Germany	61.53	29.14	44.06	2.26	NR	100.00	DAA *vs* LA
Taunton *et al*[87], 2014	United States	64.23	28.45	46.30	NR	52	NR	DAA *vs* PA
Landgraeber *et al*[66], 2013	Germany	70.66	26.90	34.21	2.06	156	100.00	LMIS *vs* LA
Barrett *et al*[53], 2013	United States	62.31	29.89	55.20	NR	52	NR	DAA *vs* PA

Ji *et al*[65], 2012	S. Korea	51.49	24.30	57.10	NR	150	37.20	LA *vs* PA
Martin *et al*[70], 2011	Belgium	64.92	30.00	31.33	2.14	52	Most	LMIS *vs* LA
Goosen *et al*[63], 2011	Netherlands	62.00	26.45	48.30	NR	NR	NR	LA *vs* PA
Pospischill *et al*[80], 2010	Austria	61.25	25.70	50.00	NR	12	100.00	LMIS *vs* LA
Yang *et al*[95], 2010	China	57.78	22.77	50.91	NR	NR	20	LA *vs* PA
Della Valle *et al*[60], 2010	United States	62.46	27.45	31.90	2.06	NR	100.00	2-incision *vs* PA
Restrepo *et al*[82], 2010	United States	59.95	25.18	39.39	2.13	NR	NR	DAA *vs* LA
Mayr *et al*[71], 2009	Switzerland	68.02	27.99	42.42	NR	NR	NR	DAA *vs* LA
Meneghini *et al*[72], 2009	United States	54.00	26.00	NR	NR	NR	NR	2-incision *vs* LA *vs* PA
Witzleb *et al*[92], 2009	Germany	55.88	27.75	48.33	NR	12	56.70	LA *vs* PA
Yan *et al*[89], 2017	China	65.42	23.97	46.10	NR	60	NR	SuperPath *vs* LA
Yuan *et al*[64], 2018	China	75.03	22.54	55.56	NR	72	NR	SuperPath *vs* PA
Dongwei *et al*[62], 2016	China	58.21	NR	NR	NR	12	100.00	SuperPath *vs* LA

RCT: Randomized controlled trial; BMI: Body mass index (kg/m^2); OA: Osteoarthritis; NR: Not reported; PA: Posterior approach; LA: Lateral approach; DAA: Direct anterior approach; 2-incision: 2 incisions approach; LMIS: Mini-lateral approach; DSA/SuperPath: Direct superior approach or Supercapsular percutaneously assisted total hip.

Secondary outcomes: DSA/SuperPath and DAA had significant longer operative time than PA (18.55 min, 95%CI: 4.84, 32.27; and 17.17 min, 95%CI: 10.91, 23.42, respectively). DAA allowed shorter length of hospital stays than PA and LA (-0.39 d, 95%CI: -0.57, -0.21; and -0.57 d, 95%CI: -1.02, -0.11, orderly). Incision lengths of DAA and DSA/SuperPath were significantly shorter than PA (USMD: -2.2; 95%CI: -4.21, -0.19; and USMD: -4.38, 95%CI: -5.61, -3.16, respectively). Furthermore, DAA also had significantly shorter incision length than LA with USMD of -1.27 (95%CI: -2.22, -0.33).

Among, the newer techniques (DAA and DSA/SuperPath) DAA encountered with higher operative blood loss than PA with USMD of 52.02 mL (95%CI: 3.77, 100.27), but DSA yielded a better result when compared to PA with USMD of -17.54 mL (-66.09, 31.01). DAA significantly increased nerve injury when compared to PA with pooled RR 13.57 (95%CI: 3.17, 58.10). There was no significant nerve injury and wound complication rates among other treatment pairs (Supplementary Tables 4 and 5).

Heterogeneity was detected and explored for source of heterogeneity (Supplementary Table 6). Funnel plots and countour enhanced funnel plot were constructed (Supplementary Figure 1).

NMA

Network maps were constructed according to the interventions and outcomes (Figure 4).

Primary outcomes: DAA significantly demonstrated higher HHS at three months and one year than PA (pooled USMD: 3.49, 95%CI: 0.98, 6.00; and pooled USMD: 1.76, 95%CI: 1,12, 2.40, respectively). DAA also contributed higher HHS at one year when compared to 2-incisions, DSA/SuperPath, LA, and PA with pooled USMDs 3.70 (95%CI: 0.62, 6.78), 1.34 (95%CI: 0.39, 2.29), 1.17 (95%CI: 0.20, 2.14), and 1.76 (95%CI: 1.12, 2.40), respectively (Table 3).

DAA was the best rank of HHS at three and twelve months with the SUCRAs of 85.9 and 90.7, respectively. Whereas at 6 mo, DSA was the best rank with the SUCRAs of 61.1. Six approaches demonstrated non-significant difference in dislocation and intraoperative fracture rates. The lowest dislocation rate was found in DAA (SUCRA: 61.5) followed by LMIS (SUCRA: 50.9) and the lowest intraoperative fracture rate was from DAA (SUCRA: 70.7) followed by PA (SUCRA: 67.3).

SUCRAs of benefit in improving HHS and risk in dislocation and fracture, indicated that DAA was the highest in HHS, dislocation and intra-operative fractures. PA was the worst in HHS with the third rank of dislocation and the second rank of intraoperative fracture.

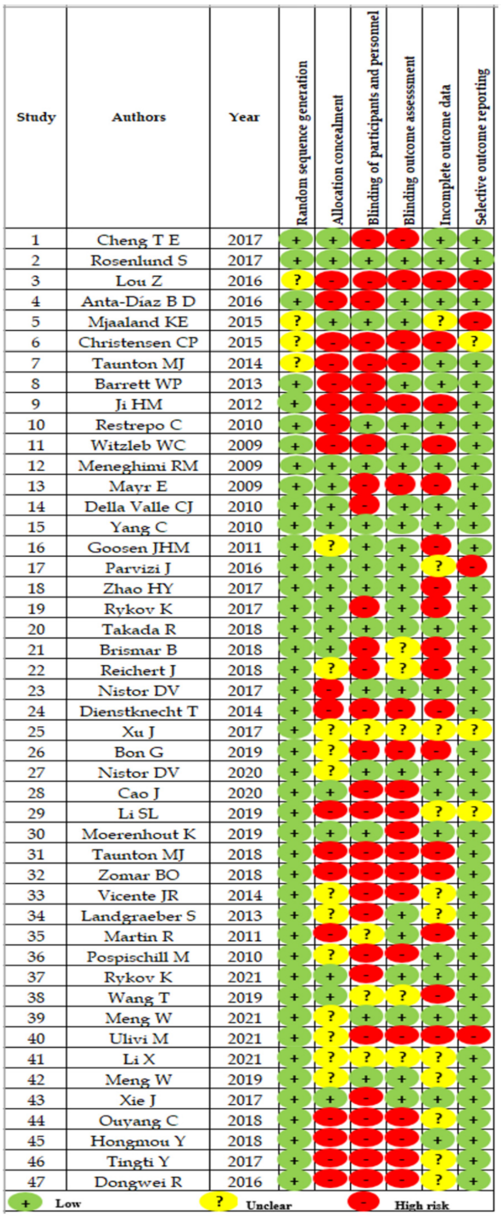
Secondary outcomes: The newer techniques, LA, DAA, LMIS and DSA/SuperPath, took significantly longer operative time than the conventional PA with USMD of 10.38 (2.04, 18.71) min, 15.38 (8.64, 22.12) min, 23.86 (4.25, 43.47) min, and 18.74 (9.69, 27.79) min, respectively. In contrast, among the newer techniques, DSA took significantly shorter length of hospital stay than other approaches except for LMIS with USMD of -1.67 (-3.28, -0.06) d, -1.36 (-2.36, -0.35) d, -2.08 (-3.12, -1.04) d, and -1.56 (-2.44, -0.69) d when compared with 2-incisions, DAA, LA and PA, respectively.

