British Medical Bulletin, 2021, **137**:98–111
doi: 10.1093/bmb/ldaa044
Advance Access Publication Date: 18 January 2021

Invited Review

Osteotomies for avascular necrosis of the femoral head

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Received 11 April 2020; Revised 27 November 2020; Accepted 27 November 2020

Abstract

Background: In osteonecrosis of the femoral head (ONFH), blood supply is insufficient for the metabolic requirements of the bone. The initial management is conservative, and, in case of failure, surgery is indicated. Osteotomies aim to change the spatial position of the necrotic portion of the femoral head. This systematic review evaluates the effectiveness and safety of osteotomies for ONFH.

Source of data: The systematic review, organized, conducted and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines, was performed on PubMed and Google Scholar. We analysed outcomes in term of Harris Hip Score, leg shortening, secondary collapse and blood loss. We also verified the percentage of patients who required total hip replacement (THR) after osteotomy for ONFH.

Areas of agreement: A total of 16 articles were selected, including 775 patients and 852 osteotomies [curved varus osteotomy in 369 (43.3%) patients; transtrochanteric rotational osteotomy in 435 (51.05%) patients; half wedge osteotomy in 48 (5.6%) patients]. There was an overall THR conversion rate of 31.5% (268 hips on 852 osteotomies).

Areas of controversy: There were no prospective randomized trials, and the outcome measures employed were often heterogeneous.

Growing points: Approximately one-third of the osteotomies performed in cases of ONFH are converted to THR over a period of ~7 years. In older patients, primary THR should be considered, especially as the conversion to THR after osteotomy is technically demanding.

Areas timely for developing research: Randomized clinical studies should be conducted in order to define the parameters of the patient that can direct towards the most suitable osteotomic technique.

Key words: osteonecrosis femoral head, avascular necrosis of the head of femur, osteotomy, total hip arthroplasty

Introduction

The term osteonecrosis was introduced in 1738 by Alexander Munro,[1] indicating a condition in which blood supply is insufficient for the metabolic requirements of the bone.[2–4] The blood supply to the head of the femur is generally provided by the medial and lateral circumflex arteries, branches of the profunda femoris artery. Further blood supply is provided by ligamentum teres artery.[2,4–8] Osteonecrosis of the femoral head (ONFH) frequently involves the anterior and superior portions, but its incidence is unknown as the condition can be silent in the early stages. The prevalence of ONFH is difficult to establish and differs in the different populations considered, in the USA a prevalence of 20 000 cases per year is reported.[9,10] The recent introduction of sensitive imaging techniques has allowed to identify the condition in its preclinical stages.[5,7]

Males between the ages of 30 and 70 are more frequently affected, and in 50% of patients the condition is bilateral.[11] In adult patients, the main cause of ONFH is traumatic, following proximal hip fractures or dislocations.[12–15] Risk factors for non-traumatic ONFH include prolonged use of corticosteroids[16,17] and alcohol abuse[18,19]; they are responsible for about 80% of cases. Other risk factors are Caisson disease (i.e. dysbaric osteonecrosis),[20] thromboembolic events either acquired (thrombophilia) or congenital (hypofibrinolysis),[21] Legg–Calvé–Perthes disease,[22] radiation,[23] cytotoxic agents,[24] Gaucher disease,[25] human immunodeficiency virus infection,[26] hyperlipidemia[27] and pancreatitis.[28] The literature reports cases of genetically determined ONFH.[29] Often the aetiology of ONFH remains unknown; these cases are classified as idiopathic.[5,7,30,31]

In the initial phases, no obvious radiographic alterations justify the patient's symptoms. In the more advanced stages, degenerative joint changes are visible,[32,33] and plain radiographs visualize the subchondral fracture as crescent sign.[32,33] Magnetic resonance imaging (MRI) is considered the most sensitive and specific diagnostic procedure,[6,8,32,34,35] allowing to formulate a diagnosis of ONFH in the early phase, long before the typical changes would be visible on plain radiography[34,35] and before patients would report pain.[32] In the early stages, MRI shows signs of increased marrow pressure, edema and geographic defect within the bone.

