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Review Article

A Review on Total Hip Replacement and Vascular Complications

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Abstract

Introduction: Total hip arthroplasty (THA) is a typical surgical procedure with uncommon and preventable complications. However, most adverse events following THA are unusual and preventable or easily treated as expected. This study examined the two common complications of the THA procedure namely: orthopedic and vascular complications and their management.

Methods: The primary search began with reviewing citations from PubMed, and Scopus, between 1991 and 2020 using the keywords: (Hip arthroplasty) or (Arthroplasty AND Hip AND vascular Complications).

Results: Overall, 117 articles were extracted with the initial search. Then 67 studies were selected and used in the present study according to inclusion criteria. The studies reputed thromboembolic disease as vascular complications. The management of vascular complications includes preoperative management, preoperative clinical investigation, intraoperative, and postoperative management.

Conclusion: In general, vascular injuries are rare in hip replacement surgeries. Vascular injuries can appear early in surgery, in the mid-term as postoperative bleeding, and later as pseudo-aneurysms.

Keywords: Arthroplasty; Complication; Hip; Management.

Introduction

The request for the primary total hip arthroplasty (THA) is growing worldwide [1]. Total hip arthroplasty (THA) is one of the most successful and cost-effective medical procedures developed during the last century and is projected to grow in volume to 635,000 procedures annually in the United States by 2030 [2]. Despite the selectivity of this method, it is performed immediately as the definitive treatment for femoral neck fractures, which account for approximately 2.7% of primary THA from 2012 to 2018 [3].

THA is one of the most expensive cases related to health care centers [4]. Regardless of its nature and safety, it is associated with some adverse outcomes, which could threaten the consequences of the procedure and result in patients' mortality [5]. Complications include surgery and the postoperative period [6]. Although rare, vascular injury occurs during hip surgery, immediately after surgery or late in the postoperative period (0.2-0.3%); however, it may be fatal [7-8]. In such cases, the arteries and vessels may be damaged, which can

be seen at the level of the pelvis or the proximal part of the limb [9]. The most common patterns of vascular injury include rupture, pseudo-aneurysm, thromboembolic fistula, and venous artery [10-12]. The causes of vascular injury during surgical procedures are as follows [13-16]:

- bending back the blood vessels by putting a sharp-edged retractor
- direct damage caused by a sharp osteotomy or a knife blade
- damage caused by an osteophyte during joint manipulation
- thermal damage, erosion, and obstruction of blood vessels due to direct contact when inserting bone cement
- over reaming of the acetabulum
- damage by inserts in the blood vessels
- injuries by drills and screws
- damage inside blood vessels during surgical procedures of arthroplasty or pelvic limb manipulation in patients with advanced arteriosclerosis. This study reviewed the complications of the THA procedure in two parts: orthopedic and vascular complications and their management.

Methods

This study was conducted about the total hip arthroplasty. The primary search began with reviewing English-language citations from PubMed, and Scopus, between 1991 and 2020 using the keywords: (Hip arthroplasty) OR (Arthroplasty AND Hip AND vascular Complications). The initial search yielded 117 articles. In the meantime, about 67 reports have been selected and used in the present study (Fig. 1).

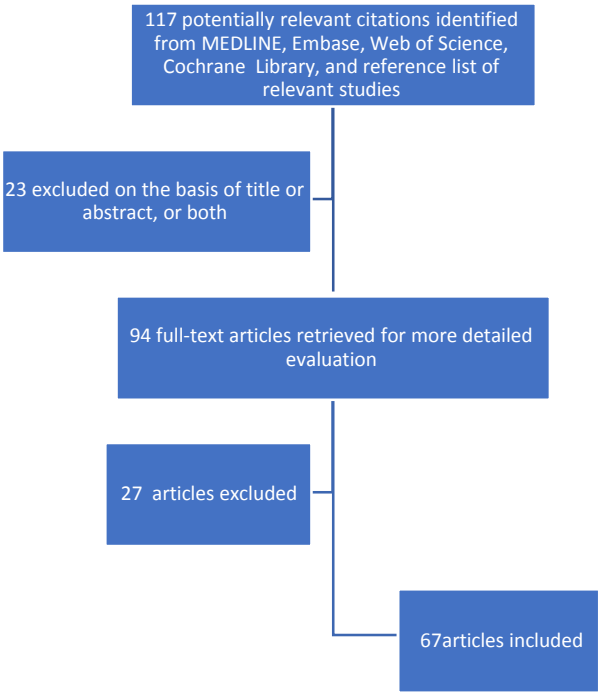

Figure 1: Study information diagram.