For incision length, DSA/SuperPath was the shortest and PA was the longest one. Conversely, operative blood loss was higher among the newer techniques without statistical significance. Regarding to the complications, LMIS tended to

Table 3 Network meta-analysis results of primary outcomes

Risk ratio/unstandardized mean difference (95%CI)						
	PA	**LA**	**DAA**	**2-incision**	**LMIS**	**DSA/SuperPath**
HHS ≤ 3 mo						
PA	[27.4; 0.0]	0.74 (-2.24, 3.72)	3.49 (0.98, 6.00)	0.83 (-7.50, 9.16)	0.02 (-10.13, 10.17)	1.57 (-1.55, 4.69)
LA	-0.74 (-3.72, 2.24)	[42.7; 0.5]	2.75 (-0.02, 5.52)	0.09 (-8.64, 8.81)	-0.72 (-10.43, 8.99)	0.83 (-2.91, 4.57)
DAA	-3.49 (-6.00, -0.98)	-2.75 (-5.52, 0.02)	[85.9; 47.5]	-2.66 (-11.31, 5.99)	-3.47 (-13.56, 6.63)	-1.92 (-5.67, 1.83)
2-incision	-0.81 (-13.86, 12.24)	-0.09 (-8.81, 8.64)	2.66 (-5.99, 11.31)	[45.5; 20.7]	-0.81 (-13.86, 12.24)	0.74 (-8.12, 9.61)
LMIS	-0.02 (-10.17, 10.13)	0.72 (-8.99, 10.43)	3.47 (-6.63, 13.56)	0.81 (-12.24, 13.86)	[41.0; 22.1]	1.55 (-8.85, 11.95)
DSA/SuperPath	-1.57 (-4.69, 1.55)	-0.83 (-4.57, 2.91)	1.92 (-1.83, 5.67)	-0.74 (-9.61, 8.12)	-1.55 (-11.95, 8.85)	[57.6; 9.2]
HHS 6 mo						
PA	[42.2; 3.0]	-0.21 (-1.67, 1.25)	0.22 (-0.95, 1.39)	1.85 (-14.14, 17.84)	NR	0.35 (-0.84, 1.53)
LA	0.21 (-1.25, 1.67)	[33.2; 4.1]	0.43 (-1.50, 2.36)	2.06 (-13.94, 18.05)	NR	0.55 (-0.88, 1.98)
DAA	-0.22 (-1.39, 0.95)	-0.43 (-2.36, 1.50)	[55.9; 19.3]	1.63 (-14.41, 17.67)	NR	0.13 (-1.62, 1.87)
2-incision	-1.85 (-17.84, 14.14)	-2.06 (-18.05, 13.94)	-1.63 (-17.67, 14.41)	[57.6; 55.2]	NR	-1.50 (-17.52, 14.51)
LMIS	NR	NR	NR	NR	NR	NR
DSA/SuperPath	-0.35 (-1.53, 0.84)	-0.55 (-1.98, 0.88)	-0.13 (-1.87, 1.62)	1.50 (-14.51, 17.52)	NR	[61.1; 18.4]
HHS 1 yr						
PA	[27.5; 0.0]	0.60 (-0.55, 1.74)	1.76 (1.12, 2.40)	-1.93 (-4.95, 1.08)	1.43 (-2.16, 5.02)	0.42 (-0.28, 1.12)
LA	-0.60 (-1.74, 0.55)	[54.8; 0.0]	1.17 (0.20, 2.14)	-2.53 (-5.75, 0.69)	0.83 (-2.57, 4.23)	-0.18 (-1.52, 1.17)
DAA	-1.76 (-2.40, -1.12)	-1.17 (-2.14, -0.20)	[90.7; 55.4]	-3.70 (-6.78, -0.62)	-0.34 (-3.87, 3.20)	-1.34 (-2.29, -0.39)
2-incision	1.93 (-1.08, 4.95)	2.53 (-0.69, 5.75)	3.70 (0.62, 6.78)	[6.0; 0.6]	3.36 (-1.32, 8.04)	2.35 (-0.74, 5.45)
LMIS	-1.43 (-5.02, 2.16)	-0.83 (-4.23, 2.57)	0.34 (-3.20, 3.87)	-3.36 (-8.04, 1.32)	[70.8; 43.7]	-1.01 (-4.66, 2.65)
DSA/SuperPath	-0.42 (-1.12, 0.28)	0.18 (-1.17, 1.52)	1.34 (0.39, 2.29)	-2.35 (-5.45, 0.74)	1.01 (-2.65, 4.66)	[50.2; 0.3]
Dislocation						
PA	[50.8; 8.6]	1.01 (0.34, 2.97)	0.90 (0.52, 1.57)	NR	1.00 (0.08, 11.81)	1.28 (0.29, 5.57)
LA	0.99 (0.34, 2.94)	[49.8; 15.2]	0.90 (0.29, 2.74)	NR	0.99 (0.11, 9.14)	1.27 (0.20, 7.90)
DAA	1.11 (0.64, 1.92)	1.11 (0.37, 3.40)	[61.5; 21.9]	NR	1.11 (0.09, 13.27)	1.41 (0.29, 6.82)
2-incision	NR	NR	NR	NR	NR	NR
LMIS	1.00 (0.08, 11.85)	1.01 (0.11, 9.28)	0.90 (0.08, 10.85)	NR	[50.9; 37.3]	1.28 (0.07, 22.70)
DSA/SuperPath	0.78 (0.18, 3.42)	0.79 (0.13, 4.90)	0.71 (0.15, 3.41)	NR	0.78 (0.04, 13.88)	[37.2; 17.0]
Intra-operative fracture						
PA	[67.3; 17.2]	1.33 (0.49, 3.58)	0.96 (0.36, 2.57)	1.84 (0.19, 18.35)	2.19 (0.22, 21.84)	1.75 (0.37, 8.35)
LA	0.75 (0.28, 2.02)	[49.0; 6.6]	0.72 (0.26, 1.95)	1.39 (0.12, 15.36)	1.65 (0.21, 13.12)	1.31 (0.21, 8.36)
DAA	1.05 (0.39, 2.82)	1.39 (0.51, 3.78)	[70.7; 30.3]	1.93 (0.17, 22.48)	2.29 (0.23, 22.94)	1.83 (0.29, 11.65)
2-incision	0.54 (0.05, 5.39)	0.72 (0.07, 8.00)	0.52 (0.04, 6.03)	[41.5; 19.9]	1.19 (0.05, 28.49)	0.95 (0.06, 15.27)
LMIS	0.46 (0.05, 4.55)	0.61 (0.08, 4.84)	0.44 (0.04, 4.36)	0.84 (0.04, 20.20)	[33.6; 15.1]	0.80 (0.05, 12.88)
DSA/SuperPath	0.57 (0.12, 2.73)	0.76 (0.12, 4.84)	0.55 (0.09, 3.47)	1.05 (0.07, 16.97)	1.25 (0.08, 20.20)	[37.9; 10.9]

Values are the risk ratio 95% confidence interval (95%CI) of dichotomous outcomes (dislocation and intra-operative fracture) or the mean difference (95%CI) of continuous outcomes comparing surgical intervention in column with surgical intervention in row (reference). Values of diagonal line in square brackets are surface under the cumulative ranking curve area and probability of being best surgical approaches (highest HHS and low risk of dislocation, intra-operative fracture). HHS: Harris Hip Score; PA: Posterior approach; LA: Lateral approach; DAA: Direct anterior approach; 2-incision: 2 incisions approach; LMIS: Mini-lateral approach; DSA/SuperPath: Direct superior approach or Supercapsular percutaneously-assisted total hip; NR: Not reported.



Study	Authors	Year	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding outcome assessment	Incomplete outcome data	Selective outcome reporting
1	Cheng T E	2017	+	+	-	-	+	+
2	Rosenlund S	2017	+	+	+	+	+	+
3	Lou Z	2016	?	-	-	-	-	-
4	Anta-Díaz B D	2016	+	-	-	+	+	+
5	Mjaaland KE	2015	?	+	+	+	?	-
6	Christensen CP	2015	?	-	-	-	-	?
7	Taunton MJ	2014	?	-	-	-	+	+
8	Barrett WP	2013	+	-	-	+	+	+
9	Ji HM	2012	+	-	-	-	-	+
10	Restrepo C	2010	+	-	+	+	+	+
11	Witzleb WC	2009	+	-	-	+	-	+
12	Meneghimi RM	2009	+	+	+	+	+	+
13	Mayr E	2009	+	+	-	-	-	+
14	Della Valle CJ	2010	+	+	-	+	+	+
15	Yang C	2010	+	+	+	+	+	+
16	Goosen JHM	2011	+	?	+	+	-	+
17	Parvizi J	2016	+	+	+	+	?	-
18	Zhao HY	2017	+	+	+	+	-	+
19	Rykov K	2017	+	+	-	+	-	+
20	Takada R	2018	+	+	+	+	+	+
21	Brismar B	2018	+	+	-	?	-	+
22	Reichert J	2018	+	?	-	?	-	+
23	Nistor DV	2017	+	-	+	+	+	+
24	Dienstknecht T	2014	+	-	-	-	-	+
25	Xu J	2017	+	?	?	?	?	?
26	Bon G	2019	+	?	-	-	-	+
27	Nistor DV	2020	+	?	+	+	+	+
28	Cao J	2020	+	+	-	-	+	+
29	Li SL	2019	+	-	-	-	?	?
30	Moerenhout K	2019	+	+	+	-	+	+
31	Taunton MJ	2018	+	-	-	-	-	+
32	Zomar BO	2018	+	-	-	-	-	+
33	Vicente JR	2014	+	?	-	-	?	+
34	Landgraeber S	2013	+	?	-	+	?	+
35	Martin R	2011	+	-	?	+	-	+
36	Pospischill M	2010	+	?	-	-	+	+
37	Rykov K	2021	+	+	-	+	+	+
38	Wang T	2019	+	+	?	?	-	+
39	Meng W	2021	+	?	+	+	+	+
40	Ulivi M	2021	+	?	-	-	-	-
41	Li X	2021	+	?	?	?	?	+
42	Meng W	2019	+	?	+	+	?	+
43	Xie J	2017	+	+	-	+	+	+
44	Ouyang C	2018	+	-	-	-	?	+
45	Hongmou Y	2018	+	-	-	-	+	+
46	Tingti Y	2017	+	-	-	-	?	+
47	Dongwei R	2016	+	-	-	-	?	+

+ Low ? Unclear - High risk

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Figure 2 Risk of bias assessment of individual randomized controlled trial.

have the highest wound infection rate. The 2-incisions and DAA had significantly more nerve injury rate than PA with USMDs of 18.97 (2.41, 149.62) and 9.82 (3.06, 31.58). Moreover, DAA was -1.35 (95%CI: -2.55, -0.14) and -0.70 (95%CI: -1.18, -0.23) significantly lower VAS at post-operative day one and two than PA. There was no significant difference between other approach pairs (Table 4).