The main staging system for ONFH, proposed by Ficat and Arlet[36] (Table 1), identifies four stages according to the radiographic features and functional impairment of the patient. Another commonly used classification is that developed by Association Research Circulation Osseus (ARCO)[37] (Table 2).

In general, the development of osteonecrosis occurs within 1–6 months following the inciting event and is influenced by factors such as age,

Table 1 Ficat and Arlet classification

Ficat classification of ONFH

	Plain radiography	MRI	Bone scan	Clinical symptoms
Stage 0	Normal	Normal		Nil
Stage I	Normal or minor osteopenia	Oedema	Increased uptake	Pain typically in the groin
Stage II	Mixed osteopenia and/or sclerosis	Geographic defect	Increased uptake	Pain and stiffness
Stage III	Crescent sign and eventual cortical collapse	Same as plain radiography	Pain and stiffness +/−	Radiation to knee and limp
Stage IV	End stage with evidence of secondary degenerative change	Same as plain radiography		Pain and limp

gender, body mass index (BMI), smoking, alcohol, steroids and genetics. One of the early features of ONFH, which is visible only on MRI as a low-density area, is the development of a wedge-shaped area of subchondral necrosis.[38] In more advanced phases, partial deposits of new bone tissue can be seen on plain radiographs as a sclerotic area.[37]

ONFH is asymptomatic during the early phases. The first symptom is pain in the hip, which can radiate to the groin and the anterior aspect of the thigh to the knee.[2,39,40] Pain tends to be in proportion with lesion size, and in general precedes the beginning of femoral head collapse, which occurs on average after 8 months. ONFH may remain asymptomatic, but in 80% of patients the necrosis progresses until the femoral head collapses.[9] Several differential diagnoses should be considered, including transient osteoporosis of the hip or bone marrow oedema syndrome, femoral head cysts, subchondral insufficiency fracture and rapidly progressive osteoarthritis.

Conservative management with non-weight bearing or limited weight bearing and rest are classically implemented in the early stages of the condition (Ficat and Arlet I–II; ARCO I–II), though it is unclear whether it will prevent or slow down the femoral head collapse. Other therapeutic options are extracorporeal shockwaves, pulsed electromagnetic fields, hyperbaric oxygen therapy, bisphosphonates, such as alendronate[41] and anticoagulants.[21]

In the early phases, several surgical procedures have been reported: core decompression,[42] bone grafting[43–47] coupled with mesenchymal stem cell injection[48,49] and osteotomies, such as transtrochanteric rotational osteotomy (TRO),[40] curved varus osteotomy (CVO)[50,51] and half wedge osteotomy (HWO).[52] The ultimate aim of all the osteotomies is to change the spatial position of the necrotic portion of the femoral head so that it is not subjected to weight bearing, reducing the load and improving the perfusion of the necrotic area.[6]

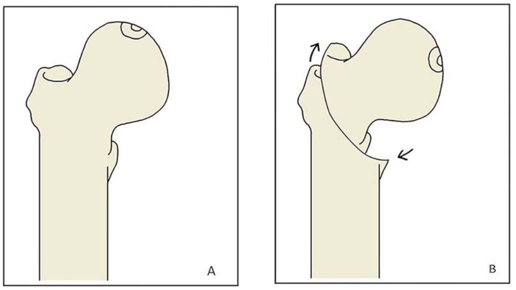

Fig. 1 CVO: the curved osteotomy is performed between the greater and the lesser trochanter; subsequently, the proximal fragment is rotated into varus in order to reduce the load on the necrotic.

In CVO, a curved osteotomy is produced made between the greater and the lesser trochanter, and the femoral head is rotated into varus[3,6,8,51,53–55] (Fig. 1).

In TRO, the femoral head is rotated anteriorly or posteriorly along the longitudinal axis[2,4,56–59] (Fig. 2).

