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Revisiting Pauwels' classification of femoral neck fractures

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Abstract

Pauwels' femoral neck fracture classification is based on the biomechanical principle that shear stress and varus force increase along more vertically oriented fractures, resulting in higher risk of fracture displacement and ultimately nonunion. This principle continues to guide construct selection for femoral neck fracture internal fixation and is the foundation for treating non-union with valgus osteotomy. However, with poor inter- and intra-rater reliability, dated treatment recommendations, and unreliable prognostic value, the Pauwels classification cannot be directly applied in its entirety to the management of femoral neck fractures in modern practice.

Key Words: Pauwels; Fracture; Femoral neck; Internal fixation; Arthroplasty

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Core Tip: Pauwels' classification of femoral neck fractures continues to guide construct selection for femoral neck fracture internal fixation and is the foundation for treating non-union with valgus osteotomy. However, with poor inter- and intra-rater reliability, dated treatment recommendations, and unreliable prognostic value, the Pauwels classification cannot be directly applied in its entirety to the management of femoral neck fractures in modern practice.

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INTRODUCTION

Femoral neck fractures are common, with an overall incidence of 146 per 100000 adults in 2013[1]. The increasing incidence with age is demonstrated by the occurrence of more than 800000 femoral neck fractures in patients older than 65 in the United States alone from 2003 to 2013[1]. The vast majority of femoral neck fractures are treated operatively, so there is morbidity and mortality associated with both the injury and its treatment[2]. Femoral neck fractures are costly not only to patients, but also the healthcare system at an estimated 17 to 20 billion dollars per year[3,4].

The first femoral neck fracture classification was described by Cooper[5] in 1823, who categorized these fractures by location into extracapsular or intracapsular variants. Later, in 1935, Pauwels[6] published his femoral neck fracture classification based on biomechanical principles. Fractures were categorized by orientation of the fracture line, across which compressive and shearing forces vary. Errors in interpretation of Pauwels' original manuscript, written in German, have caused confusion surrounding the fracture types in his classification system[7]. Meticulous analysis by several groups, as well as an English-language supplement published by Pauwels in 1976, provided subsequent clarification[7-9].

Pauwels devised his femoral neck fracture classification to: (1) Predict propensity for healing based on forces acting to displace the fracture; and (2) Identify the optimal treatment modality that neutralizes these forces. To achieve the above aims, Pauwels classified femoral neck fracture patterns as observed on anteroposterior (AP) plain films. The Pauwels classification predates modern hip fracture fixation devices and arthroplasty, which are understandably absent from the treatments recommended in the original manuscript. Both of these factors are barriers to the Pauwels classification fulfilling its purpose in current practice, as further discussed below.

CLASSIFICATION

Pauwels classified femoral neck fractures according to the degree of inclination of the fracture line measured from the horizontal on an AP radiograph (Table 1)[6-8]. The three types of femoral neck fractures according to Pauwels are: Type I, with fracture line inclination from 0° to 30°; Type II, with inclination of 30° to 50°; and Type III, with inclination of 50° and greater. Compressive forces predominate across horizontally oriented fractures with a low degree of inclination. Shear stresses and varus forces increase along more vertically oriented fractures with a high degree of inclination. As the distance between the fracture line and the center of the femoral head increases, so do these forces across the fracture.

The treatment and prognosis of femoral neck fractures according to Pauwels is determined by the biomechanical favorability at the fracture site for healing[6-8]. With low fracture line inclination there is compression at the fracture site, which promotes union. For this reason, Pauwels believed fractures with inclination angles less than 30° could be treated nonoperatively. Increasing fracture line inclination, accompanied by greater shear stress and varus force, results in higher risk of fracture displacement and ultimately nonunion. As a result, Pauwels recommended internal fixation for fractures with inclination angles of 30° to 50° and valgus osteotomy for fractures with inclination angles greater than 50°. These measures counteract and reverse, respectively, forces across steeply oriented fractures.

VALIDITY

Existing literature questions the validity of Pauwels' classification with regard to the description, treatment, and prognosis of femoral neck fractures. Several studies have found inter- and intra-observer reliability of the Pauwels classification to be worse than that of both AO and Garden classifications[10-12].

Nearly all femoral neck fractures, except for stress fractures involving the compression side, are currently treated operatively to allow early mobilization, improve healing, and prevent displacement[2]. Internal fixation or arthroplasty are the mainstays of treatment depending on patient age and physical demands[2,13]. However, Pauwels advised nonoperative management of Type I fractures in his classification scheme. Type III fractures are rarely treated with an acute valgus osteotomy as recommended by Pauwels. This procedure is now reserved for femoral neck fracture nonunion[14].

Table 1 Pauwels' classification of femoral neck fractures

	Inclination of fracture line from horizontal	Predominant force at fracture site	Treatment (original classification)	Treatment (modern)	Risk of nonunion
Type I	0-30	Compressive force	Nonoperative	Internal fixation vs arthroplasty	Low
Type II	30-50	Shearing stress	Internal fixation	Internal fixation vs arthroplasty	Medium
Type III	> 50	Significant shearing stress and varus force	Valgus osteotomy	Internal fixation vs arthroplasty	High

Pauwels believed that risk of displacement, and thus non-union, increased with femoral neck fracture line inclination. However, Parker and Dynan[15] found no relationship between Pauwels fracture type and rate of non-union. Calandruccio and Anderson[16] did not observe a higher rate of avascular necrosis with increasing Pauwels inclination angle. These findings are contrary to Pauwels' notion of more unfavorable biomechanics and healing potential at fracture sites with steeper inclination angles.