Results

Vascular complications

Contiguous arteries to the acetabulum, pelvis, and proximal areas of the lower extremities that are susceptible to be injured during total hip replacement are mainly branches of common iliac vessels; external iliac vessels, obturator vessels, superior and inferior gluteal artery, and internal pudendal arteries and veins [17]. Indeed, many vascular structures surrounding the acetabulum, pelvis and proximal areas of the lower extremities may be injured by direct and indirect trauma have been reported [18-20]. In particular, the primitive cause of injuries includes reaming during acetabular preparation, retractor-induced damage, drilling holes for fixation of screws in cementless acetabular cups, excessive traction in surgery, postoperative cup migration. Also, cement erosion

and excessive local heating by methyl methacrylate in cemented total hip replacement are further reasons for the occurrence of arterial injuries during total hip replacement [14,15,18-20]. However, there are several reported reasons in which symptoms of vessel injury were not evident. The possible reasons might be bone fragments or contamination caused due to soft-tissue defects, resulting in infections [21].

Vessel injuries giving immediate symptoms of total hip replacement are severe hemorrhage.

The most common ischemic symptoms in the delayed postoperative period include pain, decreasing hemoglobin, swelling, reduced blood pressure, and hypovolemic shock [1, 2, 4, 6, 10, 11, 22, 23]. Other presenting signs and symptoms of vessel injury in revision surgeries include excessive bleeding, loss of pulse, and instability during extraction of hip prosthesis [19].

What should be careful in these cases is that injury should be controlled with immediate pressure and ablation or ligation of the bleeding vessel [24]. It is the surgeon's responsibility to perform such procedures. However, an interventional radiologist or vascular surgeon intervenes if the bleeding is uncontrollable or severe vascular damage has occurred [25].

Vascular complications in THA are rare, and several patterns of injury can be seen (26-28):

- The acute injuries
- It is usually caused by high retractor pressure.
- Increases the severity of heavy hemorrhage
- It is seen in patients with acetabulum protrusion.
- Injuries causing delayed symptoms
- It appears a few days or years after THA.
- Hip pain
- Incidence of ischemic symptoms in the limb
- Severe hemorrhage at the time of extracting the hip prosthesis.

Choosing a precise surgical procedure should be a priority, and avoid using retractors over the lip over the acetabulum. In cases of acetabular protrusion when the significant vessels are close to the operating site, care must be taken not to penetrate the bottom of the acetabulum when drilling the holes [29]. Also, when an arterial reconstruction in cases of pseudo aneurysm is needed for the use of synthetic graft material must be avoided because of the infection risk with severe secondary complications [30].

In some reports, gender bias has also been observed as one of the causes of vessel injury. In several retrospective studies, the comparison of females' dominance of vessel injury to males (3:2) has been confirmed [16, 24, 31,32].

The relationship of pelvic vascular structures surrounding the acetabulum has been described in several studies [33].

Thromboembolic disease

Thromboembolic is a complication disease that comprises the largest risk group of post-THA patients. That’s precise etiology remains uncertain, but stasis due to torsion tourniquet of the lower limb during surgery, as well as intimal injury, are one of the causes of such a complication [34].

Symptomatic VTEs are relatively infrequent events; however, some factors increase the risk (Table 1). As is presented in table 1, the correlation between the frequency of the stenosis level and

nerve sedimentation sign was not significant (P=0.75).

Table 1: VTE s risk enhancers

Factors
A prior VTE event
Hypercoagulable states
Thrombophilias
Elevated BMI
Diabetes mellitus
Smoking
Anemia
Tamoxifen or raloxifene therapy
ASA[1] score <3
Coronary artery disease
Varicose veins
Stroke

The recurrence rate of VTE is high. According to Hansson et al. reports, the 5-year cumulative incidence of recurrent VTE events was 21.5% after a first DVT and 27.9% after a second DVT; was while the 5-year cumulative incidence of fatal PE was reported 2.6% after a first DVT [35-37]. In this group of patients, to prevent a recurrence, administration of warfarin with low molecular weight heparin (LMWH) from 24 hours after surgery to 4 days can be helpful [38].