In HWO, two different osteotomies are produced: the first is a transversal osteotomy at the level of the lesser trochanter. The second is a wedge-shaped osteotomy of the lesser trochanter; the result of these

Table 2 ARCO classification

ARCO international classification of ONFH					
Stage	**0**	**1**	**2**	**3**	**4**
Findings	All present techniques normal or nondiagnostic	Plain radiography and CT are normal At least ONE of the below mentioned is positive	NO Crescent Sign! Plain radiography Abnormal: sclerosis, osteolysis, focal porosis	Crescent Sign! on the plain radiography and/or flattening of articular surface of femoral head	OSTEOARTHRITIS! Joint space narrowing, acetabular changes, joint destruction
Techniques	Plain radiography Computed tomography (CT) Scintigraphy (bone scanning) MRI	Scintigraphy (bone scanning) MRI	Plain radiography CT Scintigraphy (bone scanning) MRI	ONLY: Plain radiography CT	ONLY: Plain radiography
Sub Classification	NO	Location: • Medial • Central • Lateral			NONO
Quantitation	NO	% Area involvement: • Minimal A < 15% • Moderate B 15–30% • Extensive >30% Length of Crescent: • A < 2 mm • B 2–4 mm • C > 4 mm % Surface collapse and dome depression: • A < 15% • B 15–30% • C > 30%			NO

osteotomy is to place the head–neck axis of the femur into varus[52,55] (Fig. 3).

Total hip replacement (THR) is normally undertaken in the advanced stages of ONFH (Ficat and Arlet III–IV; ARCO III–IV) or in cases of failure of the rescue procedures.[55,57,58,60,61]

The primary objective of this systematic review is to evaluate the use of osteotomies as salvage surgical procedure for ONFH and to analyse outcomes in term of Harris Hip Score (HHS),[62] leg shortening, secondary collapse and blood loss. The secondary objective is to verify percentage of patients who requires THR after osteotomies for ONFH.

Methods

The systematic review and its procedures were organized, conducted and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guideline[63] (Fig. 4).

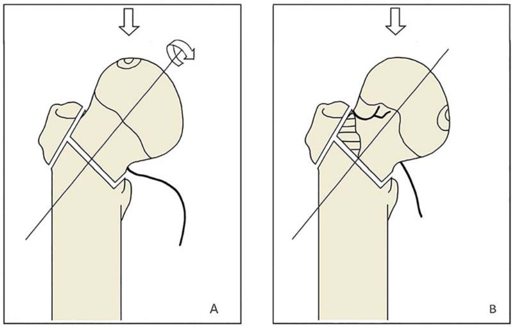

Fig. 2 TRO: the osteotomy is performed at the base of the neck to allow the rotation of the femoral head along its longitudinal axis.

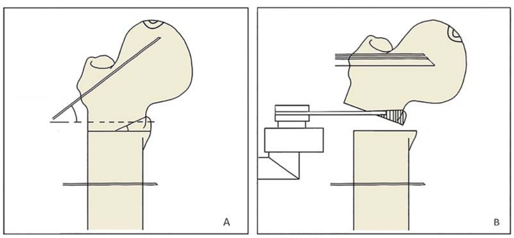

Fig. 3 HWO: a medial wedge-shaped osteotomy is performed to allow the reintegration of the proximal femur into varus.

Eligibility criteria

We searched studies about the treatment of the ONFH. Studies included are case–control studies and cohort studies on osteotomies and conversion osteotomies to THR. We excluded animal studies, case reports and studies in languages other than English.

Data sources and search

The search was performed on PubMed and Google Scholar, using the following key words and Mesh terms: Osteonecrosis Femoral Head, Necrosis of the Head of Femur, Osteotomy, THA, Total Hip Arthroplasty, THR, Total Hip Replacement, TRO, Transtrochanteric Rotational Osteotomy, CVO, Curved Varus Osteotomy, HWO, Half Wedge Osteotomy.

Study selection

The evaluation of the articles resulting from the electronic search was carried out independently by two orthopaedic residents. A researcher experienced in systematic reviews solved cases of doubt. The initial selection of articles was based on the title and reading of the abstract. In accordance with previously defined inclusion and exclusion criteria, the articles considered relevant to the purpose of the study were selected. Subsequently, these articles were read in their entirety to ascertain their true relevance to the purpose of this systematic review.