The failure to observe differences in union rate and avascular necrosis across Pauwels fracture types may be due to surgeon customization of fixation construct according to femoral neck fracture line inclination. In achieving desired union rates by appropriately counteracting fracture site shear stresses and varus forces, Pauwels' principles are validated. Multiple studies have highlighted the need for more robust fixation constructs to address the unfavorable biomechanics of Pauwels Type III fractures[13,17-20].

DISCUSSION

There are several factors that limit the applicability of the Pauwels classification. First, it may be difficult to accurately determine femoral neck fracture line inclination on immediate post-injury radiographs in which the lower extremity is often rotated, abducted, or adducted. In addition, the use of lateral radiographs for further fracture pattern evaluation is not described in Pauwels' classification. It has been suggested that inclination angle be measured on intraoperative post-reduction fluoroscopic imaging, but this diminishes the opportunity to utilize Pauwels' classification for preoperative planning[11]. Nonetheless, there are ways to consistently apply Pauwels' principles to fracture management. Femoral neck fracture line inclination can be determined using preoperative computed tomography images, ubiquitous in the workup of high energy trauma patients though not a part of Pauwels' original classification scheme.

Per Pauwels, a reference horizontal must be reliably established to measure fracture inclination but can only be arbitrarily assigned on potentially suboptimal radiographs. For this reason, Wang *et al*[21] proposed using the line perpendicular to the anatomic axis of the femur as an objective reference horizontal when measuring Pauwels' inclination angle.

Advances in fracture fixation and arthroplasty following publication of Pauwels' classification have rendered its treatment recommendations less applicable in certain circumstances. Pauwels suggested Type I fractures be treated nonoperatively, but it has since been established that nonoperative treatment of femoral neck fractures is associated with an unacceptably high mortality rate[22]. Valgus osteotomy is currently reserved for some femoral neck fracture non-unions, not Pauwels Type III fractures as originally described[13,14]. Pauwels' classification predates the advent of modern arthroplasty, so his treatment rubric does not address this modality. In older patients with displaced femoral neck fractures, fracture line inclination is less relevant as all such fractures are treated with arthroplasty[2,23]. However, the presence of a Pauwels Type III fracture in an older patient may have implications on femoral stem selection, specifically the need for a calcar replacing, fully porous coated, or distally fixed stem, if there is involvement of the lesser trochanter.

CONCLUSION

The Pauwels classification of femoral neck fractures is novel in its biomechanical basis. As a result, Pauwels contributed significantly to the evolution of our understanding and treatment of femoral neck fractures. The principles he described continue to guide construct selection for femoral neck fracture internal fixation and are the foundation for treating femoral neck fracture non-union with valgus osteotomy. However, with poor inter- and intra-rater reliability, dated treatment recommendations, and unreliable prognostic value, the Pauwels classification cannot be directly applied in its entirety to the management of femoral neck fractures in modern practice.