The first and the second probability of being the best interventions were as follows: Operative time (PA and LA), length of hospital stay (DSA/SuperPath and DAA), incision length (DSA/SuperPath and LMIS), operative blood loss (LA and PA), wound complication (PA and 2-incisions), and nerve injury (PA and LMIS). Benefit in raising HHS and risks of operative outcomes were simultaneously plotted. A clustered ranking plot was constructed for comparing overall complications and early functional outcome of each approach (Figure 5).

Adjusted funnel plots showed no evidence of asymmetry except the results of HHS at twelve weeks, length of hospital stays and incision length (Supplementary Figure 2). No evidence of inconsistency assumption was found among direct MA and NMA except those in HHS at six months, and incision length (Supplementary Table 7).

Table 4 Network meta-analysis results of secondary outcomes

Risk ratio/Unstandardized mean difference (95%CI)						
	PA	**LA**	**DAA**	**2 incisions**	**LMIS**	**DSA/SuperPath**
Operative time						
PA	[98.6; 93.2]	10.38 (2.04, 18.71)	15.38 (8.64, 22.12)	21.00 (-4.27, 46.27)	23.86 (4.25, 43.47)	18.74 (9.69, 27.79)
LA	-10.38 (-18.71, -2.04)	[70.7; 0.7]	5.01 (-2.66, 12.68)	10.62 (-15.99, 37.24)	13.49 (-4.26, 31.23)	8.36 (-3.12, 19.84)
DAA	-15.38 (-22.12, -8.64)	-5.01 (-12.68, 2.66)	[46.0; 0.0]	5.62 (-20.54, 31.78)	8.48 (-10.86, 27.81)	3.35 (-7.58, 14.29)
2-incision	-21.00 (-46.27, 4.27)	-10.62 (-37.24, 15.99)	-5.62 (-31.78, 20.54)	[33.8; 5.3]	2.86 (-29.13, 34.85)	-2.26 (-29.11, 24.58)
LMIS	-23.86 (-43.47, -4.25)	-13.49 (-31.23, 4.26)	-8.48 (-27.81, 10.86)	-2.86 (-34.85, 29.13)	[19.6; 0.8]	-5.12 (-26.26, 16.01)
DSA/SuperPath	-18.74 (-27.79, -9.69)	-8.36 (-19.84, 3.12)	-3.35 (-14.29, 7.58)	2.26 (-24.58, 29.11)	5.12 (-16.01, 26.26)	[31.4; 0.0]
Length of hospital stay						
PA	[45.5; 0.0]	0.52 (-0.36, 1.39)	-0.21 (-0.84, 0.43)	0.11 (-1.29, 1.51)	0.32 (-2.12, 2.76)	-1.56 (-2.44, -0.69)
LA	-0.52 (-1.39, 0.36)	[16.9; 0.0]	-0.72 (-1.52, 0.07)	-0.41 (-1.92, 1.10)	-0.20 (-2.48, 2.08)	-2.08 (-3.12, -1.04)
DAA	0.21 (-0.43, 0.84)	0.72 (-0.07, 1.52)	[61.3; 0.7]	0.31 (-1.17, 1.80)	0.52 (-1.89, 2.94)	-1.36 (-2.36, -0.35)
2-incision	-0.11 (-1.51, 1.29)	0.41 (-1.10, 1.92)	-0.31 (-1.80, 1.17)	[42.6; 3.0]	0.21 (-2.52, 2.94)	-1.67 (-3.28, -0.06)
LMIS	-0.32 (-2.76, 2.12)	0.20 (-2.08, 2.48)	-0.52 (-2.94, 1.89)	-0.21 (-2.94, 2.52)	[35.8; 6.3]	-1.88 (-4.38, 0.62)
DSA/SuperPath	1.56 (0.69, 2.44)	2.08 (1.04, 3.12)	1.36 (0.35, 2.36)	1.67 (0.06, 3.28)	1.88 (-0.62, 4.38)	[97.9; 90.0]
Incision length						
PA	[4.0; 0.0]	-1.53 (-3.86, 0.81)	-2.54 (-4.64, -0.45)	NR	-3.42 (-7.99, 1.16)	-5.15 (-7.29, -3.01)
LA	1.53 (-0.81, 3.86)	[31.1; 0.0]	-1.02 (-3.00, 0.96)	NR	-1.89 (-5.82, 2.04)	-3.62 (-6.52, -0.72)
DAA	2.54 (0.45, 4.64)	1.02 (-0.96, 3.00)	[55.4; 1.8]	NR	-0.87 (-5.27, 3.53)	-2.60 (-5.45, 0.24)
2-incision	NR	NR	NR	NR	NR	NR
LMIS	3.42 (-1.16, 7.99)	1.89 (-2.04, 5.82)	0.87 (-3.53, 5.27)	NR	[66.5; 24.5]	-1.73 (-6.62, 3.16)
DSA/SuperPath	5.15 (3.01, 7.29)	3.62 (0.72, 6.52)	2.60 (-0.24, 5.45)	NR	1.73 (-3.16, 6.62)	[92.9; 73.7]
Operative blood loss						
PA	[61.6; 10.7]	-25.66 (-117.26, 65.95)	23.03 (-56.18, 102.24)	46.00 (-185.02, 277.02)	59.67 (-177.38, 296.72)	23.02 (-56.58, 102.62)
LA	25.66 (-65.95, 117.26)	[75.9; 35.1]	48.69 (-47.77, 145.15)	71.66 (-176.86, 320.18)	85.33 (-133.30, 303.96)	48.68 (-62.19, 159.55)
DAA	-23.03 (-102.24, 56.18)	-48.69 (-145.15, 47.77)	[44.0; 5.6]	22.97 (-221.26, 267.19)	36.64 (-202.33, 275.61)	-0.01 (-108.84, 108.82)
2-incision	-46.00 (-277.02, 185.02)	-71.66 (-320.18, 176.86)	-22.97 (-267.19, 221.26)	[41.9; 24.3]	13.67 (-317.33, 344.68)	-22.98 (-267.33, 221.37)
LMIS	-59.67 (-296.72, 177.38)	-85.33 (-303.96, 133.30)	-36.64 (-275.61, 202.33)	-13.67 (-344.68, 317.33)	[34.4; 17.5]	-36.65 (-281.79, 208.49)
DSA/SuperPath	-23.02 (-102.62, 56.58)	-48.68 (-159.55, 62.19)	0.01 (-108.82, 108.84)	22.98 (-221.37, 267.33)	36.65 (-208.49, 281.79)	[42.2; 6.8]
Wound complication						
PA	[70.0; 16.2]	2.26 (0.72, 7.06)	1.31 (0.59, 2.88)	0.80 (0.04, 18.03)	5.45 (0.60, 49.61)	1.00 (0.15, 6.79)
LA	0.44 (0.14, 1.38)	[31.0; 0.9]	0.58 (0.18, 1.87)	0.36 (0.02, 7.11)	2.41 (0.36, 16.00)	0.44 (0.05, 4.11)
DAA	0.77 (0.35, 1.69)	1.73 (0.53, 5.62)	[54.8; 5.2]	0.62 (0.03, 14.29)	4.18 (0.45, 38.77)	0.77 (0.10, 6.09)
2-incision	1.24 (0.06, 27.95)	2.81 (0.14, 56.24)	1.62 (0.07, 37.72)	[68.8; 46.2]	6.79 (0.20, 234.54)	1.24 (0.03, 48.08)

LMIS	0.18 (0.02, 1.67)	0.41 (0.06, 2.75)	0.24 (0.03, 2.22)	0.15 (0.00, 5.09)	[12.5; 1.3]	0.18 (0.01, 3.41)
DSA/SuperPath	1.00 (0.15, 6.79)	2.26 (0.24, 20.99)	1.31 (0.16, 10.38)	0.80 (0.02, 31.03)	5.45 (0.29, 101.44)	[62.8; 30.2]
Nerve injury						
PA	[79.7; 25.6]	2.97 (0.89, 9.97)	9.82 (3.06, 31.58)	18.97 (2.41, 149.62)	1.08 (0.11, 10.20)	1.00 (0.02, 49.35)
LA	0.34 (0.10, 1.13)	[49.4; 0.5]	3.30 (1.22, 8.94)	6.38 (0.81, 50.31)	0.36 (0.05, 2.41)	0.34 (0.01, 19.93)
DAA	0.10 (0.03, 0.33)	0.30 (0.11, 0.82)	[17.9; 0.0]	1.93 (0.22, 16.92)	0.11 (0.01, 0.93)	0.10 (0.00, 5.96)
2-incision	0.05 (0.01, 0.42)	0.16 (0.02, 1.24)	0.52 (0.06, 4.54)	[9.0; 0.2]	0.06 (0.00, 0.94)	0.05 (0.00, 4.35)
LMIS	0.93 (0.10, 8.81)	2.76 (0.41, 18.42)	9.13 (1.07, 77.77)	17.63 (1.07, 291.08)	[75.1; 31.9]	0.93 (0.01, 83.77)
DSA/SuperPath	1.00 (0.02, 49.35)	2.97 (0.05, 176.30)	9.82 (0.17, 575.31)	18.97 (0.23, 1564.11)	1.08 (0.01, 97.00)	[69.0; 41.8]