Data collection

After reading the full text of the articles, the data were collected in an Excel database. Doubts and inconsistencies were followed and solved by discussion. The information recorded are:

- Demographic characteristics, mean age
- Aetiology
- Length of follow-up
- Type of osteotomy procedure: TRO, CVO, HWO
- Clinical outcomes: HHS, blood loss, leg shortening
- THR conversion rates

Methodological assessment

We used the Modified Coleman Methodology Score (MCMS)[64] criteria to assess the studies reviewed. A score from 0 to 100 is assigned to each study; a score of 100 indicates a study in which there are no confounding factors or bias. The Pearson's correlation coefficient was used to correlate MCMS with publication year to examine the chronological trend in methodology.

Data availability statement

No new data were generated or analysed in support of this review.

Results

Literature review

The first search performed on both search engines provided a total of 3743 articles, which included 23

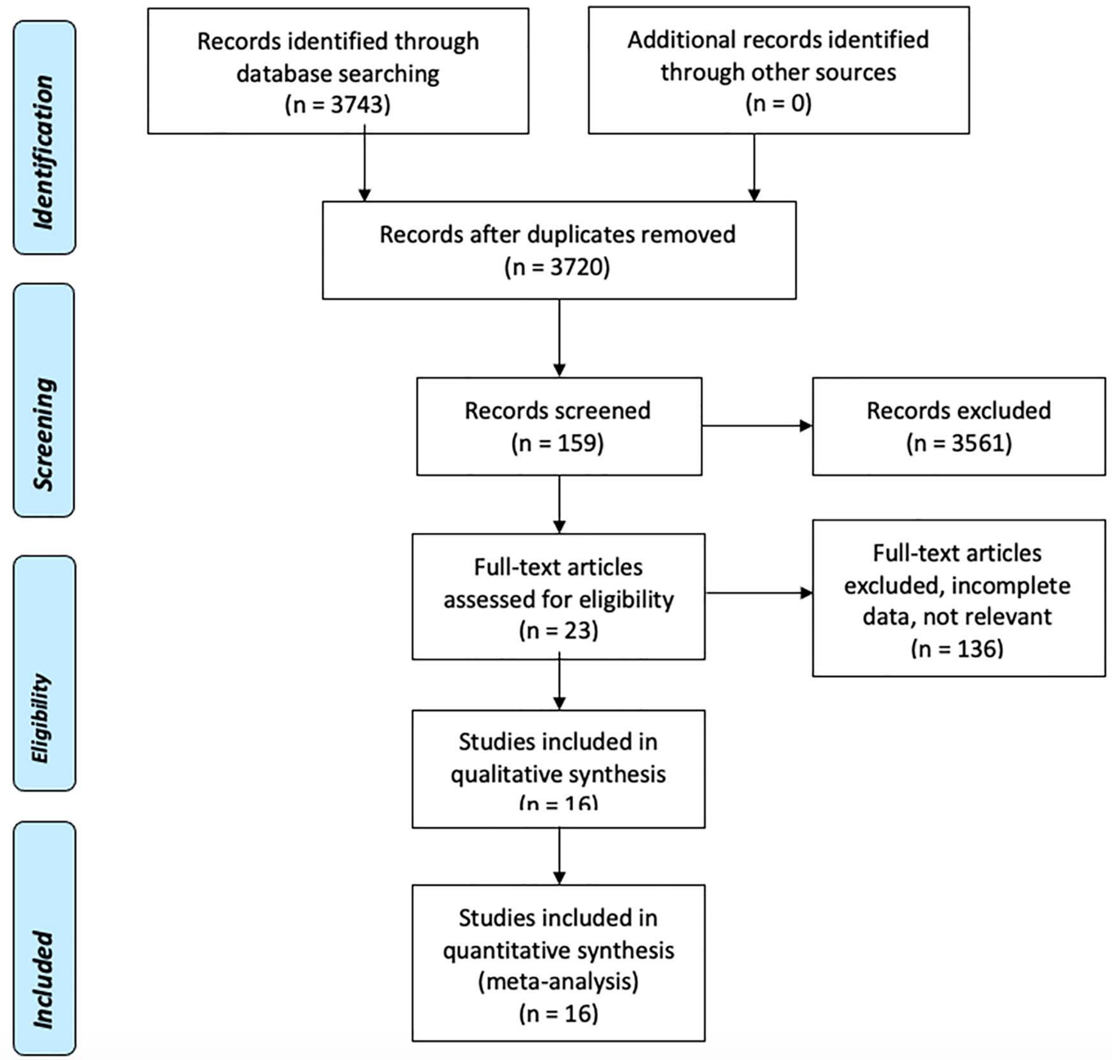

Fig. 4 PRISMA flow diagram 2009.

duplicates. Based on title and abstract, and with the exclusion of articles not written in English, 3651 articles were eliminated. Of the remaining articles, another 136 were not relevant. Finally, following full reading of the 23 remaining articles, 16 articles were selected (Table 3).

This systematic review includes 775 patients, with an average age of 38.6 years [standard deviation (SD) 7.9; range from 28 to 58.4] and an average follow-up of 7.69 years.

Surgical procedures

In the 775 patients identified in the study, 77 (9.9%) had bilateral involvement, and thus, a total of 852 osteotomies were performed. Patients with bilateral involvement had the same osteotomy in both hips.

