Injury 55 (2024) 111723

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

CT scan-based 3D fracture mapping in civilian gunshot intracapsular fractures of the femur neck.

S. Maqungo [a,b,*], A. Nicol [c], H. Yimam [d,e], R. Dey [d,e], A. Exadaktylos [f], M. Laubscher [a]

[a] Orthopaedic Trauma Service, Division of Orthopaedic Surgery, University of Cape Town
[b] Trauma Care & Injury Prevention, Division of Global Surgery, University of Cape Town
[c] Trauma Unit, Division of General Surgery, University of Cape Town
[d] Division of Human Biology, University of Cape Town
[e] Biomedical Engineering Research Centre, University of Cape Town
[f] Department of Emergency Medicine, Inselspital, Bern, Switzerland

ARTICLE INFO

Keywords:
Civilian gunshot
neck of femur fractures
fracture mapping

ABSTRACT

Introduction: Displaced intracapsular neck of femur (NOF) fractures secondary to civilian gunshots are rare injuries with universally poor outcomes following surgical fixation. No studies have been published on fracture mapping in NOF fractures secondary to civilian gunshots.
Objectives: We performed CT scan-based fracture mapping to identify the most common fracture patterns in these injuries.
Methods: ***Design:*** Retrospective search of prospectively collected data. ***Setting:*** Single Level 1 Trauma hospital. ***Patient selection criteria:*** All patients presenting with gunshot fractures to the femur neck between 01 January 2009 and 31 December 2022 were identified. Once identified from Picture Archiving and Communication System (PACS), computed tomography (CT) scans in Digital Imaging and Communication in Medicine (DICOM) format were imported into Mimics 16 software and fracture fragments were segmented and three-dimensional (3D) reconstruction was generated. The reduced fractures were exported to 3-Matic software to merge the fragments and adjust the orientation in three planes. An uninjured femur model was used as a template for reduction. Fracture lines and heat maps were then generated. Our outcome measures were successful mapping of the identified fracture lines.
Results: A total of 25 intracapsular femur neck fractures were identified and suitable for CT scan mapping. All patients were male with an average age of 22 (range 18-32). Once generated, fracture maps were used to show the location, distribution and frequency of the fracture lines. In all but two cases the fracture line propagation remained within the confines of the hip joint capsule. In three cases there was fracture extension into the superior aspect of the femur head, and in one case extension into the inferior aspect.
Conclusion: This is the first study to perform 3D fracture mapping for intracapsular femur neck fractures secondary to civilian gunshot injuries. The exercise has helped us better understand the commonest fracture patterns and assisted us with surgical planning and execution.

Introduction

Gunshot fractures of the femur neck are devastating injuries that affect mostly the younger population. Their characteristics differ from the more commonly encountered (1.6 million cases annually) osteoporosis related neck of femur fractures which affect mostly the elderly population [1]. They are high energy, penetrating injuries with resultant comminution of the femur neck and typically affect younger patients. Gunshot wounds (GSW) to the hip joint are relatively rare, with an incidence reported at 7.1 % of extremity GSW [2–4]. The treatment of these is controversial and there is paucity of literature related to intracapsular femur neck fractures secondary to civilian GSW. Available literature is limited to small retrospective series, review articles and case reports [5–12]. Some reports have grouped intracapsular and extracapsular fractures together, as well as a part of a bigger series including pelvic fractures [7,8,11,13,14]. All have reported universally poor

* Corresponding author at: H49 Old Main Building, Groote Schuur Hospital, Main Road, Observatory, Cape Town, South Africa
E-mail address: sithombo@msn.com (S. Maqungo).

https://doi.org/10.1016/j.injury.2024.111723
Accepted 7 July 2024
Available online 14 July 2024

outcomes regardless of treatment method used.

Civilian gunshot injuries are caused by low velocity firearms with muzzle velocities less than 2000 feet per second (f/s). They differ from military gunshot injuries which are caused by high velocity rifles with muzzle speeds above 2000 f/s [15], and these cause excessive soft tissue destruction.