Selective estrogen receptor modulators increasing the VTE risk [39]. According to a 1999 report, patients treated with tamoxifen had a 2-fold increase in PE. Similar results have been observed with Raloxifene as a selective estrogen receptor modulator. Based on the available evidence, the simultaneous use of two or more samples of these drugs is associated with an increased risk of VTE [40,41].

Given all the factors that increase the risk of VTE in THA; Anticipating actions to prevent this or minimize it is a requirement [42]. These actions are defined based on runtime at three levels [43-46]:

A. Preventive measures before performing THA surgical procedure

- Discontinuation of procoagulant drugs
- Pre donation of autologous blood

B. Preventive measures during the THA surgical procedure

- Hypotensive epidural anesthesia with the administration of intraoperative heparin (15 U/Kg)
- Reduction of the time of femoral vein occlusion and blood loss

C. Preventive measures after performing THA surgical procedure

- Aspirin for low-risk patients.
- Warfarin for patients with intermediate clinical predisposing factors for VTE and patients who have an intolerance to aspirin.
- Low molecular weight heparin for when the risk of VTE is high

Prevention of vascular injuries

Obey quadrant system

Earlier, to prevent these injuries during the fixation of acetabular screws, a simple method of the acetabulum quadrant system was proposed by Wasilewski et al. [47]. Various anatomical studies have shown that screw fixation in complete cement-free hip replacement, especially in revision surgeries, is the most prominent cause of vascular injury.

Wasilewski et al. Have defined an acetabular four-section system for managing the secure placement

[1] American Society of Anesthesiologists

of screws during primary and revised hip replacement surgeries (Fig. 2). A quadratic system has been suggested to explain the relationship between acetabular bone structure and surrounding vascular structures to prevent vascular structures [48].

Figure 2: Acetabular quadrant designation to determine safe zones for transacetabular screw fi xation. Line A is fi rst drawn from the anterior superior iliac spine (ASIS) through the center of the hip joint, and Line B is made perpendicular to that at the level of the center of the acetabulum. Anterior-superior quadrant [68].

The quadratic system of the acetabulum consists of four parts of the acetabulum by dividing acetabulum by two intersecting vertical lines. The first line A originates in the upper anterior iliac spine (ASIS) and travels directly to the center of the acetabulum, dividing the acetabulum into two halves and collectively referred to as the anterior and posterior quadrants. The second line B originates from the center of the acetabulum and is perpendicular to the first line, resulting in two upper and lower halves [49]. For this purpose, these two vertical lines intersect at the center of the acetabulum to form four quadrants, collectively referred to as the upper anterior quadrant, anterior inferior quadrant, posterior superior quadrant, and posterior inferior quadrant. Most of the published work on vascular damage has been done on the corpse bone. The authors attempted to provide a clear picture of the quadrant system using a computed tomography model of angiography (A-CT) with a three-dimensional computational model of the pelvis and the surrounding vascular structure. In the development of three-dimensional models of vascular constructions, some vessels and vessels are not visible due to the limitations of computed tomography imaging [50]. The Quadrant system identifies safe areas for repairing acetabular screws of appropriate size, which are carefully examined during hip replacement surgery. It does the following:

This quadrant contains the external iliac artery and vein. The acetabular screws fixed in this quarter are directed towards these vessels. However, it was found that the external iliac vein is in a more intermediate position than the artery and is, therefore, more dangerous than the artery [51].

Anterior-inferior quadrant

Obturator artery is present in this quadrant, and the bone stock is thin in respect of other quadrants. This order will increase the possibility of vessel injury during screw placement [52].

Posterior-superior quadrant

The number of three-dimensional reports shows that the superior posterior quadrant has good bone stock. This quadrant has the superior gluteal artery and vein as they pass to the pelvis through the greater sciatic notch. The suitable-sized screw may be considered for secure placement as the bone stock in the central zone of this quadrant is more than 25 mm [53].

Posterior-inferior quadrant

The fixed screws in this quadrant are directed to the lower gluteal and pudendal vessels. This quadrant is considered safe due to the bone center presence suitable for screw placement. Depending on the structure of this quadrant, the proper size of a screw may not touch the vessel structure, thereby preventing damage to the arteries [54].