Values are the risk ratio (95% confidence interval; 95%CI) of dichotomous outcomes (wound complication and nerve injury) or the mean difference (95%CI) of continuous outcomes [operative time (min), length of hospital stay (d), incision length (cm), operative blood loss (mL) comparing surgical interventions in column with surgical intervention in row (reference)]; Values of diagonal line in square brackets are surface under the cumulative ranking curve area and probability of being best surgical approaches (lowest operative time, length of hospital stay, incision length, operative blood loss and low risk of wound complication, nerve injury). PA: Posterior approach; LA: Lateral approach; DAA: Direct anterior approach; 2-incision: 2 incisions approach; LMIS: Mini-lateral approach; DSA/SuperPath: Direct superior approach or Supercapsular percutaneously-assisted total hip; NR: Not report.

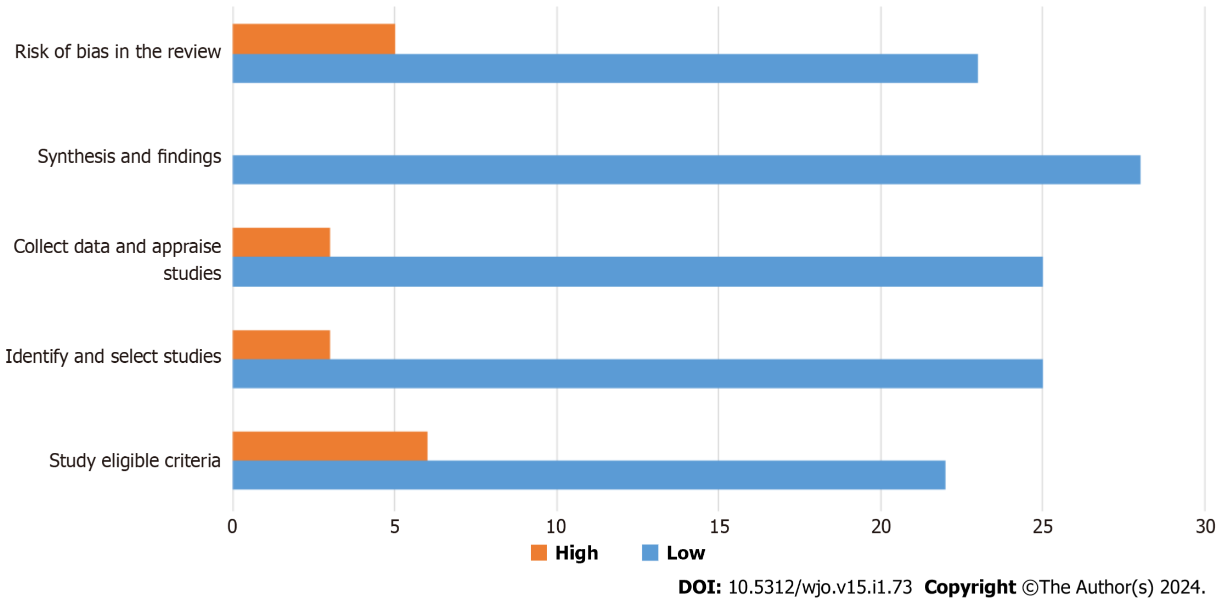
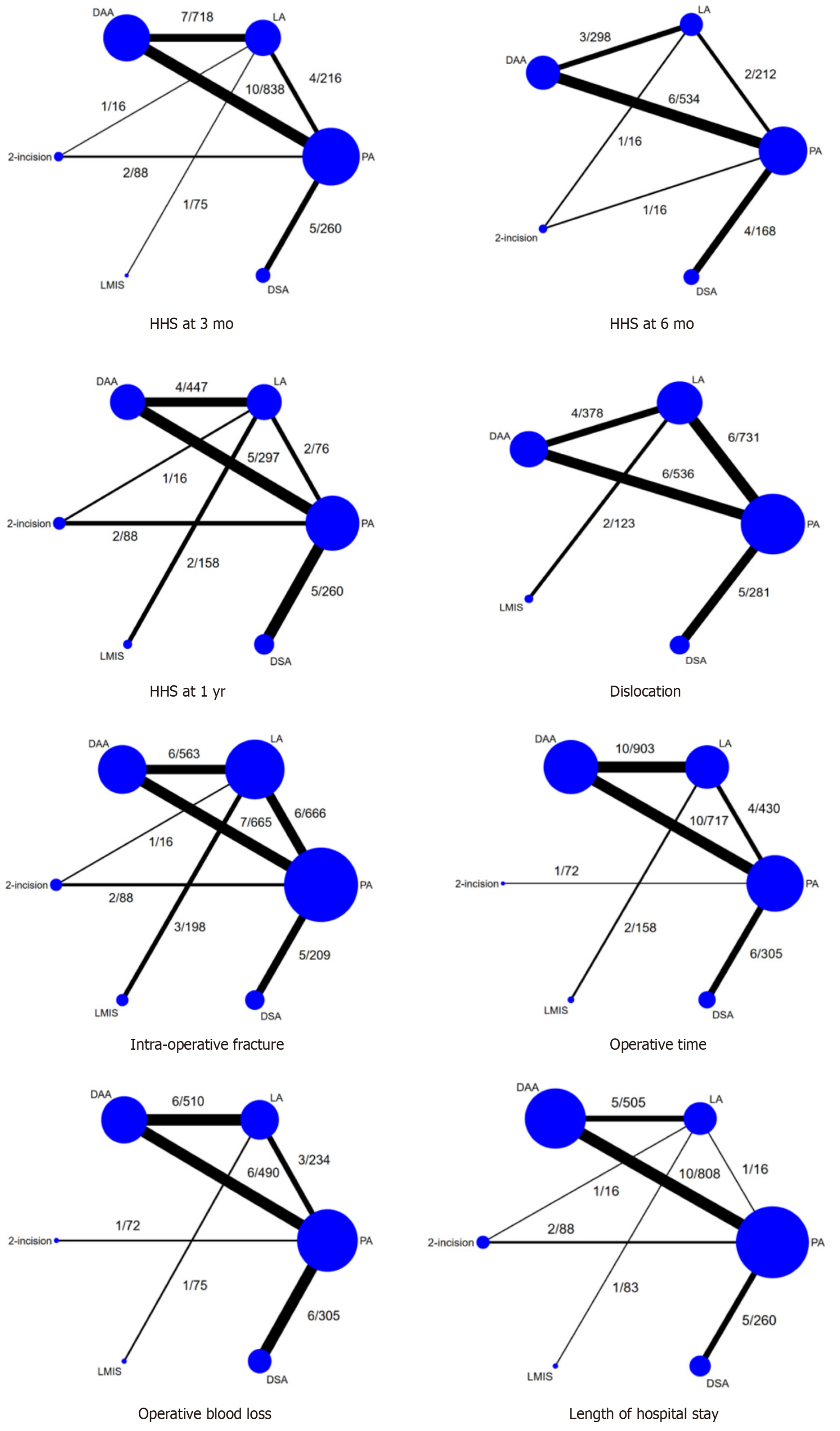


Figure 3 Chart of a Risk of Bias Assessment Tool for Systematic Reviews from multiple reviews.

DISCUSSION

This umbrella review summarized the findings of multiple MAs comparing each THA approach in terms of efficacy and complications. DAA was the highest rank for HHS, dislocation and intra-operative fractures. DSA/SuperPath might be beneficial for short incision length and length of hospital stay. PA diminished operative blood loss and operative time. On the other hand, PA was the worst in HHS with the third rank of dislocation and the second rank of intraoperative fracture.