In closed femur neck fractures, it has been shown that anatomic reduction is an important predictor of good outcome [16]. No such evidence exists for penetrating injuries, but it can be inferred that such reduction is also desirable in GSW fractures. A better understanding of common fracture patterns following GSW is therefore required.

We aimed to use three-dimensional (3D) fracture mapping in order to create comprehensive fracture maps to identify location, distribution and frequency of the fracture patterns. This is the first study to perform computed tomography (CT) scan-based 3D fracture mapping for intracapsular gunshot fractures of the femur neck. We hypothesised that the exercise of fracture mapping would reveal different fracture line patterns based on location of the fracture that differ from closed fractures.

Methods

To conduct this study, all cases of civilian gunshot fractures involving the femoral neck between 01 January 2009 and 31 December 2021 that presented to a single Level 1 Trauma Unit were retrospectively reviewed. Inclusion criteria were: age above 18 years, intracapsular neck of femur (NOF) fracture, CT scans available for analysis. Exclusion criteria were: paediatric and adolescent patients younger than 18 years, extra-capsular or trochanteric fractures (unless as part of extension of intracapsular fracture), lack of CT scans as well as the presence of retained projectiles within the femur neck which led to metal artefacts on CT scans.

A total of 25 appropriate cases were identified and their CT scans were obtained from the Picture Archiving and Communication System, PACS (Phillips, Netherlands).

Research Ethics clearance was obtained from our institution for this study (HREC 803/2021).

3D fracture reconstruction and reduction

Once identified from the PACS server, the CT scan images in Digital Imaging and Communications in Medicine (DICOM) format were imported into Mimics v.16.0 (Materialise, NV, Leuven, Belgium). The fracture fragments were segmented and reconstructed separately using thresholding and region grow features of the software. The fracture segments were then exported as independent stereolithography (.stl) files to Materialise Mimics and reduced in 3-Matic by orientating the fractured fragments into correct anatomical locations (Fig. 1). After achieving satisfactory reduction, two dimensional (2D) images were obtained in the anterior, posterior, and lateral views.

Fracture mapping

A non-fractured template of femoral head and proximal shaft was used to create the fracture map. A 2D snapshot of the anatomically reconstructed bone was obtained. A fracture line was created by tracing the edges of the fracture in GNU Image Manipulation Program (GIMP). This image was superimposed on a non-fractured hip image from the fractured image. This process was repeated for all the femoral neck fractures to create the final fracture map and finally digitised to create the heat map.

Two dimensional fractured images of each fractured femoral neck were aligned to the non-fractured template by making sure that the centre of the femoral head and neck and the edges aligned (Fig. 2). Compilation of the fracture lines was performed in an open-source graphic image editor, GIMP 2.10. The virtual reduction and fracture maps were performed by the bioengineers (HY and RD) and approved by the senior trauma surgeon and lead author (SM).

Heat maps

In order to graphically represent relative fracture line intensity in colour on heat maps, the fracture maps were digitized and converted into co-ordinate points using a custom code generated in matplotlib 3.3 in Python. The density of these co-ordinate points was plotted, where high density regions were represented by red colour and low-density regions were represented by blue colour in a manner similar to the one described by Mellema et al [17]. See Fig. 3.

Results

A total of 25 fractures in 25 males (average age 22years, range 18 – 32) were available for fracture mapping. Fourteen of the cases involved the right neck of femur, and 11 the left side. Nineteen were complete fractures with displacement, 6 were undisplaced or had unicortical involvement.

All fractures revealed some degree of comminution, including the cases that appeared to be unicortical on plain film radiography. The six undisplaced or unicortical involvement cases revealed more extensive fracture lines that were not initially appreciated on x-ray (Fig. 4). All but two cases remained within the capsular confines of the femur neck. The two exceptions were cases where the primary fracture lines are within the neck, but there is propagation beyond the femur neck to include the lesser trochanter and subtrochanteric areas. In each of cases the fractures were caused by a single projectile.