Center of the acetabulum

Lines A and B intersect at the center of the acetabulum. The current position is very close to the obturator artery, so its use to insert screws is avoided. However, the screws of line A in the upper part of the acetabulum lead to the external iliac artery. The screws along line A at the bottom of the acetabulum are close to the constrictor. Thus, the external iliac arteries, constrictor vessels, and upper gluteal artery appear most damaged. Avoid placing screws in the anterior quadrant during complete hip surgery, as most arteries are in this quadrant. The posterior quadrant is usually safer to set a screw of the appropriate size because it has good bone density and structure, regardless of the vessel structure [55].

High hip center

In these cases, the quadrant system acts like a normal pelvis. In the upper hip, the posterior upper and lower posterior quadrants are secure for placement with well-preserved bone screws at the margin of the acetabulum.

In addition, a rare case of deviated vascular anatomy has been reported that requires caution when installing screws as they are more prone to damage [56].

If there is bone loss in the posterior quadrant surgery, it is necessary to place the screw in the anterior quadrant. The screws and drill bits can be passed through the anterior quadrant with visual perception to set the proper screws in the anterior columns and describe soft tissues accurately.

The quadrant system is prevalent among total hip arthroplasty surgeons until the normal hips are taken into account. In the technical demand for the total hip replacement of Crowe type-IV developmental dysplasia, the posterior superior quadrant system is condemned because the center of the acetabulum is shifted anteroinferior in the hip with a high, complete dislocation. Screws lying in the safe quadrant may frequently injure the obturator blood vessels. In these cases, a modified quadrant system must be used on surgeon recommendations [57, 58].

Acetabular retractors positioning

During hip arthroplasty, retractors are usually located around the acetabulum. Studies show that the surgeon's approach can lead to future injuries. Therefore, the proper position of the retractor during the hip arthroplasty procedure can play an active role in reducing possible vascular damages. Safely, the best location to prevent such conditions is to place the anterior acetabular retractor in the anterior inferior iliac spine. Also, placing an inadequate acetabular retractor on the anterior wall can prevent these injuries [59].

Acetabular reinforcement ring and antiprotrusio cage

In reconstructive surgeries and damaged hips, acetabular amplification rings, as well as the anti-protrusion cages, are typically used. The advantage of using these prostheses is that in addition to providing the conditions for screw adjustment, they restore the previous anatomical state of the acetabulum. Often, screws are not placed in the dorsal and abdominal position of the prosthesis to prevent possible damage to the arteries. In such cases, radiological intervention during surgery is usually on the agenda [60].

Cement

During hip replacement surgery with bone cement, cement is usually prevented from reaching the pelvis. Cement extrusion in areas with the defective acetabular wall can affect the external iliac arteries and cause several complications. Besides, excessive use of this cement can lead to exothermic reactions and eventually vascular thrombosis. In some cases, the cement spicule is worn by the arteries, causing a false aneurysm in the postoperative period. If intrapelvic cement is not well extracted and corrective surgery is necessary, there is a possibility of a vascular avulsion [61].

Management

Preoperative management

Preoperative clinical investigation

Clinical evaluation of vessels in the preoperative stage is crucial. Understanding the anatomy of the vessels surrounding the pelvis and using methods such as color Doppler ultrasound to measure arterial occlusion pressure are some of the things that should be on the agenda. During preoperative evaluations, although injuries of the femoral artery are easily detectable, injuries to the obturator and superior gluteal arteries do not appear to be easy [62].

1. Management

1.1. Preoperative management

1.1.1. Preoperative clinical investigation

1.1.2. Preventive measures

In cases that the hip is damaged during the hip reconstructive surgery, preoperative angiography should be done by a surgeon [63].

1.2. Intraoperative management

During hip surgery, timely diagnosis and treatment of vascular damage require the surgeon's care and ingenuity. During surgery, many causes can lead to sudden vascular damage. In some cases, may the vascular damage happen because of broken bone edges, implants, or instruments used in surgery. Therefore, rapid and accurate diagnosis of the site of injury and control of bleeding, even in cases of minor bleeding, is one of the most significant measures during surgery [64].