REFERENCES

- 1 **Ju DG**, Rajae SS, Mirocha J, Lin CA, Moon CN. Nationwide Analysis of Femoral Neck Fractures in Elderly Patients: A Receding Tide. *J Bone Joint Surg Am* 2017; **99**: 1932-1940 [PMID: 29135667 DOI: 10.2106/JBJS.16.01247]
- 2 **Florschütz AV**, Langford JR, Haidukewych GJ, Koval KJ. Femoral neck fractures: current management. *J Orthop Trauma* 2015; **29**: 121-129 [PMID: 25635363 DOI: 10.1097/BOT.0000000000000291]
- 3 **Brauer CA**, Coca-Perrillon M, Cutler DM, Rosen AB. Incidence and mortality of hip fractures in the United States. *JAMA* 2009; **302**: 1573-1579 [PMID: 19826027 DOI: 10.1001/jama.2009.1462]
- 4 **Becker DJ**, Kilgore ML, Morrisey MA. The societal burden of osteoporosis. *Curr Rheumatol Rep* 2010; **12**: 186-191 [PMID: 20425518 DOI: 10.1007/s11926-010-0097-y]
- 5 **Cooper A**. A treatise on dislocations and on fractures of the joints: fractures of the neck of the thigh-bone. *Clin Orthop Relat Res* 1973; (**92**): 3-5 [PMID: 4575877]
- 6 **Pauwels F**. Der schenkelhalsbruch, ein mechanisches problem. *Z Orthop Ihre Grenzgeb* 1935; **63**: 1 [DOI: 10.1002/bjs.1800239227]
- 7 **Bartonicek J**. Pauwels' classification of femoral neck fractures: correct interpretation of the original. *J Orthop Trauma* 2001; **15**: 358-360 [PMID: 11433141 DOI: 10.1097/00005131-200106000-00009]
- 8 **Pauwels F**. Biomechanics of the normal and diseased hip. Berlin: Springer, 1976 [DOI: 10.1007/978-3-642-66212-6]
- 9 **PUGH WL**. A self-adjusting nail-plate for fractures about the hip joint. *J Bone Joint Surg Am* 1955; **37-A**: 1085-1093 [PMID: 13263352]
- 10 **Gašpar D**, Crnković T, Durović D, Podsednik D, Slišurić F. AO group, AO subgroup, Garden and Pauwels classification systems of femoral neck fractures: are they reliable and reproducible? *Med Glas (Zenica)* 2012; **9**: 243-247 [PMID: 22926358]
- 11 **Turgut A**, Kumbaracı M, Kalenderer Ö, İlyas G, Bacaksız T, Karapınar L. Is surgeons' experience important on intra- and inter-observer reliability of classifications used for adult femoral neck fracture? *Acta Orthop Traumatol Turc* 2016; **50**: 601-605 [PMID: 27889406 DOI: 10.1016/j.aott.2015.11.004]
- 12 **van Embden D**, Roukema GR, Rhemrev SJ, Genelin F, Meylaerts SA. The Pauwels classification for intracapsular hip fractures: is it reliable? *Injury* 2011; **42**: 1238-1240 [PMID: 21146815 DOI: 10.1016/j.injury.2010.11.053]
- 13 **Liporace F**, Gaines R, Collinge C, Haidukewych GJ. Results of internal fixation of Pauwels type-3 vertical femoral neck fractures. *J Bone Joint Surg Am* 2008; **90**: 1654-1659 [PMID: 18676894 DOI: 10.2106/JBJS.G.01353]
- 14 **Prakash J**, Keshari V, Chopra RK. Experience of valgus osteotomy for neglected and failed osteosynthesis in fractures neck of femur. *Int Orthop* 2020; **44**: 705-713 [PMID: 31650211 DOI: 10.1007/s00264-019-04422-x]
- 15 **Parker MJ**, Dynan Y. Is Pauwels classification still valid? *Injury* 1998; **29**: 521-523 [PMID: 10193494 DOI: 10.1016/s0020-1383(98)00118-1]
- 16 **Calandruccio RA**, Anderson WE, 3rd. Post-fracture avascular necrosis of the femoral head: correlation of experimental and clinical studies. *Clin Orthop Relat Res* 1980; (**152**): 49-84 [PMID: 7438624]
- 17 **Stoffel K**, Zderic I, Gras F, Sommer C, Eberli U, Mueller D, Oswald M, Gueorguiev B. Biomechanical Evaluation of the Femoral Neck System in Unstable Pauwels III Femoral Neck Fractures: A Comparison with the Dynamic Hip Screw and Cannulated Screws. *J Orthop Trauma* 2017; **31**: 131-137 [PMID: 27755333 DOI: 10.1097/BOT.0000000000000739]
- 18 **Noda M**, Saegusa Y, Takahashi M, Tezuka D, Adachi K, Naoi K. Biomechanical Study Using the Finite Element Method of Internal Fixation in Pauwels Type III Vertical Femoral Neck Fractures. *Arch Trauma Res* 2015; **4**: e23167 [PMID: 26566507 DOI: 10.5812/atr.23167]
- 19 **Biz C**, Tagliapietra J, Zonta F, Belluzzi E, Bragazzi NL, Ruggieri P. Predictors of early failure of the cannulated screw system in patients, 65 years and older, with non-displaced femoral neck fractures. *Aging Clin Exp Res* 2020; **32**: 505-513 [PMID: 31677126 DOI: 10.1007/s40520-019-01394-1]
- 20 **Giordano V**, Alves DD, Paes RP, Amaral AB, Giordano M, Belangero W, Freitas A, Koch HA, do Amaral NP. The role of the medial plate for Pauwels type III femoral neck fracture: a comparative mechanical study using two fixations with cannulated screws. *J Exp Orthop* 2019; **6**: 18 [PMID: 31677126 DOI: 10.1007/s40520-019-01394-1]

- 31049738 DOI: 10.1186/s40634-019-0187-3]
- 21 **Wang SH**, Yang JJ, Shen HC, Lin LC, Lee MS, Pan RY. Using a modified Pauwels method to predict the outcome of femoral neck fracture in relatively young patients. *Injury* 2015; **46**: 1969-1974 [PMID: 26113033 DOI: 10.1016/j.injury.2015.06.016]
 - 22 **Chlebeck JD**, Birch CE, Blankstein M, Kristiansen T, Bartlett CS, Schottel PC. Nonoperative Geriatric Hip Fracture Treatment Is Associated With Increased Mortality: A Matched Cohort Study. *J Orthop Trauma* 2019; **33**: 346-350 [PMID: 30844953 DOI: 10.1097/BOT.0000000000001460]
 - 23 **Shen M**, Wang C, Chen H, Rui YF, Zhao S. An update on the Pauwels classification. *J Orthop Surg Res* 2016; **11**: 161 [PMID: 27955672 DOI: 10.1186/s13018-016-0498-3]



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