In three cases there was fracture extension into the superior aspect of the femoral head, and one case showed extension into the inferior part of

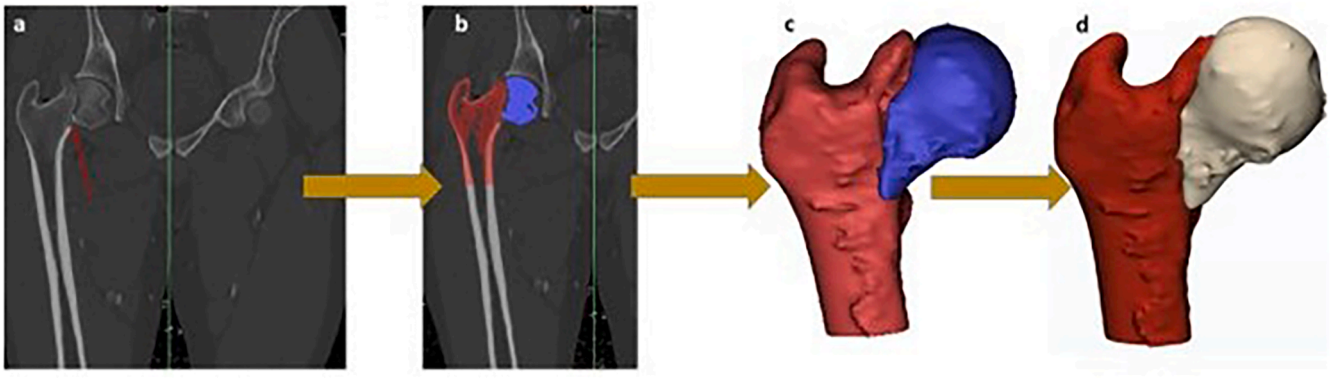

Fig. 1. Schematic representation of the workflow to reduce and reorientate the fractures from CT scans. a) CT scan obtained from the patient b) Identified fractures segmented on Materialise Mimics c) Fractures exported to 3-Matic d) Fracture segments after anatomical realignment.

