# Very Little is Known of What Causes Femoral Neck Stress Fractures at the Tissue Level

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**Disclosures:** The authors have nothing to disclose.

**INTRODUCTION**: The femoral neck (FN) is a complex anatomical structure. Details of the stress distribution across the FN during typical walking and running has long been debated. In the late 19th century Julius Wolff published his 'trajectorial theory' of trabecular bone adaptation that popularized and spread the view that the superior cortex of the FN is subject primarily to tension, while the inferior FN cortex is subject primarily to compression **[1, 2]**. Since then, several authors have highly criticized and rebutted Wolff's trajectorial theory (see reviews in: **[2, 3]**), though his tension/compression paradigm of stresses in the FN has persisted as the dominant belief in the fields of orthopaedics and bone adaptation. In a previous work we analyzed the prevalence of the tension/compression paradigm in the literature from the late 19th century to modern day **[4]**. A clinical problem where the forces acting upon the FN are of particular interest is FN stress fractures (FNSFs). FNSF is a serious condition because some can progress to complete fracture **[5, 6]**. Although usually seen in military recruits, this type of injury is becoming increasingly more common in the civilian population as the popularity of endurance sports has increased **[7]**. An accurate understanding of the *in vivo* forces acting upon the FN can inform pharmaceutical and surgical interventions for hip fragility/stress fractures. Recent animal studies have shown that administration of parathyroid hormone correlates with increased bone deposition in areas subject naturally to compression are loaded in compression (when compared to tension loading) **[8]**. We sought to review the literature on FNSFs in order to gain a better understanding of what investigators/researchers from various disciplines believe are the specific stress/strain modes (tension, compression, shear) and their regional distributions acting on the FN during typical loading that lead to FNSF development.

**METHODS:** A systematic literature search was performed using Google Scholar and PubMed. The primary terms searched were: stress fracture, femoral neck, fatigue fracture, and insufficiency fracture. We identified additional papers by doing subsequent searches of citing papers in Google Scholar for certain key papers identified; namely, Egol et al. (1998), Bernstein et al. (2022), Rohena-Quinquilla et al. (2018), and Steele et al. (2018) **[7, 9-11]**. Within each paper the following keywords were searched: femoral neck, tension/tensile, compression/compressive, shear, bending, superior, inferior, upper, and lower. Papers were excluded that did not directly address FNSFs, or that did not make any statement in relation to loading conditions that might cause FNSFs. Papers meeting the criteria for inclusion were further classified according to the type of statement the authors made about the forces they felt were acting upon the FN. It was noted early in the search that the majority of authors classify FNSFs related to a 'system' originally established by Fullerton and Snowdy **[12]**. This system is based upon Wolff's tension/compression paradigm in which fractures of the superior FN are referred to as "tension-sided," and fractures of the inferior FN are referred to as "compression-sided." Publications that only used this nomenclature without any further discussion of loading conditions occurring at the FN were differentiated from publications that discussed the loading conditions beyond the classical nomenclature.

**RESULTS:** 191 papers were reviewed, of which 112 were included in the study. Of the included papers 83 used the classical nomenclature system of Fullerton and Snowdy without any further discussion of the forces acting upon the femoral neck, 27 discussed the loading conditions believed to lead to FNSF, and two discussed forces but did not specify what force/stress characteristics were acting on the superior femoral neck. (References can be found at: https://teambone.com/themes/)

**DISCUSSION:** The vast majority of authors still seem to, whether advertently or inadvertently, follow Wolff's tension/compression paradigm by using the classical nomenclature set forth by Fullerton and Snowdy to classify FNSFs. Of the papers that explicitly mention the possible loading conditions that induce a FNSF, there are generally two camps. The first camp is in line with Wolff's paradigm that typical walking/standing induces a bending moment at the FN that produces net tensile strains on the superior neck that lead to stress fracture development, and net compressive strains leading to stress fracture on the inferior FN **(Fig. 1)**. The second camp is consistent with the mechanistic interpretation put forth by Egol et al. **(Fig. 2)**, wherein normal loading the hip abductor muscles neutralize the tensile forces across the superior FN. When these muscles become fatigued the neutralizing effect is minimized and net tensile strains are then experienced by the superior FN, which can eventually lead to stress fracture. A similar mechanism has been discussed in the field of anthropology (**Fig. 3**). Only Edwards et al. **[13]** made mention of shear force in the development of FNSF. In their review article, Bernstein et al. **[7]** call into question the existence of an isolated-tension-sided fracture. They point out that in the large series of patients with FNSFs diagnosed via MRI reported by both Rohena-Quinquilla et al. **[10]** and Steele et al. **[11]** that no isolated tension-sided FNSFs were observed. Bernstein et al. **[7]** postulate that due to the lack of MRI based evidence for tension-sided FNSFs it is likely the tension-sided fractures reported in radiograph-based studies were actually minimally displaced complete fractures. Whether or not there are truly isolated "tension-sided" FNSFs, the vast majority of FNSFs do occur along the inferior portion of the FN. We hypothesize that perhaps, similar to the description of Egol et al., the action of the hip abductor muscles could move the neutral axis of the FN such that it is in the vicinity of the superior cortex of the FN, and this could explain why the vast majority of FNSFs are seen along the inferior cortex of the neck. In other words, the strain is magnified because the inferior cortex is even farther from the neutral axis than what would be seen in the T/C paradigm (neutral axis in the middle of the neck) (**Fig. 1)**. An upward shifting neutral axis in the setting of some torsion (typical of hip loading) would also increase shear stresses.