A CVO was performed on 369 (43.3%) patients; a TRO was performed on 435 (51.1%) patients, and an HWO was performed in 48 (5.6%) patients (Table 4).

Table 3 Studies included and main features

Study authors	Sample size	Mean age	Treatment	Follow-up (years)	Conversion to THR (number)
Biswal *et al.*[2]	50	28	60 TRO	7	1
Sugioka and Yamamoto[59]	47	37	47 TRO	1.2	47
Ha *et al.*[56]	105	34.3	113 TRO	9.2	14
Zhao *et al.*[8]	62	33.3	73 TRO	12.4	6
Ito *et al.*[52]	28	33	34 HWO	18.1	4
Hamanishi *et al.*[6]	51	38	53 CVO	6.3	1
Park *et al.*[57]	18	38.1	18 TRO	4.5	18
Sonoda *et al.*[39]	28	34.8	28 TRO	12.3	28
Takegami *et al.*[61]	30	43	30 CVO	6.2	20
Kubo *et al.*[65]	20	38	20 TRO	2.5	20
Okura *et al.*[3]	93	38.8	102 CVO	10.1	11
Osawa *et al.*[60]	29	51.6	34 TRO	10	34
Lee *et al.*[54]	143	–	65 CVO 91 TRO	7.7	7 CVO 15 TRO
Utsunomiya *et al.*[4]	20	58.4	24 TRO	8.3	24
Asano *et al.*[53]	36	33.8	42 CVO	2.6	0
Sonohata *et al.*[55]	15	–	4 CVO 14 HWO	6.2	4 CVO 14 HWO

Table 4 Post-surgical outcomes and complications

	CVO	HWO	TRO	TOT
Patients	369	48	435	775
Age, years (SD; range)	37.4 (3.98; 33.3 to 43)	33 (19–53)	40 (9.95; 28–58.4)	38.57 (7.9; 28–58.4)
Conversion	49 (13.9%)	18 (37.5%)	201 (46.2%)	268 (31.5%)
HHS pre-op (SD; range)	61.4 (6.7; 53.8–70)	51 (26–75)	47.3 (8.02; 32–52.4)	
HHS post-op (SD; range)	87.8 (3.3; 85.7–93.6)	81 (45–100)	86.6 (5.1; 70.1–95)	
Blood loss (ml) (SD; range)	629 (297; 390–963)	776.4 (365.9; 260–1532)	452.6 (109; 329–550)	
Collapse	41 (11.1%)	9 (18.75%)	70 (16.1%)	120 (15.5%)
Leg shortening (mm) (SD; range)	4.6 (3.09; 1.7–9)	19 (8–36)	9.9 (3.6; 7.3–14.1)	

Harris Hip Score

The pre- and post-surgical functional evaluation was carried out using the HHS.[62] The average pre-surgical HHS was 53.2 points, which improved to an average of 85.1 points after surgery.