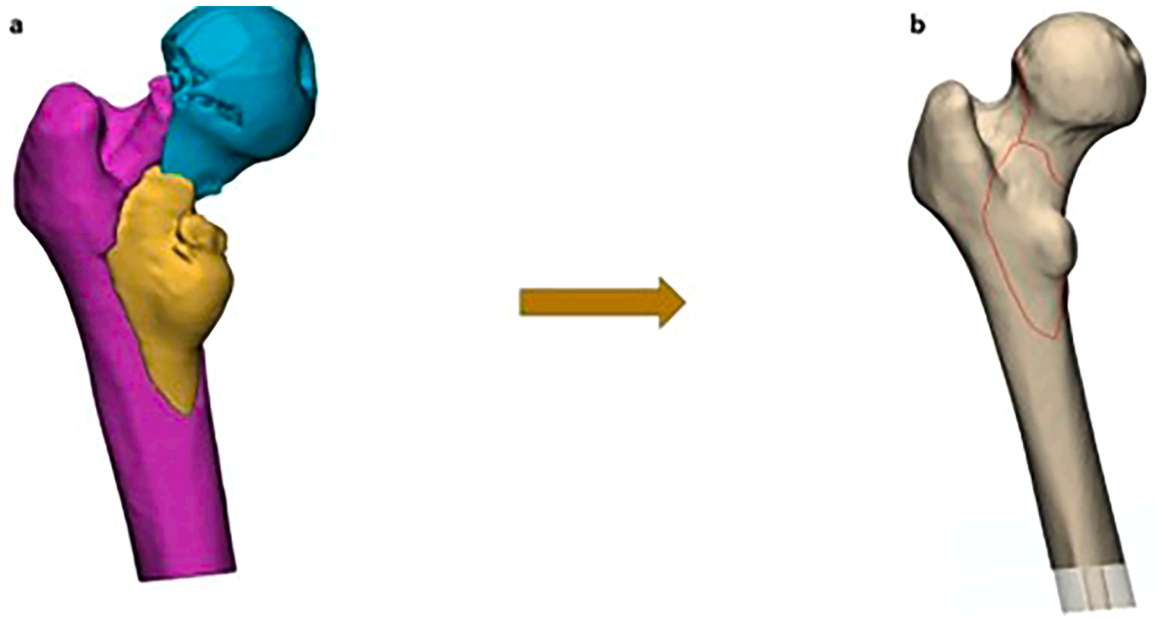

Fig. 2. Schematic representation showing the process of creating a fracture map from a set of femoral neck fractures.

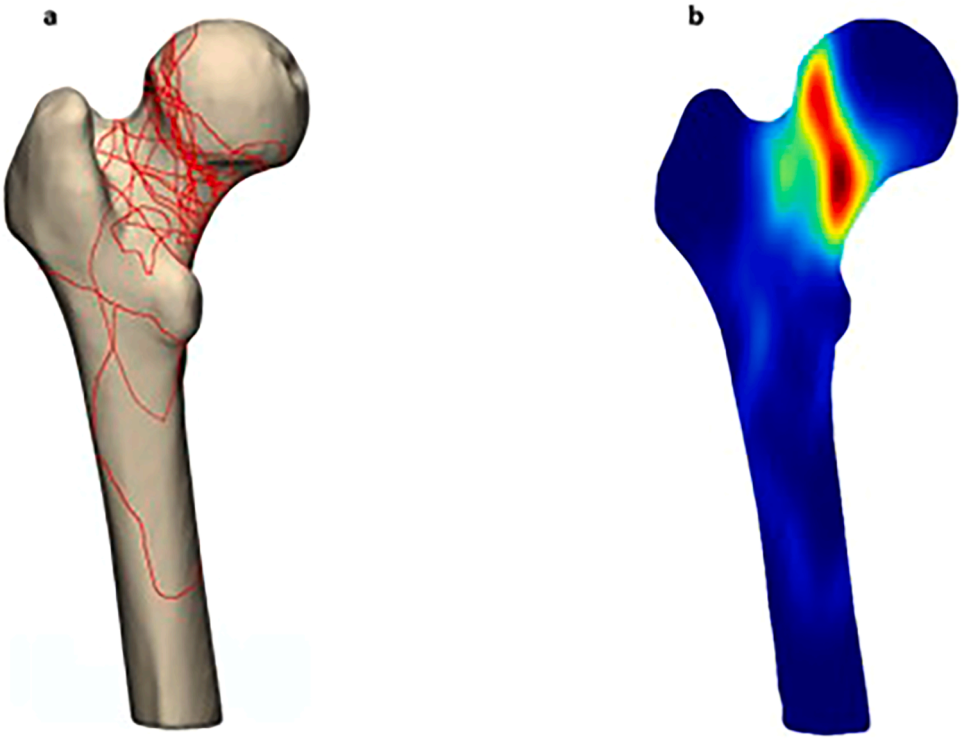

Fig. 3. a) The final fracture map after including all the fracture lines b) The final heat map.

the femoral head. There was no uniform or predictable pattern of propagation of the fracture lines from the entry point of the projectile.

Discussion

Closed neck of femur fractures in young patients are often the result of high energy trauma, and there are many gaps identified in their treatment [16]. When treated with internal fixation they have high complication rates with avascular necrosis, early implant failure and non-union having been reported in up to 28 % of patients [18–21]. It has been shown that anatomic reduction and stable fixation are good predictors of outcome and are the only factors within the surgeon's control [22,23]. Gunshot fractures of the femur neck are notoriously difficult to treat with universally poor outcomes and have been described as 'doomed to failure' [14].