The surgeon must not underestimate the urgency of vessel injury, even in slight signs of bleeding. Several steps must be followed in such types of situations, which are listed below [64,65]:

- In massive bleeding or slight signs of bleeding, immediate bleeding sights must be identified visually and operated to stop the hemorrhage. Additionally, ultrasonography is the most rapid way to recognize the bleeding site in closed or open cases.
- In acute hemorrhage at the first site, surgeons must pressure for local control at either end of injured vessels.
- Additional supplies of blood and fresh frozen plasma must be prepared.
- For smaller vessels, coagulation and ligation techniques can be utilized to control bleeding.
- If the compression technique is unsuccessful at the first attempt, it must be followed by surgical ligation, endovascular stenting, and bypass as the next step for sites of vessel injury.
- Without time delay, vascular surgeons must be intervened to take the operative actions and stop the bleeding immediately.
- The operating orthopedic surgeon must be familiar with the advanced operative techniques like the ilioinguinal and the Stoppa approaches for intrapelvic exposure, generally used in major injured vessel repair.

1.3. Postoperative management

Careful monitoring of the condition of the arteries after surgery for several days after recovery is also essential to prevent postoperative vascular complications. There are many signs and symptoms after surgery and in the late postoperative period. The most important symptoms of vascular injury are unexplained hypotension, tachycardia, nerve palsy, hypovolemic shock, hemoglobinemia, and hypertension. In such cases, immediate axial imaging or radiography, contrast angiography, color ultrasound are the most natural methods to diagnose the source of bleeding.

Careful monitoring of these symptoms is better and can be treated without delay with open repair, stenting, bypass, coil, or chemotherapy [37-39]. The late symptoms of pseudoaneurysm formation can be confusing and treated with surgery after determining vascular damage [66].

This hip replacement surgery is mostly performed in elderly patients, and the possibility of damage to arterial vessels should be considered, as these vessels are more vulnerable to these injuries [67].

Conclusion

In general, vascular injuries are rare in hip replacement surgeries; however, careful preoperative planning, selection of better and more accurate instruments, knowledge of anatomical structures, and careful surgical procedures are essential to prevent vascular injury. Vascular injuries can appear early in bleeding during surgery, in the medium term as postoperative bleeding, and later as pseudo-aneurysms. The management of these complications focuses on the prevention of these injuries.

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Conflict of Interest Disclosures

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Authors' Contributions

All the authors met the standard criteria of authorship based on recommendations of the international committee of medical journals editors.

Ethical Statement

This research does not require a code of ethics.

References

1. Knight SR, Aujla R, Biswas SP. Total Hip Arthroplasty-over 100 years of operative history. *Orthopedic reviews*. 2011: 6;3(2).

2. Kurtz SM, Ong KL, Schmier J, Mowat F, Saleh K, Dybvik E, et al. Future clinical and economic impact of revision total hip and knee arthroplasty. *JBJS*. 2007;89(suppl_3):144-51.

3. Loppini M, Grappiolo G. Uncemented short stems in primary total hip arthroplasty: the state of the art. *EFORT Open Reviews*. 2018;3(5):149-59.

4. Siopack JS, Jergesen HE. Total hip arthroplasty. *Western journal of medicine*. 1995;162(3):243.

5. Williams O, Fitzpatrick R, Hajat S, Reeves BC, Stimpson A, Morris RW, et al. Mortality, morbidity, and 1-year outcomes of primary elective total hip arthroplasty. The Journal of arthroplasty. 2002;17(2):165-71.

6. De Geest T, Vansintjan P, De Loore G. Direct anterior total hip arthroplasty: complications and early outcome in a series of 300 cases. Acta Orthop Belg. 2013;79(2):166-73.

7. Wasielewski RC, Crossett LS, Rubash HE. Neural and vascular injury in total hip arthroplasty. The Orthopedic clinics of North America. 1992;23(2):219-35.

8. Hwang SK. Vascular injury during total hip arthroplasty: the anatomy of the acetabulum. International orthopaedics. 1994;18(1):29-31.

9. Parvizi J, Pulido L, Slenker N, Macgibeny M, Purtill JJ, Rothman RH. Vascular injuries after total joint arthroplasty. The Journal of arthroplasty. 2008;23(8):1115-21.

10. Wilson JS, Miranda A, Johnson BL, Shames ML, Back MR, Bandyk DF. Vascular injuries associated with elective orthopedic procedures. Annals of vascular surgery. 2003;17(6):641-4.