Evaluating each procedure separately, patients who underwent TRO improved from a pre-surgical HHS of 47.3 (SD 8.0; range from 32 to 52.4) to an average final score of 86.6 points (SD 5.1; range from 70.1 to 95) (an increase of 39.3 points). The second best procedure from a functional viewpoint is the HWO, which increases the HHS from 51 (range from 26 to 75) to 81 points (range from 45 to 100). Finally, the CVO increases the HHS from 61.4 points

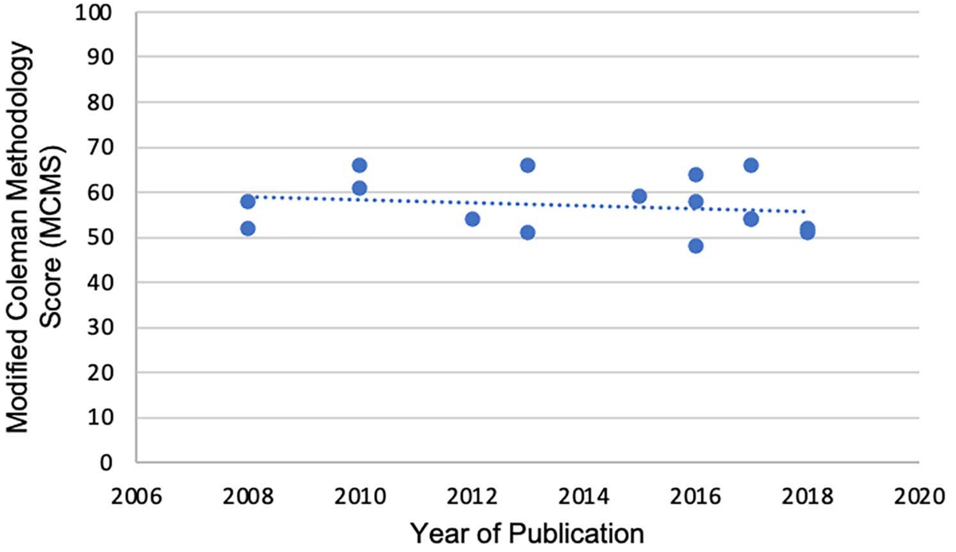

Fig. 5 Correlation between MCMS and year of publication.

(SD 6.7; range from 53.8 to 70) to 87.8 (SD 3.3; range from 85.7 to 93.6).

Leg shortening

One of the most relevant consequences of osteotomies is the shortening produced in the affected limb. Considering the HWO, we found an average shortening of 19 mm (range from 8 to 36). In the other procedures, the average leg shortening was 9.9 mm (SD 3.6; range from 7.3 to 14.1) in TRO and 4.6 mm (SD 3.09; range from 1.7 to 9) in CVO.

Blood loss

The greatest blood loss was reported in HWO with an average of 776.4 ml (SD 365.9; range from 260 to 1532); a slightly inferior loss was reported in CVO at 629 ml (SD 297; range from 390 to 963), whereas TRO is associated with the least blood loss, with an average of 452.6 ml (SD 109; range from 329 to 550).

Secondary collapse

Progressive collapse of the femoral head occurred in 15.31% of cases (120 patients). The greatest progression towards collapse was observed in HWO, at 18.75%, followed by TRO at 16.1% and finally CVO with the lowest rate at 11.1%. No data on the progression time to collapse were reported.

THR conversion rate

From the data extracted from the studies included in the present systematic review, the average THR conversion rate was 13.3% (49 patients) following CVO, 46.2% (201 patients) following TRO, finally 37.5% (18 patients) following HWO, with a total average THR conversion rate for all procedures of 31.5% (268 hips on 852 cases) and a mean time from osteotomy to THR of 7.6 years (range from 0.25 to 31.1).