We aimed to identify the location, distribution and frequency of femur neck fracture patterns secondary to civilian gunshot injuries. Currently there is no available literature on fracture mapping in civilian gunshot fractures of the femoral neck. Available studies have been performed in closed injuries and the benefits of this technique have been

Fig. 4. An example showing fracture extent not apparent on plain films, but visible on CT scans

confirmed in the scapula, olecranon, femur, tibia plateau and ankle, acetabulum fractures [17,24–31]. Superimposing fracture lines from a diverse number of injuries onto a standard template assists with improving of understanding of the injuries.

In our analysis we have identified common fracture patterns, as well as the presence of comminution that is nearly constant. The presentation of fracture lines is rather diverse, and the morphologic characteristics reveal common involvement of the subcapital and posterior regions of the femur neck, which may explain the poor prognosis of these injuries [14,32]. Extension beyond the confines of the hip joint capsule is rare, we only found two cases with fracture line propagation that extended into the trochanteric region.

Comminution is standard and this alone is a known risk factor for poor outcome in femur neck fractures. The presence of comminution often precludes the surgeon's ability to both obtain and maintain a perfect reduction. Some fracture line propagation was only apparent on CT scanning and in some of these cases the extent of the fracture line was not appreciated on plain film radiography. Not appreciating the non-visible fracture lines on plain radiography can lead to missed NOF fractures and delayed diagnosis [33].

Current classification systems exist for intracapsular neck of femur fractures, but these are based on closed fractures, rather than penetrating injuries [34–36]. In their case report, Ho et al note that "there is yet a worldwide consensus on the classification system or management guidelines for the management of gunshot injuries" [6]. We noticed in our series that in some cases there was fracture line propagation into the superior and inferior parts of the femur head (Fig. 3). This extension is not catered for in the current OTA/AO classification.

The retrospective nature as well as the low number of cases studies represent a limitation in our study. These are however rare injuries, from an area with a high incidence of civilian gunshot injuries, so this series represents unique work form a high-volume centre. The evaluation of fracture frequency using heat maps was qualitative and can therefore only provide visual information.

Also, this was a radiological study only and therefore the treatment modalities utilised as well as clinical outcomes of these patients were beyond the scope of this manuscript.

Conclusion

This was the first study to perform 3D fracture mapping for civilian gunshot fractures to neck of femur. There was universal presence of comminution in the fractures, and in some cases extension into the femoral head. Some of the fracture line propagation does not fit into the current OTA/AO Fracture Classification system.

This exercise has helped with better understanding of the commonest fracture patterns and it also assisted with surgical planning, fracture reduction and fixation.

Further studies with higher patient numbers are required in order to add onto this sparse body of knowledge.

CRediT authorship contribution statement

S. Maqungo: Writing – original draft, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **A. Nicol:** Writing – review & editing, Supervision, Conceptualization. **H. Yimam:** Software, Formal analysis, Data curation. **R. Dey:** Software, Formal analysis, Data curation. **A. Exadaktylos:** Methodology, Funding acquisition. **M. Laubscher:** Writing – review & editing, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding acknowledgement

This research has been funded in part by the National Research Foundation of South Africa. Grant No. 138208

