

WEIGHT LIMITS ASSOCIATED WITH COMMONLY USED FEMORAL STEMS FOR TOTAL HIP ARTHROPLASTY

<https://doi.org/10.71165/epzi-om3t>

AUTHORS

Jamie Griffiths - Hampshire Hospitals NHS, Hampshire, England
Michael C. Quaye - University Hospital Southampton, Southampton, United Kingdom
Sherif Abouel-Enin - University Hospital Southampton, Southampton, United Kingdom
Piers Yates - Freemantle Hospital, Perth, Australia
Richard Carey-Smith - Sir Charles Gairdner Hospital, Perth, Australia
Jeremy Latham - University Hospital Southampton, Southampton, United Kingdom

SUMMARY

Background: The global prevalence of obesity is increasing, with a corresponding rise in the proportion of overweight and obese patients undergoing total hip arthroplasty (THA). Although modern high-strength super alloys have reduced the incidence of femoral stem fatigue fractures to between 0.23% and 10.7%, this complication persists. Excessive body mass increases the bending moment acting on the prosthesis, particularly in cases with inadequate proximal medial calcar support, leading to cantilever bending and potential structural failure.

Objective: This study aimed to identify manufacturer-imposed weight restrictions for the most frequently utilized cemented and uncemented femoral stem implants in the United Kingdom, as identified by National Joint Registry (NJR) data.

Key Points: Data from the NJR 10th Annual Report identified the five most common cemented and uncemented stems. Manufacturer inquiries revealed that only the Corail size 6 uncemented stem has a formal weight limit (60 kg). Literature review indicates that fatigue fractures are frequently associated with high body mass index (BMI >25 kg/m²), the use of undersized stems in obese patients, and modular neck-stem junctions. High nitrogen stainless steel (HNSS) stems appear more susceptible to fatigue than cobalt-chrome alloys. Mechanical failure is often propagated by a combination of patient weight, increased offset, and loss of proximal osseous support.

Conclusion: Most common femoral stems lack formal manufacturer weight restrictions despite a clear clinical association between obesity and fatigue failure. Surgeons should prioritize achieving optimal proximal femoral support and consider avoiding small-diameter or high-offset modular stems in overweight populations to mitigate fracture risk.

KEYWORDS

Arthroplasty, Replacement, Hip; Prosthesis Failure; Body Mass Index; Hip Prosthesis; Alloys

INTRODUCTION

The World Health Organisation (WHO) suggests obesity to affect 200 million men and 300 million women worldwide ⁽¹⁾. Obesity is defined per body mass index (BMI), with a patient being classified as overweight with a BMI of $\geq 25 \text{Kg/m}^2$, obese with a BMI $\geq 30 \text{Kg/m}^2$ and morbidly obese with a BMI $\geq 40 \text{Kg/m}^2$ ⁽²⁾. Currently, in the UK, 26.1% of the adult population are thought to be obese ⁽³⁾. This figure is expected to rise to 60% of adult men and 50% of adult women by 2050 ⁽⁴⁾. The NJR has reported an increase in the number of THR's being performed in patients with a BMI between 25 Kg/m^2 -44 Kg/m^2 from 69% in 2004 to 79% in 2012 ⁽⁵⁾. The rising incidence of obesity has led to an increase in the number of overweight/obese patients undergoing an elective THR surgery.

Failure of a THR due to fatigue fracture of the femoral stem is a rare complication. Its incidence varies between 0.23% and 10.7% ⁽⁶⁾. It was more commonly seen with the traditional forged stainless steel or cast cobalt chrome implants due to their relatively low fatigue strength and defects in their crystalline lattice microstructure ^{(7) (8) (9) (10) (11) (12) (13)}. The introduction of the high strength 'super alloys' including forged cobalt chrome, high nitrogen stainless steel (HNSS) and titanium-6-aluminium-4-vanadium alloy has resulted in a significant decrease in the incidence of stem fractures. However, although uncommon, fatigue fractures of these modern alloy stems have still been reported ^{(14) (15) (16) (17) (18) (19) (20) (21) (22) (23) (24) (25) (26) (27)}. One factor thought to be important in such fatigue failure is excessive patient weight leading to an increased bending moment acting on the stem.