For primary outcomes, HHS, which is the clinician-based outcome measure frequently used to evaluate patients following a THA, showed advantages in DAA from most of the previous MAs[30,34,44,98]. The results of this study re-pooled RCTs after adding DSA/SuperPath, the newest technique, showed that DAA remained in the first ranking without statistical significance from the second rank DSA/SuperPath. Even though DAA was significantly higher HHS at three months than PA (USMD: 3.49, 95%CI: 0.98, 6.00), the differences did not meet the minimally clinical significance (15.9-18.0 points)[99]. Positive properties of DAA in functional outcomes may be explained by: (1) The approach through tensor fascia lata and sartorius interval without muscle dissection; (2) preserved posterior soft tissue; (3) less muscle damage supported by low level of creatinine kinase and inflammatory responses [Interleukin (IL): IL-6, IL-8, IL-10, and tumor necrotic factor (TNF)] as well as good soft tissue response in magnetic resonance imaging[59]; (4) less post-operative pain, excellent cadence, pelvic tilt and sagittal balance[96]; and (5) good recovery outcomes with unnecessary for physical therapy[74]. DSA/SuperPath preserved the gluteus minimus and tensor fasciae latae muscles[17,16]. This


DAA
7/718
LA
4/216
10/838
1/16
2-incision
PA
2/88
1/75
5/260
LMIS
DSA
HHS at 3 mo
LA
3/298
DAA
2/212
6/534
1/16
PA
1/16
2-incision
4/168
DSA
HHS at 6 mo
DAA
4/447
LA
2/76
5/297
1/16
2-incision
PA
2/88
2/158
5/260
LMIS
DSA
HHS at 1 yr
LA
4/378
DAA
6/731
6/536
2/123
PA
5/281
LMIS
DSA
Dislocation
DAA
6/563
LA
6/666
7/665
1/16
2-incision
PA
2/88
3/198
5/209
LMIS
DSA
Intra-operative fracture
DAA
10/903
LA
4/430
10/717
1/72
2-incision
PA
2/158
6/305
LMIS
DSA
Operative time
DAA
6/510
LA
3/234
6/490
1/72
2-incision
PA
1/75
6/305
LMIS
DSA
Operative blood loss
DAA
5/505
LA
1/16
10/808
1/16
2/88
2-incision
PA
1/83
5/260
LMIS
DSA
Length of hospital stay

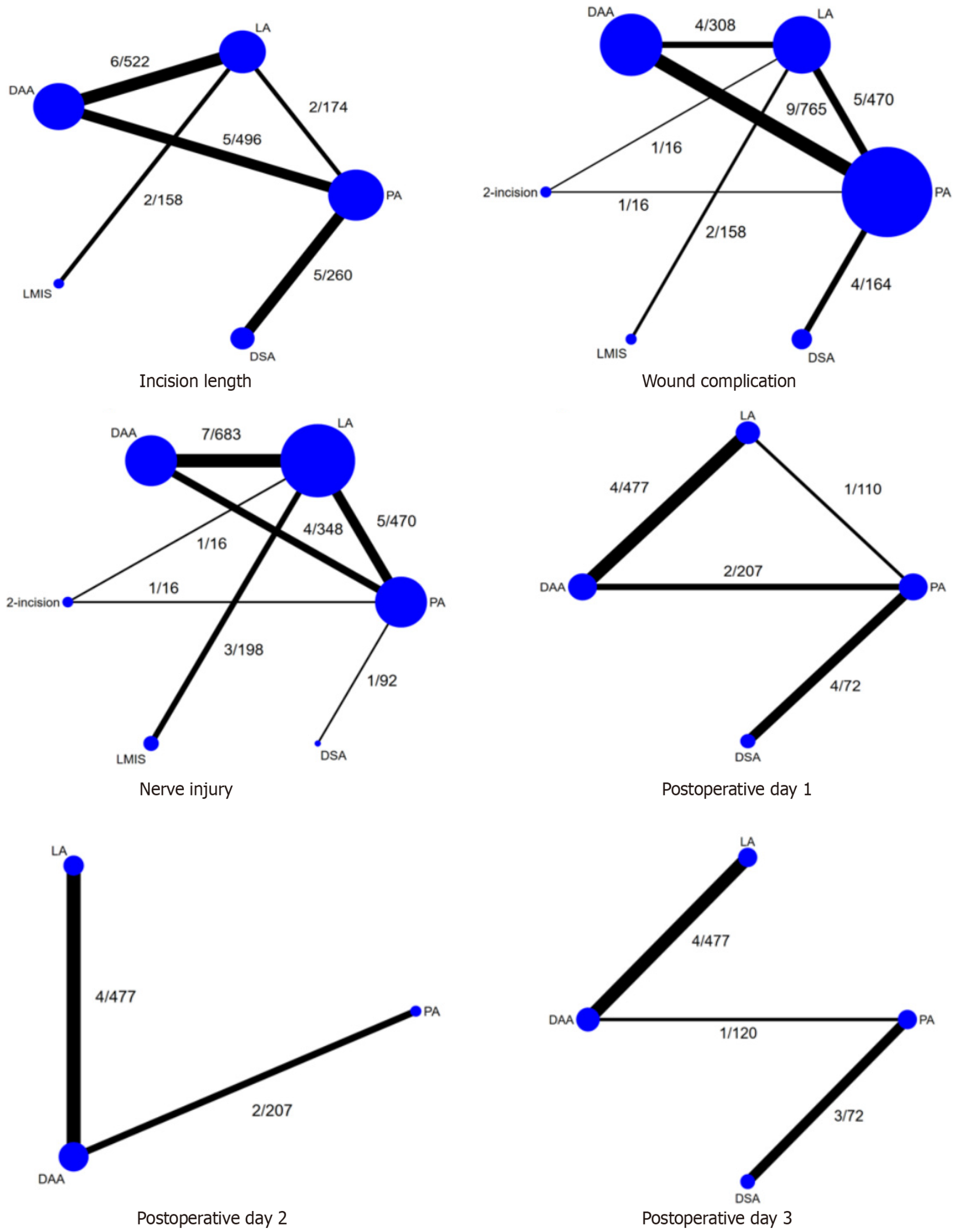


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Figure 4 Network map, the line's width is proportional to the numbers of studies and the node size is proportional to the sample size. Numbers along the lines refer to numbers of studies/numbers of patients corresponding to direct comparisons. HHS: Harris Hip Score; DAA: Direct anterior approach; LA: Lateral approach; PA: Posterior approach; DSA/SuperPath: Direct superior approach or Supercapsular percutaneously-assisted total hip; LMIS: Mini-lateral approach; 2-incision: 2 incisions approach.

could promote post-operative ambulatory and functional status[16]. Without a learning curve, DSA allowed good prosthesis positioning and comparable functional outcomes to the mini-posterolateral hip approach[16].

For dislocation rate, which is the most common complication of THA, especially in PA, DAA still provided the best result without significant difference from other approaches. Its effects in prevention of hip dislocation are from: (1) The supine position allows anatomical pelvic alignment and precise acetabular cup positioning[96]; and (2) fluoroscopic guidance supports cup and stem placement and preserves posterior soft tissue. LMIS was the second rank for hip dislocation. This method avoids muscular detachment by approaching between the tensor fascia lata and gluteus medius. Preservation of the gluteus medius would preclude Trendelenburg gait, secure good hip function[66,70,80], and might prevent hip dislocation.

Lastly, the intra-operative fracture rate showed disadvantages in DAA from most of the previous MAs studies[28,30,37]. The results from this study re-pooled RCTs stated in the opposite way. DAA became the first rank in lowering intra-operative fracture rate instead of PA. This could be surgeon's experience or familiarity with DAA to prevent fracture complication. DAA required performer's experience of at least 60-100 cases to achieve optimal operative time, blood loss,

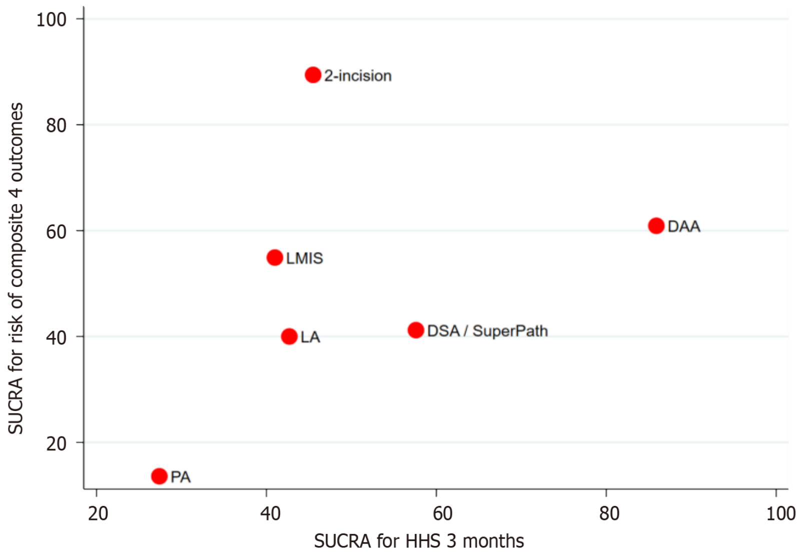

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Figure 5 Cluster rank for network meta-analysis. Cluster rank between Harris Hip Score at 3 mo and composite outcomes of complication (dislocation, intra-operative fracture, wound complication, and nerve injury). HHS: Harris Hip Score; PA: Posterior approach; LA: Lateral approach; DAA: Direct anterior approach; 2-incision: 2 incisions approach; LMIS: Mini-lateral approach; DSA/SuperPath: Direct superior approach or Supercapsular percutaneously-assisted total hip; SUCRA: Surface under the cumulative ranking curve.

and acceptable complications[100-102]. Mastery in this technique may help in femoral canal broaching and component application to prevent intra-operative fracture. PA was the second rank for intra-operative fracture such as one calcar crack[53]. DSA/SuperPath still had higher rate of intra-operative fracture than DAA and PA without statistical significance. DSA/SuperPath may cause intra-operative fracture from limited proximal femoral exposure, and is unsuitable for proximal femoral deformity[17].