Modified Coleman Methodology Scores

The MCMS for each study is reported in Table 5. Calculating the Pearson's correlation between MCMS and the year of publication (Fig. 5) we obtained a negative correlation ($r = -0.19$), which was not statistically significant (Student *t*-test; $P = 0.69$).

Table 5 Reported MCMS

Author	Year of publication	Time to follow-up (years)	N. of hips	MCMS
Biswal *et al.*[2]	2008	7	60 TRO	58
Sugioka and Yamamoto[59]	2008	1.2	47 TRO	52
Ha *et al.*[56]	2010	9.2	113 TRO	66
Zhao *et al.*[8]	2010	12.4	73 TRO	61
Ito *et al.*[52]	2012	18.1	34 HWO	54
Hamanishi *et al.*[6]	2013	6.3	53 CVO	66
Park *et al.*[57]	2013	4.5	18 TRO	51
Sonoda *et al.*[39]	2015	12.3	28 TRO	59
Takegami *et al.*[61]	2016	6.2	30 CVO	58
Kubo *et al.*[65]	2016	2.5	20 TRO	48
Okura *et al.*[3]	2016	10.1	102 CVO	65
Osawa *et al.*[60]	2017	10	34 TRO	54
Lee *et al.*[54]	2017	7.7	65 CVO 91 TRO	66
Utsunomiya *et al.*[4]	2017	8.3	24 TRO	54
Asano *et al.*[53]	2018	2.6	42 CVO	52
Sonohata *et al.*[55]	2018	6.2	4 CVO-14 HWO	51

The mean MCMS was 57.1. Table 6 reports mean, SD and range for each MCMS criteria. The main issues of the studies are: type of study (all studies were retrospective); rehabilitation and compliance (only one study described the post-operative rehabilitation protocol); selection (only three studies indicated selection criteria).

Discussion

Osteotomy to reorient the femoral head in patients with symptomatic ONFH aims to limit the necrotic progression of the femoral head in order to avoid or otherwise delay THR. The effectiveness of osteotomy procedures is likely related to a biomechanical effect: they aim to modify the position of the necrotic lesion so that it is located in a lower weight-bearing area and, at same time, ensuring that weight bearing take place on a relatively healthy part of the femoral head.

The patient history plays a significant role in establishing the aetiology of ONFH. In the present systematic review, in only five patients the aetiology of the ONFH was not reported. In the other 770 patients, the pathology was associated with corticosteroids in 39.6% of cases (305 patients), alcohol in 33.12% of cases (255 patients), idiopathic in 22.98% of cases (177 patients) and post-traumatic in 4.28% of cases (33 patients). Amongst the different risk factors such as Perthes disease,[22] Caisson disease[20] and others,[23–29,66,67] the principal risk factors are corticosteroids.[68,69]

Post-surgical outcomes and complications

The TRO is the most commonly performed procedure (51.05% of cases) followed by CVO (43.3% of cases) and HWO (5.6% of cases).

The HHS scoring system was used for the pre- and post-surgical functional evaluation.[62] The TRO showed the greatest functional improvement (47.3–86.6 points), followed by HWO (51–81 points) and finally by CVO (61.4–87.8 points). Therefore, even though patients undergoing a TRO started with

Table 6 Mean score for each MCMS criteria

Methodology criterion	Mean score (SD)	Range
Part A		
1. Study size	3.75 (3.97)	0–10
2. Follow-up	8.6 (2.4)	4–10
3. N procedures	9.4 (1.2)	7–10
4. Type of study	0 (0)	0
5. Diagnostic certainly	5.0 (0)	5
6. Description of surgical technique	10 (0)	10
7. Rehabilitation & compliance	0.31 (1.25)	0.5
Part B		
1. Outcome criteria	7.0 (0)	7
2. Outcome assessment	12.0 (0)	12
3. Selection process	0.93 (2.01)	0–5
MCMS	57.125 (6.2)	48–66

lower function, the resulting functional status was significantly higher than what obtained with the other two procedures.