Medico-legal cases against doctors are also increasing ⁽²⁸⁾. Therefore in a health system where the average weight of the population is increasing and doctors are being held more frequently accountable for treatment failure, clarity is required regarding any restrictions placed on the use of implants, based on patient weight. The aim of this study was to identify any restrictions placed on the commonly used femoral stem implants, by the manufacturers, based on patient weight.

MATERIALS AND METHODS

The NJR ⁽⁵⁾ was used to identify the five most commonly used cemented and uncemented femoral stem implants in the UK. The manufacturing companies responsible for these stems were contacted and asked to provide details of any weight restrictions on these implants.

RESULTS

The only femoral stem to have a restriction placed on it, based on patient weight, is the Corail size 6 femoral stem, which has a weight restriction of 60Kg (Tables I (A+B) and II (A+B)).

Femoral stem brand	Maunufacturing compagny
EXETER V40 STEM	Stryker*
CPT STEM	Zimmer*
C STEM AMT	DePuy*
C STEM	DePuy*
CHARNLEY STEM	DePuy*

*Stryker Corporation, Michigan USA*Zimmer, Warsaw, Indiana USA*DePuy Orthopaedics, Warsaw, Indiana USA
 Table IA: The five most commonly used cemented femoral stems as published in the NJR 10th annual report.

Femoral stem brand	Prosthetic material	Weight restrictions
EXETER V40	Stainless Steel	None
CPT	Cobalt Chrome	None
C STEM AMT	Stainless Steel	None
C STEM	Stainless Steel	None
CHARNLEY STEM	Stainless Steel	None

Table IB: Materials and weight restrictions related to the five most commonly used cemented stems.

Femoral stem brand	Maunufacturing compagny
CORAIL	DePuy ¹
FURLONG	JRI ²
ACCOLADE	Stryker ³
TAPERLOC CEMENTLESS	Biomet ⁴
M/L TAPER	Zimmer ⁵

¹DePuy Orthopaedics, Warsaw, Indiana USA - ²JRI Orthopaedics, Yorkshire UK - ³Stryker Corporation, Michigan USA -
⁴Biomet Inc., Warsaw, Indiana USA - ⁵Zimmer, Warsaw, Indiana USA
 Table IIA: The five most commonly used uncemented femoral stems as published in the NJR 10th annual report.

Femoral stem brand	Prosthetic material	Weight restrictions
CORAIL	Titanium	60 Kg on the size 6 CDH stem
FURLONG	Titanium	None
ACCOLADE	Titanium	None
TAPERLOC CEMENTLESS	Titanium	None
M/L TAPER	Titanium	None

Table IIB. Materials and weight restrictions related to the five most commonly used uncemented stems.

DISCUSSION

Fatigue fracture of the femoral stem is thought to occur as a result of patient and mechanical factors. Patient factors include excessive patient weight and activity levels^{(7) (10) (14) (15)}. Mechanical factors include undersizing and varus malpositioning of the implant^{(9) (15)}, surface damage or defects in the crystalline lattice microstructure of the implant^{(12) (14) (16)} and loosening and loss of the proximal medial calcar support^{(11) (14) (29)} resulting in cantilever bending of the implant. The implant geometry and prosthetic materials also play a significant role^{(6) (7)}.

The most commonly used cemented implant in the NJR is the Exeter V40 stem. The excellent clinical results from this polished tapered stainless steel implant are well recognised, with a 97.8% survivorship at 10 years⁽³⁰⁾ and 93.5% survivorship at 34 years considering aseptic loosening as the end point⁽³¹⁾. The original Exeter stem (1970-1976) was made from 58J stainless steel and had a fracture rate reported at 3%⁽³²⁾. In 1976, the matt finished stem was introduced. Here the fracture rate was reported to be between 2-11%^{(13) (33)}. In an attempt to strengthen the stem, the prosthetic material was changed to wrought HNSS (Orthinox, Stryker BG, Caen, France) in 1983. In order to reduce the endosteal lysis associated with particulate debris from the matt finish stem, the taper polish design was re-introduced in 1986.