For secondary outcomes, previous MAs show pros and cons between DAA and PA. DAA was better in terms of short length of hospital stay, incision length and decreased VAS pain. The downsides were raised nerve injury rate, operative time, and operative blood loss. Nerve injury can be avoided by: (1) Placing the incision more lateral than a traditional sartorius/tensor fascia lata interval; and (2) carefully performing fascial and subcutaneous layer closures to preclude the lateral femoral cutaneous nerve entrapment[103]. High blood loss was associated with long operation time[56]. Prolonged operative time and high blood loss may be caused by: (1) The fracture table and fluoroscopic set up time; (2) posterior capsular bleeding due to limited visualization; and (3) stretching and detaching the tensor fascia lata in MIS technique [85]. However, some studies[35,36,44] reported insignificantly different complications from other techniques. The results of this study re-pooled RCTs, which showed DSA/SuperPath allowed more advantages over PA, and could diminish length of hospital stay, incision length, wound complication and nerve injury rate more than DAA. For operative blood loss, DSA/SuperPath tended to have better results than DAA, but could not overcome PA. Even though SuperPath required shorter incision length than PA, soft tissue injury and long operative time contributed to high blood loss[19].

This study has strengths in many aspects. First, this study summarized all MAs assessing hip approaches in terms of efficacy and complications. The recently proposed DSA/SuperPath was considered and ranked in the analysis. In addition, this study also re-pooled data and updated new studies since the last MAs in 2023 and added RBA. All included studies were RCTs, the best available evidences with good quality (low risk of biases). However, limitations could not be avoided. The quality assessment of included MAs and RCTs indicated that some included RCTs were at high risk of bias. The results cannot be considered as independent set of evidence due to high degree of overlap with CCA of 11.0%-15.0% (14.9%). Exclusion of mini-posterior and modified posterior techniques precluded evaluation of the results among these approaches.

For clinical application, the best approaches regarding the primary outcome and the major complication were DAA, followed by DSA/SuperPath with lower overall complication rate (Figure 5). Surgeons need to select according to their familiarity. For training program, the DAA and DSA/SuperPath techniques are recommended. Lastly, DSA/SuperPath might be the good choice for surgeons who are familiar with PA in order to achieve better outcomes and reduce major complications. Furthermore, DSA/SuperPath is another choice of MIS technique for surgeons who are not familiar in anterior direction, which can lead to many problems such as infection[104] or vascular injury[105,106]. Also, DSA has been reported as "no learning curve" compared to mini-PA[16].

CONCLUSION

This umbrella review and updated re-pooling date from RCTs published indicate that DSA/SuperPath which is the newest technique has better functional outcome (HHS) than PA, but still cannot overcome the result of DAA. In terms of complications, it is still in the middle between PA and DAA. Future study should be conducted to update the information of DSA/SuperPath and directly compare with DAA and PA.

ARTICLE HIGHLIGHTS

Research background

Various hip approaches have been proposed for total hip arthroplasty. Many systematic reviews and meta-analysis (MAs) reported their benefits for hip function, and pain relief. The disadvantages, such as hip dislocation, intra-operative fracture, blood loss, and nerve injury, depended on types of surgical techniques. This is the first umbrella review comprehensively compared six approaches including direct anterior (DAA), direct superior (DSA)/supercapsular percutaneously-assisted total hip (SuperPath), lateral (LA), mini-lateral (LMIS), 2-incision, and posterior approach (PA) techniques.

Research motivation

Comparisons of different hip approaches, particularly DSA/SuperPath to PA in terms of important clinical outcomes and complications have not yet been in previous network MAs.

Research objectives

To compare hip approaches including DAA, DSA/SuperPath, LA, LMIS, 2-incision, and PA. The best approach is determined by constructing cluster ranking plots between benefits of Harris Hip Score (HHS), and risks of hip dislocation, intra-operative fracture, wound complication, and nerve injury.

Research methods

MA and updated randomized controlled trials (RCTs) were identified from large two databases (MEDLINE and Scopus) up to year 2023. Two evaluators independently assessed the quality, and extracted data from included studies comparing hip approaches, and reporting at least one outcomes of interest. This review was performed with robust methodology by re-pooling data, network MA, surface under cumulative ranking curve, corrected covered area for overlapping studies, and publication bias assessment.

Research results

Considering HHS, clinical important outcomes and complications, re-pooled 47 RCTs demonstrated DAA was the best hip approach followed by DSA/SuperPath. These evidences were from moderate quality RCTs without publication bias. High degree of CCA indicated overlapping between RCTs among previous MAs.

Research conclusions

DSA/SuperPath provided good functional outcome in the middle between PA and DAA. Without learning curve, this approach might be useful for surgeons who are familiar to PA or inexperienced in DAA to avoid adverse outcomes.

Research perspectives

Future study should be conducted to update the information of DSA/SuperPath and directly compare with DAA and PA.

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FOOTNOTES

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CASE REPORT

Surgical treatment of an old avulsion fracture of the ischial tuberosity and ischial ramus: A case report

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Abstract

BACKGROUND

Avulsion fracture of the ischial tuberosity is a relatively clinically rare type of trauma that is mainly incurred by adolescents during competitive sports activities. According to previous literature, the most commonly involved sports are soccer, sprinting, and gymnastics, in descending order. Dance-induced avulsion fracture of the ischial tuberosity and ischial ramus is extremely clinically rare.

CASE SUMMARY

A case of a neglected avulsion fracture of the ischial tuberosity and ischial ramus was diagnosed in a young female dancer who complained of pain and restricted movement of her right hip. She stated that she had suffered the injury while performing a split leap during a dance performance 9 mo prior. Eventually, she underwent surgery and obtained satisfactory treatment results.

CONCLUSION

Early diagnosis of these fractures is important to ensuring early proper treatment towards a quicker recovery. For old fractures with nonunion and chronic buttock pain, surgery is a preferred therapeutic choice with good treatment outcomes.

Key Words: Ischial tuberosity; Ischial ramus; Avulsion fracture; Delayed diagnosis; Split-leap injury; Case report

Core Tip: Avulsion fracture of ischial tuberosity is a rare type of trauma, mainly incurred by adolescents during competitive sports activities. According to previous literature, the most commonly involved sports are soccer, sprinting, and gymnastics. Dance is rarely involved in these fractures. We here report a case of old avulsion fracture of ischial tuberosity and ischial ramus in a young female dancer. She suffered the injury while split-leaping during a dance performance 9 mo prior. Eventually she underwent surgery and obtained satisfactory treatment results. For fractures with nonunion and chronic buttock pain, surgery is a preferred therapeutic choice with good outcomes.

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INTRODUCTION

Avulsion fractures of the ischial tuberosity are a clinically rare type of trauma and are mainly incurred by adolescents during sports activities[1]. A number of cases, including some cases of old fractures, have been reported in the literature [2-4]; however, few cases have been reported involving dance, and specifically split-leap injury. We here report a case of a neglected avulsion fracture of ischial tuberosity and ischial ramus in a young female dancer. She suffered the injury while split-leaping during a dance performance 9 mo before her presentation. Eventually, she underwent surgery and obtained satisfactory treatment results.

CASE PRESENTATION

Chief complaints

A 17-year-old female dancer presented with pain and restricted movement of her right hip in the outpatient clinic of our hospital.

History of present illness

The patient reported that she sustained the right hip injury 9 mo previously while performing a split leap during a dance show. She felt a "pop" and subsequently experienced severe pain in the right hip, followed by difficulty walking. The patient thought that it was a muscle strain, so she rested at home without medical consultation. A month later, the pain had abated and she was able to walk, albeit with a slight limp. However, she was still unable to fully return to her dance training. The pain continued over 8 mo, especially when she was sitting for a long period of time or attempted to return to her dance training. Therefore, she visited a local hospital and a plain pelvic radiograph was taken, which demonstrated an old fracture of ischial tuberosity and ischial ramus. Thus, she was referred to our hospital for further treatment.

History of past illness

The patient had no medical history of past illness.

Personal and family history

The patient had no special personal and family history.

Physical examination

Upon physical examination, there was mild tenderness over the ischial tuberosity and ischial ramus. Pain was induced with flexion, abduction, and external rotation of the hip. The abduction and extension muscle strength of the affected right hip were diminished compared to those of the left hip.

Laboratory examinations

There were no abnormalities in the laboratory examinations.

Imaging examinations

The plain radiograph of the pelvis (Figure 1A) demonstrated an unhealed fracture of ischial tuberosity and partial ischial ramus. The fragment was displaced anterolaterally by approximately 2 cm. The computed tomography (CT) scan and the 3D reconstruction of the pelvis (Figure 1A and B) showed that the fracture fragment of the ischial tuberosity and partial ischial ramus measured 6.4 cm × 1.3 cm × 2.9 cm in size.