11. Kennon RE, Keggi JM, Wetmore RS, Zatorski LE, Huo MH, Keggi KJ. Total hip arthroplasty through a minimally invasive anterior surgical approach. JBJS. 2003;85(suppl_4):39-48.

12. Bergqvist D, Carlsson AS, Ericsson BF. Vascular complications after total hip arthroplasty. Acta Orthopaedica Scandinavica. 1983;54(2):157-63.

13. Kim YH, Oh SH, Kim JS. Primary total hip arthroplasty with a second-generation cementless total hip prosthesis in patients younger than fifty years of age. JBJS. 2003;85(1):109-14.

14. Bono JV, Axelson Jr SL, Bastian A, inventors; Howmedica Osteonics Corp, assignee. Patient-specific total hip arthroplasty. United States patent US 8,932,299. 2015 Jan 13.

15. Hwang SK. Vascular injury during total hip arthroplasty: the anatomy of the acetabulum. International orthopaedics. 1994;18(1):29-31.

16. Manson TT, Johnson AJ. Conversion Total Hip Arthroplasty. InAcetabular Fractures in Older Patients 2020 (pp. 143-164). Springer, Cham.

17. SooHoo NF, Farng E, Lieberman JR, Chambers L, Zingmond DS. Factors that predict short-term complication rates after total hip arthroplasty. Clinical Orthopaedics and Related Research®. 2010 ;468(9):2363-71.

18. White LM, Kim JK, Mehta M, Merchant N, Schweitzer ME, Morrison WB, et al. Complications of total hip arthroplasty: MR imaging—initial experience. *Radiology*. 2000 ;215(1):254-62.

19. Nolan DR, Fitzgerald Jr RH, Beckenbaugh RD, Coventry MB. Complications of total hip arthroplasty treated by reoperation. *The Journal of bone and joint surgery*. American volume. 1975 ;57(7):977-81.

20. Bloebaum RD, Beeks D, Dorr LD, Savory CG, DuPont JA, Hofmann AA. Complications with hydroxyapatite particulate separation in total hip arthroplasty. *Clinical orthopaedics and related research*. 1994; 298:19-26.

21. Healy WL, Iorio R, Clair AJ, Pellegrini VD, Della Valle CJ, Berend KR. Complications of total hip arthroplasty: standardized list, definitions, and stratification developed by the hip society. *Clinical Orthopaedics and Related Research*. 2016;474(2):357-64.

22. Bergqvist D, Carlsson AS, Ericsson BF. Vascular complications after total hip arthroplasty. Acta Orthopaedica Scandinavica. 1983 ;54(2):157-63.

23. An S, Shen H, Feng M, Li Z, Wang Y, Cao G. Femoral artery injury during total hip arthroplasty. Arthroplasty today. 2018 ;4(4):459-63.

24. Massat BJ, Vasseur PB. Clinical and radiographic results of total hip arthroplasty in dogs: 96 cases (1986-1992). Journal of the American Veterinary Medical Association. 1994;205(3):448.

25. Toms AP, Marshall TJ, Cahir J, Darrah C, Nolan J, Donell ST, et al. MRI of early symptomatic metal-on-metal total hip arthroplasty: a retrospective review of radiological findings in 20 hips. Clinical radiology. 2008 ;63(1):49-58.

26. Lamb JN, Baetz J, Messer-Hannemann P, Adekanmbi I, van Duren BH, Redmond A, et al. A calcar collar is protective against early periprosthetic femoral fracture around cementless femoral components in primary total hip arthroplasty: a registry study with biomechanical validation. The bone & joint journal. 2019;101(7):779-86.

27. Ranawat A, Zelken J, Helfet D, Buly R. Total hip arthroplasty for posttraumatic arthritis after acetabular fracture. The journal of arthroplasty. 2009 ;24(5):759-67.

28. Strum H, Nilsson O, Milbrink J, Mallmin H, Larsson S. The effect of early weight bearing on migration pattern of the uncemented CLS stem in total hip arthroplasty. The journal of arthroplasty. 2007;22(8):1122-9.