**SIGNIFICANT/CLINICAL RELEVANCE:** The literature is strongly biased by the Wolffian view of femoral neck loading that is likely inaccurate. Accurate knowledge of the loading conditions occurring at the femoral neck is needed to devise effective interventions for promoting osteogenesis in the femoral neck, especially in the context of typical and activity-related changes in the regional distribution of stresses/strains (mode and magnitude) and the development of FNSFs.

**REFERENCES:** **[1]** Wolff J. Berlin: Springer-Verlag; 1892; **[2]** Skedros JG, et al. (2023) *J of Theor Bio* 567: 111495; **[3]** Skedros JG, Baucom SL (2007) *J Theor Bio* 244: 15-45; **[4]** Walker JK, et al. (2023) ORS meeting abs no. 503; **[5]** Sundkvist J, et al. (2022) *Acta Orthop*: 413; **[6]** Scott SJ, et al. (2012) *Military Med* 177: 1081-1089; **[7]** Bernstein EM, et al. (2022) *J Am Acad Ortho Surg* 30: 302-311; **[8]** Rooney AM, et al. (2023) *J Bone Min Res* 38: 59-69; **[9]** Egol KA, et al. (1998) *Clin Ortho Related Res* 348: 72-78; **[10]** Rohena-Quinquilla IR, et al. (2018) *Am J of Roentg* 210: 601-607; **[11]** Steele CE, et al. (2018) *JBJS* 100: 1496-1502; **[12]** Fullerton LR and Snowdy HA (1998) *Am J Sports Med* 16: 365-377; **[13]** Edwards WB, et al. (2008) *Clin Biomech* 23: 1269-1278

**Figure 1 (from Wolff, see Skedros and Baucom 2007)**

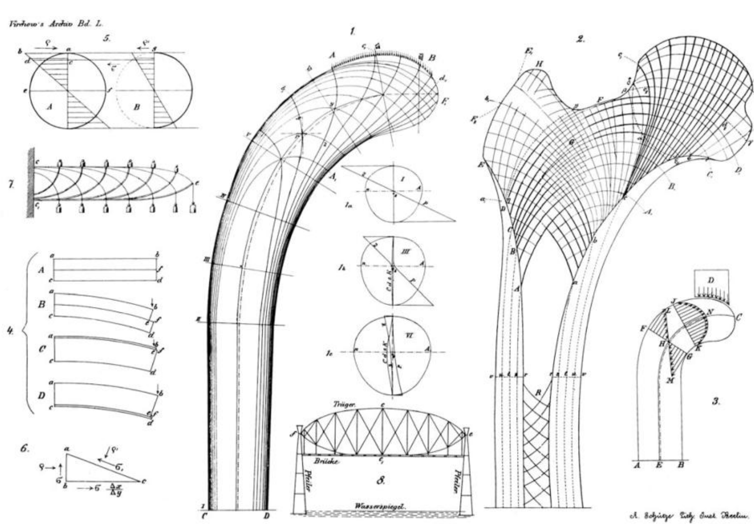


**Figure 2 (from Egol et al. 1998)**

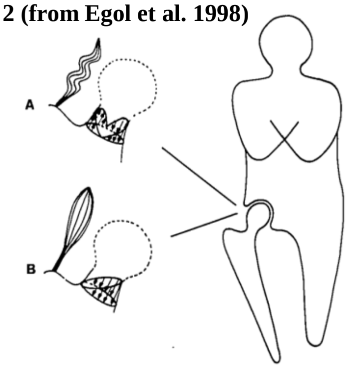
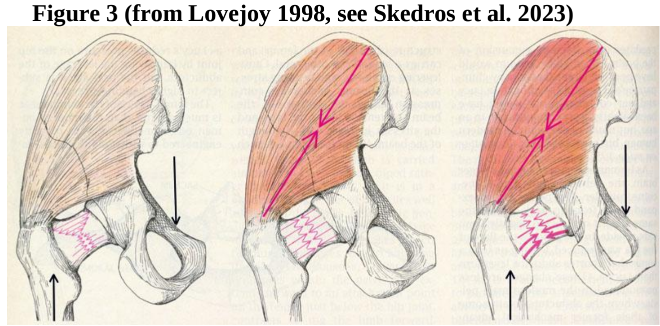



**Figure 3 (from Lovejoy 1998, see Skedros et al. 2023)**



**References:** The complete list of references identified in our literature search can be found at: https://teambone.com/themes/