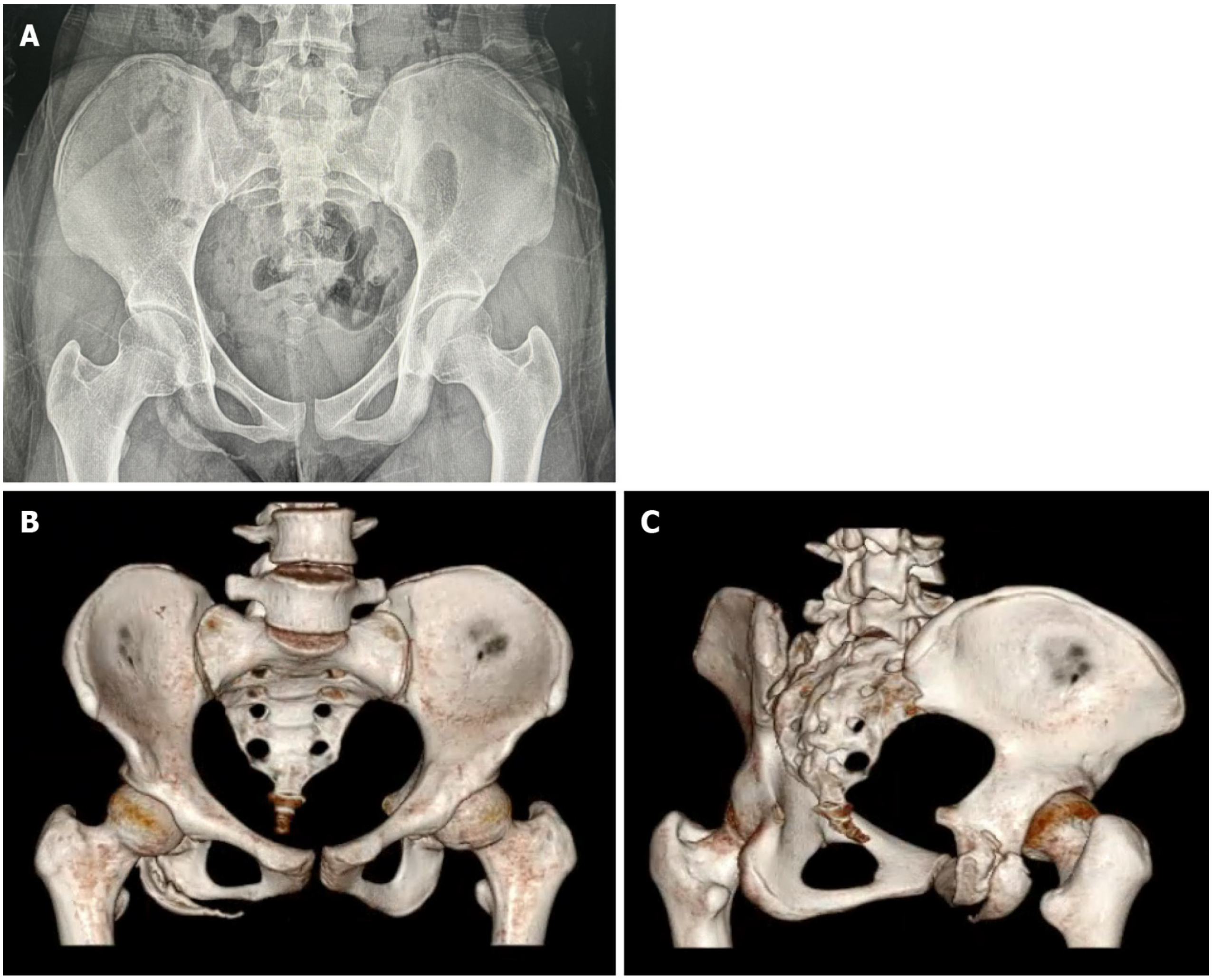

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Figure 1 Imaging examinations photos. A: Plain X-ray film of the pelvis, revealing an unhealed avulsion fracture of ischial tuberosity and partial ischial ramus. The fragment is displaced anterolaterally by approximately 2 cm; B and C: Computed tomography scan and 3D reconstruction of the pelvis exhibiting a fracture nonunion of the ischial tuberosity and partial ischial ramus, with the fragment measuring 6.4 cm × 1.3 cm × 2.9 cm in size.

FINAL DIAGNOSIS

Based on the history and the physical examination and imaging investigation results, the patient was diagnosed with an old ununited avulsion fracture of the ischial tuberosity and partial ischial ramus.

TREATMENT

After the patient was informed as to the treatment options for the fracture, she communicated a strong preference for operative treatment for the fracture in her right hip. Soon after, she was admitted to the orthopedic ward and underwent surgery. During the procedure, the patient was posted in a lateral position with the hip and knee flexed at 90°. An 8-cm transverse incision was made along the gluteal crease. With the retraction of the gluteus muscles, the sciatic nerve was identified, and the fracture fragment of ischial tuberosity and ischial ramus was exposed (Figure 2A). Fibrous scar tissue was removed with a curet to freshen the ends of the fracture, and the fragment was restored to its original position. Four φ 1.2-mm Kirschner wires were utilized as guides (Figure 2B), along which four φ 4.0-mm cannulated compression screws with washers were screwed in to fix the fracture (Figure 2C). The tapering ischial ramus was tied using absorbable threads. C-arm fluoroscopy confirmed that the fracture was properly reduced and that the screws were an appropriate length and in appropriate position (Figure 2D). Postoperatively, the right hip was immobilized for 6 wk, and rehabilitation with hip abduction and flexion exercises was started thereafter.

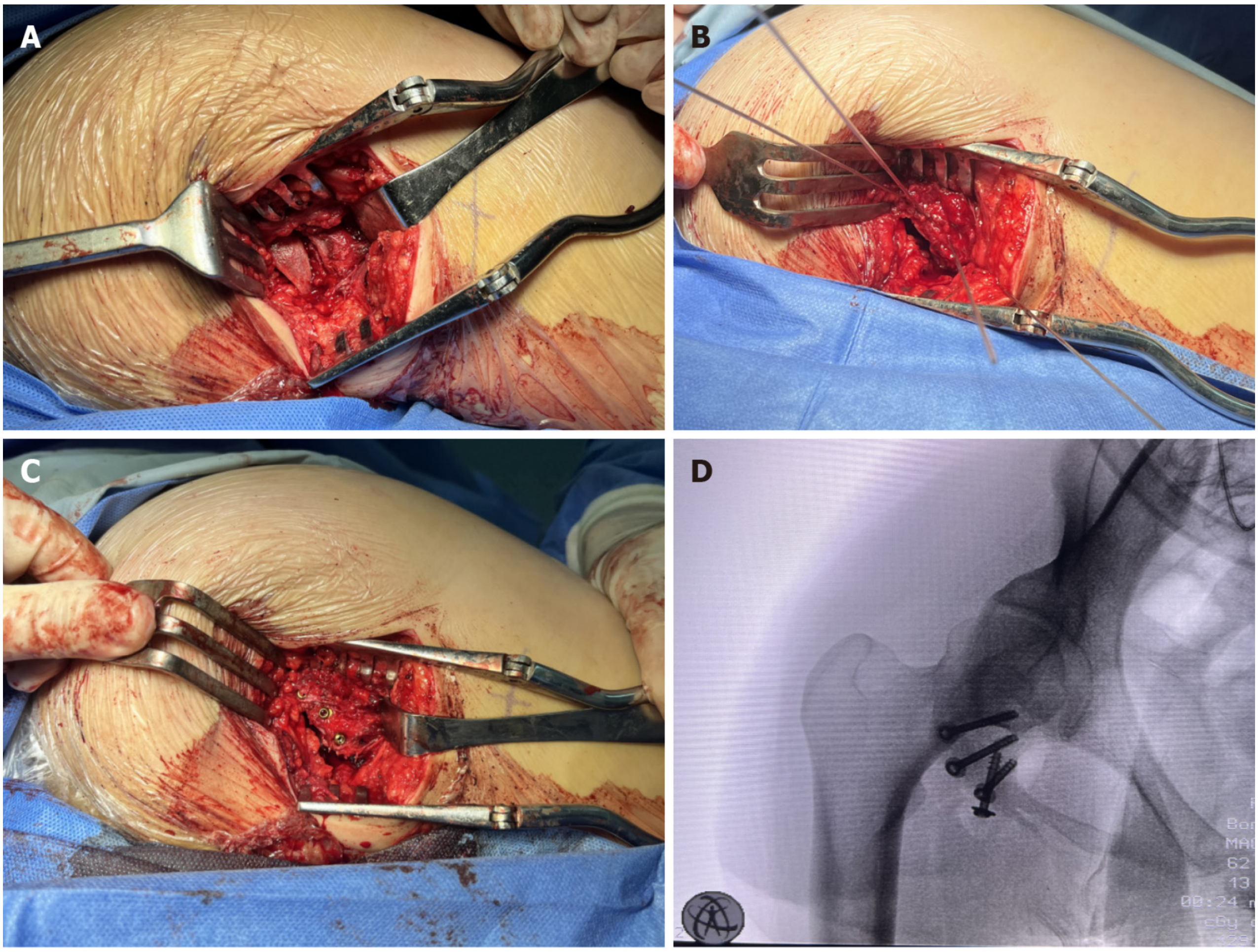

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Figure 2 The photos of treatment. A: The fracture was exposed and the fragment was seen anterolaterally displaced during the surgery; B: The fracture was temporarily fixed with Kirschner wires during the surgery; C: Four φ 4.0-mm cannulated compression screws were inserted to fix the fracture; D: C-arm fluoroscopy displayed that the fracture was properly reduced and the screws were an appropriate length and in appropriate position.