References

[1] Johnell O, Kanis JA. An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. Osteoporos Int 2006;17(12):1726–33.
[2] Persad IJ, Srinivas Reddy R, Saunders MA, Patel J. Gunshot injuries to the extremities: Experience of a U.K. trauma centre. Injury 2005;36(3):407–11.
[3] Najibi S, Tannast M, Latini JM. Civilian gunshot wounds to the genitourinary tract: Incidence, anatomic distribution, associated injuries, and outcomes. Urology [Internet] 2010;76(4):977–81. https://doi.org/10.1016/j.urology.2010.01.092. Available from:.
[4] Maqungo S, Hoppe S, Kauta JN, McCollum GA, Laubscher M, Held M, et al. Surgical hip dislocation for removal of retained intra-articular bullets. Injury 2016;47(10).
[5] Maqungo S, Fegredo D, Brkljac M, Laubscher M. Gunshot Wounds to The Hip. J Orthop 2020;22(3):530–4.
[6] Chan H, Chan K yan K, Ip K chun, Li W. Open transcervical fracture of femur resulted from gunshot injury: A case report. J Orthop Trauma Rehabil. [Internet]. 2018;25:87–90. https://doi.org/10.1016/j.jotr.2018.03.001. Available from:.
[7] Bartkiw MJ, Sethi A, Coniglione F, Holland D, Hoard D, Colen R, et al. Civilian gunshot wounds of the hip and pelvis. J Orthop Trauma 2010;24(10):645–52.
[8] Tisnovsky I, Katz SD, Pincay JI, Garcia Reinoso L, Redfern JAI, Pascal SC, et al. Management of gunshot wound-related hip injuries: A systematic review of the current literature. J Orthop 2021 Jan 1;23:100–6.
[9] Laubscher M, Ferreira N, Birkholtz FF, Graham SM, Maqungo S, Held M. Civilian gunshot injuries in orthopaedics: a narrative review of ballistics, current concepts, and the South African experience. European Journal of Orthopaedic Surgery and Traumatology, 31. Springer-Verlag Italia s.r.l.; 2021. p. 923–30.
[10] Miller AN, Carroll EA, Pilson HTP. Transabdominal gunshot wounds of the hip and pelvis. J Am Acad Orthop Surg 2013;21(5):286–92.