In relation to leg shortening, of the studies reporting the results of HWO, the investigation by Ito *et al*.[52] is the only one detailing the shortening produced, and we do not know whether a shortening of nearly 2 cm is to be expected routinely when undertaking such procedure. If this were confirmed, HWO would be the procedure with the most notable leg shortening.

From our finding, in TRO an average leg shortening of 9.9 mm was reported, and in CVO the shortening was 4.6 mm. However, also, in these procedures, there is a high variance in the values reported. In fact, Asano *et al*.[53] report the lowest average leg shortening after CVO, at 1.7 mm, whereas Hamanishi *et al*.,[6] for the same procedure, report an average leg shortening of 9 mm. This variance is probably related to the fine technical details of the procedure, the size and location of the lesion, which influence the varus angle to reach.

The clinically most significant complication of any osteotomy, and the main cause for further surgery, is the progressive collapse of the femoral head, which accounts for ∼50% of all cases of conversion to THR.

Secondary collapse is influenced by the characteristics of the lesion, in particular its location and size. Zhao *et al*.[8] observed that, to reduce the risk of secondary collapse, the post-surgical intact ratio should not be >33.6%.

The different procedures can influence the rate of collapse of the femoral head. HWO showed the greatest progression towards collapse (18.75%), followed by TRO (16.1%) and CVO (11.1%). This result is in concert with what observed by Lee *et al*.[54]

Establishing the real rate of conversion in THR for each of type of osteotomy is difficult, given the notable variability in results obtained by individual studies. For example, Hamanishi *et al*.[6] report a conversion rate of CVO to THR of 1.8%, i.e. a single case of 53 patients. At the other end of the spectrum, Takegami *et al*.[61] report a conversion rate of 66.6%, i.e. 20 conversions from a total 30 patients. Thus, the same procedure can result in totally different outcomes. The same variability is evident in TRO and HWO.

This marked difference in THR conversion rate between studies could be caused by several factors, some of which are aetiology, the characteristics and stage of the initial lesion and the technical skill of the surgeon. However, these factors were not accounted for in the original investigations, and it is therefore impossible to formulate any evidence-based recommendations on this particular issue.

In our study, of the 48 initial HWO surgeries conversion to a THR occurred in 18 (37.5%) cases. Of 369 CVO surgeries, conversion to a THR occurred in 49 cases (13.3%). Finally, of 335 TRO surgeries, conversion to THR occurred in 201 (46.2%) cases. The average THR conversion rate resulting is 31.5% (268 hips in 852 cases). Therefore, about one-third of the ONFH patients undergoing osteotomies to salvage the femoral head, over an average follow-up period of 7 years, a THR was undertaken.

Amongst the most common causes for conversion to THR is the progressive collapse of the femoral head, occurring in 15.31% of cases (120 patients), and therefore responsible for about half of all conversion to THR. Other causes are progressive osteoarthritis, non-union, infection and fracture.

Limitations

This study has several limitations. First of all, no study was a randomized trial. Moreover, the follow-up period is relatively short for the purposes of evaluating the real effectiveness of procedures, which require a prolonged observation period. Another limitation is represented by the design of the studies themselves, as no standardization for choice of the procedure according to, for example, the stage of ONFH, duration and severity of symptoms, location of the area of ONFH was available.

Conclusion

Following a proximal femoral osteotomy for the management of ONFH, about one-third of patients undergoes a THR by 7 years after the index procedure. It is not clear which factors (age, BMI, location and size of the lesion) contribute to failure of the osteotomy, and fine differences in surgical techniques cannot be accounted for. A proximal femoral osteotomy should be planned only after careful staging of the condition, and the choice of procedure should be based on patient's needs. For older patients, the elevated risk of a further major procedure, i.e. a THR, should be carefully considered. In particular, the fact that a conversion to THR would take place at an even more advanced age must be taken into consideration, along with the subsequent increased risk of morbidity and mortality.

Acknowledgements

Many thanks are given to Miss Natalia Weronika Rapala for the help given in producing the figures.

Conflict of interest statement

The authors have no potential conflicts of interest.

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