Jacco Van Doorn et al⁽¹⁷⁾ first reported a fracture involving the HNSS Exeter V40 stem in a 52 year old 70 Kg female, who had undergone an impaction grafting revision 3.4 years prior to the stem fracture. They suggested loss of proximal support with good distal fixation led to a large moment arm acting on the prosthesis therefore resulting in fatigue failure. Yates et al⁽¹⁴⁾ reported on 14 cases of fracture of HNSS stems (5 Exeter V40, 8 CPT AND 1 C Stem), all of which involved patients with a BMI >25Kg/m² (25Kg/m²-49Kg/m²). They suggested heavier patients with small femoral canals and poor proximal support were the main risk factors for stem fracture. Davies et al⁽¹⁸⁾ reported on 4 fractures involving the Exeter V40 stem. Again all patients were overweight with a BMI >25 Kg/m². Similarly, small stems in obese patients and loss of the proximal support were thought to be key factors in the failure mechanism. There are further reports of stem fractures in obese patients involving the HNSS Exeter V40 stem⁽¹⁹⁾ and interestingly the Exeter cement in cement revision stem⁽²⁰⁾. The cement in cement revision stem is a short stem with a 44mm offset and in the case in question was noted to have good

proximal support. Fatigue failure secondary to an increased bending moment as a result of the patient's excess weight was again suggested to be the cause of failure.

Fractures involving the HNSS CPT, Charnley and C stems are also documented ^{(14) (21) (22) (23) (24) (25)}. In all cases excessive weight leading to increased cantilever bending were identified as a principle causative factor for the stem failure. The use of smaller stems in obese patients is an area of particular concern. Wright et al ⁽²¹⁾ reported on two cases of fracture of the HNSS congenital dysplasia of the hip (CDH) C-stem in patients both with a BMI >25Kg/m². Increased loads were identified as a principle factor in the failure mechanism. It was thus recommended that the use of the CDH stem should be avoided where possible, but if it was to be used, particular attention to the patient's weight should be made. Furthermore, Raj et al ⁽²⁵⁾ reported a case of stem fracture involving a size 0 HNSS CPT stem in a female patient with a BMI of 33.9Kg/m². Again excessive weight was thought to be a major factor contributing to the stem failure and it was recommended a size 0 CPT stem should be avoided in overweight patients.

It is interesting that there are currently no restrictions on the use of any of the above HNSS stems, including the smaller CDH stems, based on patient weight, as clearly there is a risk of stem fracture in the heavier patients particularly when the smaller stems are used. Indeed, the packaging to the smaller Exeter V40 stems (30 and 33 mm offset stems) states a maximum offset of +4mm. Thus, although there are no formal weight restriction on this prosthesis, the offset options are limited to only the +4mm offset. Therefore, it is clear that even with small increases in offset, there is a significant increase in the risk of stem fracture as a result of an increased bending moment. In an attempt to reduce the stem fracture risk, Zimmer (Warsaw Indiana) moved away from the use of HNSS to the stronger cobalt chrome molybdenum alloy as the prosthetic material of choice for the CPT stem in 2003. Finer grain size and high degree of chemical homogeneity are thought to be the main factors responsible for the increased fatigue strength observed with forged cobalt-chromium alloy compared with HNSS alloy ⁽³⁴⁾. In their product information sheet for the stainless steel CPT stem they recommended that "young, heavy patients and those who engage in high physical activity levels are not suitable candidates for the smaller sized femoral prosthesis." ⁽³⁵⁾ They also state that patients with a weight >102Kg or those with higher activity levels are more likely to incur complications in any of their total hip prosthesis.

Of the five most common cemented stems documented in the NJR, the CPT is currently the only stem to be manufactured from cobalt chrome alloy. Although the increased fatigue strength provides a reduced fracture rate, fatigue fracture this CPT stem has been documented, albeit in the revision, impaction bone graft setting ⁽²⁶⁾. Again, excessive weight in combination with loss of proximal support leading to increased cantilever bending was one of the proposed mechanisms of failure.