[11] Christie DB, Bozeman AP, Stapleton TR, Ashley DW. Gunshot wound to the femoral neck: A unique case. J Trauma Inj, JTI. 2007;62(3):785.
[12] Shu HT, Ghanem D, Rogers DL, Covarrubias O, Izard P, Hacquebord J, et al. Failure after operative repair is higher for ballistic femoral neck fractures than for closed, blunt-injury fractures: a multicenter retrospective cohort study. Trauma Surgery and Acute Care Open. BMJ Publishing Group; 2024.
[13] Evanson BJ, Mullis BH, Anglen JO. Nonunion of a pertrochanteric femur fracture due to a low-velocity gunshot STAR: System for Telementoring with Augmented Reality View project Nonunion dynamization and exchanges View project [Internet]. 2011. Available from: https://www.researchgate.net/publication/51459028.
[14] Zhang Y, Wright B, D'Amore P, Hightower C, Stang T, Israel H, et al. Gunshot wounds to the hip: Doomed to failure? Southern Orthopaedic Association [Internet] 2020;29(3):135–40. Available from: https://www.researchgate.net/publication/347964329.
[15] Laubscher M, Ferreira N, Friedrich F, Simon B, Graham M, Maqungo S, et al. Civilian gunshot injuries in orthopaedics : a narrative review of ballistics, current concepts, and the South African experience. Eur J Orthop Surg Traumatol [Internet] 2021:0123456789. https://doi.org/10.1007/s00590-021-02934-0. Available from:.
[16] Della Rocca GJ. Gaps and opportunities in the management of the young femoral neck fracture. Injury [Internet] 2015;46(3):515–8. https://doi.org/10.1016/j.injury.2014.11.015. Available from:.
[17] Lubberts B, Mellema JJ, Janssen SJ. Ring D. Fracture line distribution of olecranon fractures. Arch. Orthop. Trauma 2017;137(1):37–42.
[18] Slobogean GP, Sprague SA, Scott T, McKee M, Bhandari M. Management of young femoral neck fractures: Is there a consensus? Injury [Internet] 2015;46(3):435–40. https://doi.org/10.1016/j.injury.2014.11.028. Available from:.
[19] Zlowodzki M, Ayieni O, Petrisor BA, Bhandari M. Femoral neck shortening after fracture fixation with multiple cancellous screws: Incidence and effect on function. Journal of Trauma - Injury, Infection and Critical Care. 2008;64(1):163–9.
[20] Gardner S, Weaver MJ, Jerabek S, Rodriguez E, Vrahas M, Harris M. Predictors of early failure in young patients with displaced femoral neck fractures. J Orthop [Internet] 2015;12(2):75–80. https://doi.org/10.1016/j.jor.2014.01.001. Available from:.
[21] Liporace F, Gaines R, Collinge C, Haidukewych GJ. Results of internal fixation of pauwels type-3 vertical femoral neck fractures. J. Bone Jt Surg 2008;90(8):1654–9. Aug 1.
[22] Chan DS. Femoral neck fractures in young patients: state of the art. J Orthop Trauma 2019;33:S7–11.
[23] George Haidukewych BJ, Rothwell WS, Jacofsky DJ, Torchia ME, Berry DJ. Operative Treatment of Femoral Neck Fractures in Patients Between the Ages of Fifteen and Fifty Years [Internet]. J. Bone Jt Surg 2004. Available from: http://journals.lww.com/jbjsjournal.
[24] Yimam HM, Dey R, Rachuene PA, Kauta NJ, Roche SJL, Sivarasu S. Identification of recurring scapular fracture patterns using 3-dimensional computerized fracture mapping. J Shoulder Elbow Surg [Internet] 2022;31(3):571–9. https://doi.org/10.1016/j.jse.2021.08.036. Available from:.
[25] Xie X, Zhan Y, Dong M, He Q, Lucas JF, Zhang Y, et al. Two and Three-Dimensional CT Mapping of Hoffa Fractures. J. Bone Jt. Surg. 2017;99(21):1866–74.
[26] Armitage BM, Wijdicks CA, Tarkin IS, Schroder LK, Marek DJ, Zlowodzki M, et al. Mapping of scapular fractures with three-dimensional computed tomography. Journal of Bone and Joint Surgery - Series A 2009;91(9):2222–8.
[27] Li M, Li ZR, Li JT, Lei MX, Su XY, Wang GQ, et al. Three-dimensional mapping of intertrochanteric fracture lines. 2019 [cited 2021 Nov 10]; Available from: www.cmj.org.
[28] Mellema JJ, Doornberg JN, Molenaars RJ, Ring D, Kloen P. Tibial Plateau Fracture Characteristics. J Orthop Trauma 2016;30(5):e144–51.
[29] Mangnus L, Meijer DT, Stufkens SA, Mellema JJ, Steller EP, Kerkhoffs GMMJ, et al. Posterior malleolar fracture patterns. J Orthop Trauma 2015;29(9):428–35.
[30] Yang Y, Zou C, Fang Y. Mapping of both column acetabular fractures with three-dimensional computed tomography and implications on surgical management. BMC Musculoskelet Disord 2019;20(1):1–7.
[31] Cole PA, Mehrle RK, Bhandari M, Zlowodzki M. The pilon map: fracture lines and comminution zones in OTA/AO Type 43C3 pilon fractures. J Orthop Trauma 2013;27(7):e152–6.
[32] Huang TW, Hsu WH, Peng KT, Lee CY. Effect of integrity of the posterior cortex in displaced femoral neck fractures on outcome after surgical fixation in young adults. Injury 2011 Feb;42(2):217–22.
[33] Bartkiw MJ, Sethi A, Coniglione F, Holland D, Hoard D, Colen R, et al. Civilian gunshot wounds of the hip and pelvis. J Orthop Trauma [Internet] 2010;24(10):645–52. Oct [cited 2021 Apr 8]Available from: https://journals.lww.com/00005131-201010000-00008.
[34] Garden RS. Low-Angle Fixation in Fractures of the Femoral Neck. J Bone Joint Surg Br 1961;43-B(4):647–63.
[35] AO OTA Classification.
[36] Bartoníček J. Special interest paper pauwels' classification of femoral neck fractures: correct interpretation of the original [Internet]. 2001. Available from: http://journals.lww.com/jorthotrauma.