OUTCOME AND FOLLOW-UP

At the 8-wk postoperative follow-up, the patient could stand and walk without any discomfort. She was instructed to start training to develop the full range of motion and muscle strength of the hip. At the 3-mo follow-up, her right hip showed rather good function, and the radiograph revealed that the fracture line was fuzzy; however, heterotopic ossification was seen surrounding the fracture (Figure 3A). At the 6-mo follow-up, hip function was well recovered and the flexion and extension strength of the affected hip was basically the same as that of the left hip, albeit the hip abduction strength was slightly weaker. The patient had taken up physical exercises such as playing badminton and could jump without any pain in her buttocks. The fracture was well healed according to the X-ray film without exacerbation of heterotopic ossification (Figure 3B). At the latest 16-mo follow-up, the patient reported no discomfort in daily activities and no pain while sitting for a long time, even when performing straddling with flexion and abduction of the hip in combination with extension of the knee. The fracture had fully healed according to the X-ray film (Figure 3C and D).

DISCUSSION

Avulsion fractures of ischial tuberosity almost always occur in adolescents, in whom the vulnerable unfused epiphysis can be easily avulsed with a sudden and forceful eccentric contraction of the hamstrings[5]. Avulsion fractures are usually incurred during competitive sports, such as soccer, sprinting, and gymnastics[6], when the affected leg is forced into hyperflexion of the hip with full extension of the knee[7]. Avulsion fractures sustained in the course of dancing are uncommon, because dancers often have higher flexibility than athletes who play other competitive sports that require greater strength[8,9]. To the best of our knowledge, there have been only three cases reported in the literature[2,9,10]. In the present case, the avulsion fracture of ischial tuberosity along with ischial ramus occurred while the patient was performing a split jump in a dance show. The anterolateral displacement of the fracture fragment implied that the injury resulted from the intense contraction of the hamstring and adduction muscles, and in the context of the abrupt flexion

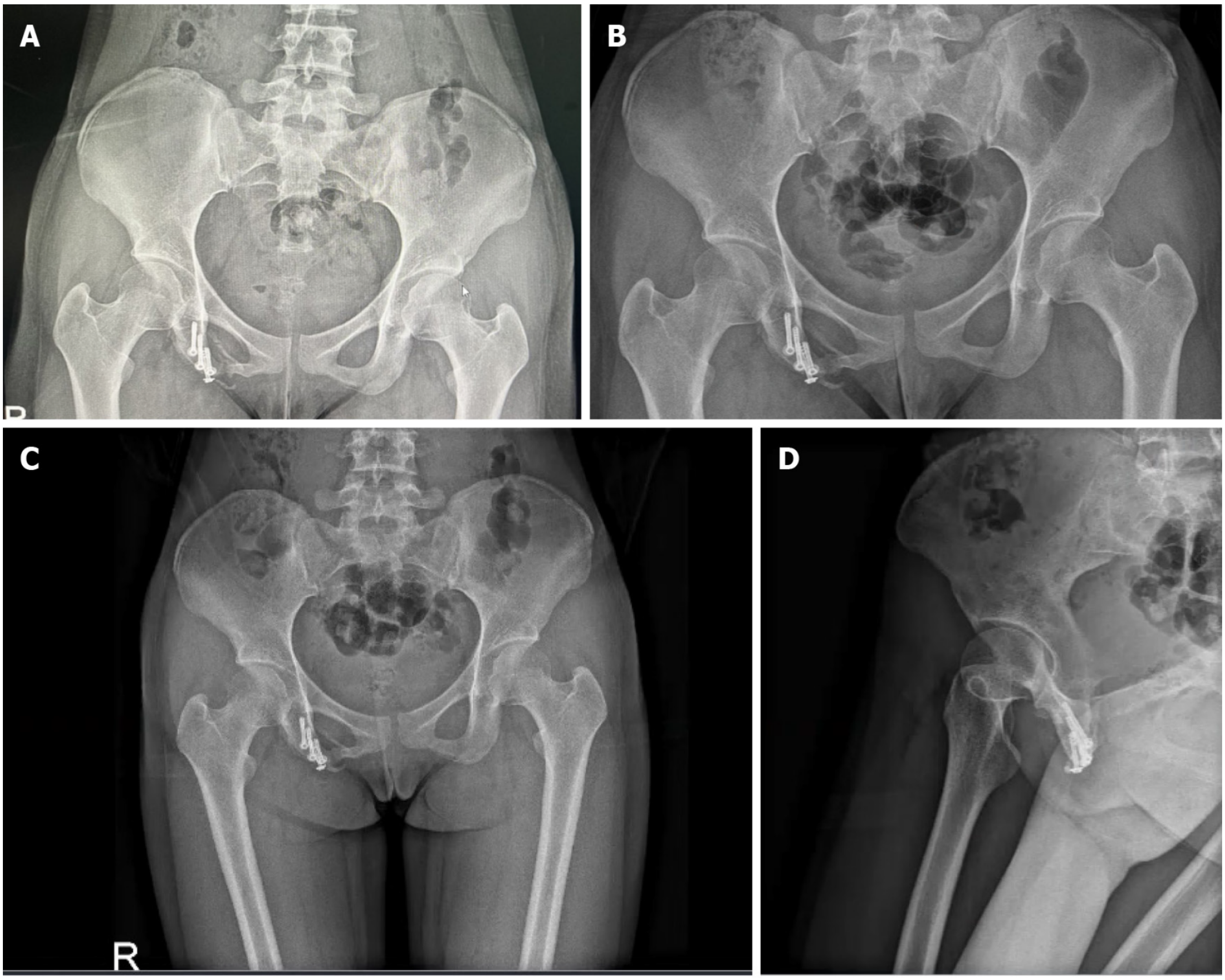

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Figure 3 The results of outcome and follow-up. A: The radiograph revealed the fracture line was fuzzy, but heterotopic ossification occurred surrounding the fracture at the 3-mo follow-up after surgery; B: The X-ray film at the 6-mo follow-up after surgery revealed that the fracture healed well without exacerbation of heterotopic ossification; C and D: The X-ray film at the 16-mo follow-up after surgery revealed that the fracture had fully healed.

and abduction of the hip in combination with extension of the knee.

Nearly all avulsion fractures can be identified with standard pelvic X-rays[11]. Nevertheless, the aspecificity of reported symptoms and the lack of awareness of these injuries frequently result in them being misdiagnosed as muscular strains or tendinous tears[1,6]. CT and magnetic resonance imaging scans are useful for the differential diagnosis of avulsion fractures with no or minimal displacement from muscular or tendinous tears[12].

Currently, there is no consensus on the treatment of avulsion fractures of ischial tuberosity due to a lack of evidence-based management guidelines[13]. However, the degree of fragment displacement is generally an important factor to consider in the selection of treatment methods[14]. For fractures with no or minor displacement, conservative treatment is often adequate, but strict immobilization of the affected hip for a time period and proper or graded physical rehabilitation are essential[11]. However, strict immobilization of the affected hip is sometimes unacceptable or unattainable for some active patients, and improper movement of the hip may induce displacement of the fragment. Operative treatment is generally suggested for fractures with a displacement > 2 cm[11,15], or even > 1.5 cm in athletes and manual laborers to allow for a faster return to pre-injury activities[16,17]. Old fractures frequently present with symptoms including pain, muscle weakness, and nerve complications, and old fractures with radiological manifestations of nonunion always require surgery[3,4,18]. The presented fracture radiographically exhibited 2.0 cm of displacement and nonunion, and the patient did not achieve the expected level of healing after 9 mo of rest. Given the persistent pain and restricted motion of the hip, the patient opted for operative treatment. The surgery was performed in a lateral position, with the hip and the knee flexed at 90°, enabling passive movements of the joints and clear exposure of the ischial tuberosity during the operation[17]. In addition, a sub-gluteal transverse approach was selected for the surgery in consideration of the location, shape, and size of the fracture fragment. The transverse approach facilitates the exposure and reduction of the fracture and has cosmetical advantages.

The follow-up results with regards to function evaluation in the present case were satisfactory. The latest follow-up showed that the patient had no discomfort while carrying out daily activities and was able to take up moderate-intensity sports. Her hip abduction strength remained slightly weak, and as a result the patient decided to end her pre-injury career as a dancer, which she regretted.

CONCLUSION

In conclusion, avulsion fractures of the ischial tuberosity are relatively rare injuries and are usually incurred during high-intensity sports. Early diagnosis of these injuries, which can occur during sport activities, even including dancing, is important to ensure early proper treatment for a quicker recovery. For old fractures with nonunion and chronic buttock pain, surgery is the preferred therapeutic choice that can lead to good treatment outcomes.

FOOTNOTES

Author contributions: Chen ZR collected the clinical data, and drafted the manuscript; Liao SJ assisted in performing the research; Yang FC designed and performed the research, and revised the manuscript; and all authors have read and approve the final manuscript.

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