29. Harkess JW, Crockarell Jr JR. Arthroplasty of the hip. Campbell's Operative Orthopaedics E-Book. 2012 :158.

30. Johnson WD, Engh G, inventors; Alexandria Res Tech LLC, assignee. Apparatus and method for minimally invasive total joint replacement. United States patent. 2009.

31. Beldame J, Lagrave B, Lievain L, Lefebvre B, Frebourg N, Dujardin F. Surgical glove bacterial contamination and perforation during total hip arthroplasty implantation: when gloves should be changed. Orthopaedics & Traumatology: Surgery & Research. 2012 ;98(4):432-40.

32. Singh NK, Rai S, Rastogi A. Vascular Injury in Total Hip Replacement: Management and Prevention. Total Hip Replacement: An Overview. 2018:145.

33. Gao F, Sun W, Guo W, Li Z, Wang W, Cheng L. Topical application of tranexamic acid plus diluted epinephrine reduces postoperative hidden blood loss in total hip arthroplasty. The Journal of arthroplasty. 2015;30(12):2196-200.

34. Huo MH, Salvati EA. Thromboembolic disease in total hip arthroplasty. Contemp Orthop. 1991; 22:407.

35. Zhang ZH, Shen B, Yang J, Zhou ZK, Pei FX. Risk factors for venous thromboembolism of total hip arthroplasty and total knee arthroplasty: a systematic review of evidences in ten years. BMC musculoskeletal disorders. 2015 ;16(1):24.

36. Zhang J, Chen Z, Zheng J, Breusch SJ, Tian J. Risk factors for venous thromboembolism after total hip and total knee arthroplasty: a meta-analysis. Archives of Orthopaedic and Trauma Surgery. 2015 ;135(6):759-72.

37. Lieberman JR, Geerts WH. Prevention of venous thromboembolism after total hip and knee arthroplasty. JBJS. 1994;76(8):1239-50.

38. White RH, Gettner S, Newman JM, Trauner KB, Romano PS. Predictors of rehospitalization for symptomatic venous thromboembolism after total hip arthroplasty. New England Journal of Medicine. 2000 ;343(24):1758-64.

39. Wolowacz SE, Roskell NS, Plumb JM, Caprini JA, Eriksson BI. Efficacy and safety of dabigatran etexilate for the prevention of venous thromboembolism following total hip or knee arthroplasty. Thrombosis and haemostasis. 2009;101(01):77-85.

40. Lieberman JR, Heckmann N. Venous thromboembolism prophylaxis in total hip arthroplasty and total knee arthroplasty patients: from guidelines to practice. JAAOS-Journal of the American Academy of Orthopaedic Surgeons. 2017 ;25(12):789-98.

41. Streiff MB, Haut ER. The CMS ruling on venous thromboembolism after total knee or hip arthroplasty: weighing risks and benefits. JAMA. 2009;301(10):1063-5.

42. Friedman RJ. Optimal duration of prophylaxis for venous thromboembolism following total hip arthroplasty and total knee arthroplasty. JAAOS-Journal of the American Academy of Orthopaedic Surgeons. 2007;15(3):148-55.

43. Anderson Jr FA, Hirsh J, White K, Fitzgerald Jr RH. Hip and Knee Registry Investigators. Temporal trends in prevention of venous thromboembolism following primary total hip or knee arthroplasty 1996–2001: findings from the Hip and Knee Registry. Chest. 2003;124(6):349S-56S.

44. Lachiewicz PF. Comparison of ACCP and AAOS guidelines for VTE prophylaxis after total hip and total knee arthroplasty. Orthopedics (Online). 2009;32(12):74.

45. Baser O. Prevalence and economic burden of venous thromboembolism after total hip arthroplasty or total knee arthroplasty. American Journal of Managed Care. 2011;17(1):S6.

46. Fuji T, Fujita S, Kawai Y, Nakamura M, Kimura T, Fukuzawa M, et al. Efficacy and safety of edoxaban versus enoxaparin for the prevention of venous thromboembolism following total hip arthroplasty: STARS JV. Thrombosis Journal. 2015;13(1):27.

47. Wasilewski R, McDonald JP, Heatley G, Lütjen-Drecoll E, Kaufman PL, Croft MA. Surgical intervention and accommodative responses, II: forward ciliary body accommodative movement is facilitated by zonular attachments to the lens capsule. Investigative ophthalmology & visual science. 2008;49(12):5495-502.

48. Hwang SK. Vascular injury during total hip arthroplasty: the anatomy of the acetabulum. International orthopaedics. 1994;18(1):29-31.

49. Watts CD, Martin JR, Fehring KA, Griffin WL. Inferomedial hip center decreases failure rates in cementless total hip arthroplasty for Crowe II and III hip dysplasia. The Journal of arthroplasty. 2018 ;33(7):2177-81.

50. Dietze S, Perka C, Baecker H. Blood vessel and nerve damage in total hip arthroplasty. Der Orthopade. 2014 ;43(1):64.

51. Shoenfeld NA, Stuchin SA, Pearl R, Haveson S. The management of vascular injuries associated with total hip arthroplasty. Journal of vascular surgery. 1990 ;11(4):549-55.

52. Rue JP, Inou N, Mont MA. Current overview of neurovascular structures in hip arthroplasty: anatomy, preoperative evaluation, approaches, and operative techniques to avoid complications. Orthopedics. 2004;27(1):73-81.

53. Brown GD, Swanson EA, Nercessian OA. Neurologic injuries after total hip arthroplasty. AMERICAN JOURNAL OF ORTHOPEDICS-BELLE MEAD-. 2008 ;37(4):191.

54. Cooke CC, Hozack W, Lavernia C, Sharkey P, Shastri S, Rothman RH. Early failure mechanisms of constrained tripolar acetabular sockets used in revision total hip arthroplasty. The Journal of arthroplasty. 2003;18(7):827-33.

55. Stans AA, Pagnano MW, Shaughnessy WJ, Hanssen AD. Results of total hip arthroplasty for Crowe Type III developmental hip dysplasia. Clinical orthopaedics and related research. 1998 (348):149-57.

56. Kelley SS. High hip center in revision arthroplasty. The Journal of Arthroplasty. 1994 ;9(5):503-10.

57. Komiyama K, Nakashima Y, Hirata M, Hara D, Kohno Y, Iwamoto Y. Does high hip center decrease range of motion in total hip arthroplasty? A computer simulation study. The Journal of arthroplasty. 2016;31(10):2342-7.

58. Bozic KJ, Freiberg AA, Harris WH. The high hip centers. Clinical Orthopaedics and Related Research (1976-2007). 2004; 420:101-5.

59. Shubert D, Madoff S, Milillo R, Nandi S. Neurovascular structure proximity to acetabular retractors in total hip arthroplasty. The Journal of Arthroplasty. 2015 ;30(1):145-8.

60. Gerber A, Pisan M, Zurakowski D, Isler B. Ganz reinforcement ring for reconstruction of acetabular defects in revision total hip arthroplasty. JBJS. 2003 ;85(12):2358-64.

61. Parvizi J, Saleh KJ, Ragland PS, Pour AE, Mont MA. Efficacy of antibiotic-impregnated cement in total hip replacement. Acta orthopaedica. 2008 ;79(3):335-41.

62. Ruder C, Staub LP, Eggli S, Dietrich D, Busato A, Mьller U. Influence of preoperative functional status on outcome after total hip arthroplasty. JBJS. 2007;89(1):11-7.

63. Haddad FS, Masri BA, Garbuz DS, Duncan CP. The prevention of periprosthetic fractures in total hip and knee arthroplasty. Orthopedic Clinics of North America. 1999 ;30(2):191-207.

64. Haidukewych GJ, Jacofsky DJ, Hanssen AD, Lewallen DG. Intraoperative fractures of the acetabulum during primary total hip arthroplasty. JBJS. 2006;88(9):1952-6.

65. Molli RG, Lombardi AV, Berend KR, Adams JB, Sneller MA. A short-tapered stem reduces intraoperative complications in primary total hip arthroplasty. Clinical Orthopaedics and Related Research®. 2012;470(2):450-61.

66. Youm T, Maurer SG, Stuchin SA. Postoperative management after total hip and knee arthroplasty. The Journal of arthroplasty. 2005 ;20(3):322-4.

67. Siopack JS, Jergesen HE. Total hip arthroplasty. Western journal of medicine. 1995 ;162(3):243.

68. Azar FM, Canale ST, Beaty JH. Campbell's Operative Orthopaedics, E-Book. Elsevier; 2020 Dec 21.