The use of an uncemented femoral component enables the femoral canal to be filled with a larger diameter component, thereby theoretically reducing the fracture risk. However, fatigue fractures particularly involving smaller stems in heavier patients have again been reported. The JRI-Furlong hydroxyapatite ceramic (HAC) – coated femoral stem is manufactured from wrought titanium alloy and as illustrated in the 10th annual report of the NJR, is one of the five most common uncemented implants used in the UK in 2012 (5). Reports of fracture of this uncemented femoral stem have been documented ^{(36) (37) (38)}. Again, all fractures involved patients with a BMI >25Kg/m² and all fractures occurred in the smaller size 9 or 10 stems. Retrieval studies demonstrated no attributable abnormality, therefore suggesting fatigue failure and cantilever bending to be the likely cause of fracture ^{(36) (38)}. This led to suggestions that the smaller stems, particularly size 9, should not be used in obese patients ⁽³⁸⁾.

The femoral neck is subjected to high loads and stresses and an appropriately sized femoral neck is paramount to the prevention of fatigue failure in this region. Vatani et al reported on 9 fractures through the neck of the

prosthesis in 35 THR's⁽³⁹⁾. They concluded all fractures were due to an inadequate confluent radius causing abnormal transmission forces through the neck. In addition they demonstrated the greater the load, the greater the fracture risk, thus suggesting the fracture risk to be greatest in men and heavy patients⁽³⁹⁾. In 2001, JRI announced a change to the manufacturing process of the stem, increasing the radius between the neck and shoulder of all femoral components. To our knowledge only one fracture involving the JRI HAC-coated Furlong stem has been reported since this change⁽³⁸⁾.

In addition to the size of the femoral neck, modularity in the region of the neck (either the neck-stem or head-neck region) represents another area of concern. Modularity allows for more accurate reconstruction of hip kinematics in terms of version, offset and leg length independent of the position of the distal stem. However, retrieval studies have demonstrated crevice corrosion and fretting to occur at the taper junction between the head-neck and/or neck-stem modular junction⁽⁴⁰⁾ which can lead to early failure and fracture of the neck. This degradative process was greater at the neck-stem compared to head-neck junction and was suggested to be secondary to the increased lever arm and thus increased mechanical stress in this region⁽⁴⁰⁾. At the proximal head-neck junction the taper lies at the centre of rotation of the hip. Here high compressive and shear forces are experienced. However, at the distal neck-stem junction the long moment arm produces a bending moment which exerts a tension force on the lateral edge of the taper and a compressive force on the medial edge. These forces are increased further in a patient with an extended offset, those with a retroverted neck⁽⁴¹⁾ or those with increased weight. Indeed, studies reporting fractures of modular femoral necks demonstrated the fracture to occur at the distal neck-stem junction⁽⁴²⁾⁽⁴³⁾. Both patients had a high BMI (25.6 Kg/m² and 39.3 Kg/m² respectively) and in both cases excessive weight in combination with a long lever arm were thought to be the main causative factors⁽⁴²⁾⁽⁴³⁾.

Mechanical failure at the modular junction is also a concern in the revision setting. Revision of a THR with a long uncemented femoral prosthesis provides the surgeon with an option to bypass proximal deficiencies and achieve fixation distally. The fixation options for these stems include distal, proximal or extensive stem fixation. If proximal fixation is not achieved, increased cantilever forces will be placed on the stem increasing the risk of fracture. The ZMR revision hip stem (Zimmer, Warsaw Indiana) is manufactured from titanium alloy, offers all three fixation options and in 2003 its proximal taper body was withdrawn due to a higher than expected failure rate⁽⁴⁴⁾. In 2011, Lakstein et al⁽⁴⁵⁾ reported six cases of mechanical failure of the ZMR stem. All patients had a significantly higher BMI (25Kg/m²-34Kg/m²) than those who had not experienced mechanical failure of their femoral component. Furthermore in all six cases a lack of proximal osseous support at the level of the junction was demonstrated. They concluded stem failure was initiated by fretting at the body-stem taper junction and propagated by a bending fatigue mechanism as a result of the excess weight and lack of proximal support⁽⁴⁵⁾.

There are currently no restrictions on any of the above uncemented stems with regard to patient weight, except for that of the Corail size 6 CDH stem, which has a weight restriction of 60Kg. This stem has a short offset, is designed to fit small, dysplastic femora and clearly is too small to withstand the bending moments and stress exerted by patients of weight >60Kg. It is therefore interesting that there are no weight restrictions placed on any of the other CDH stems, cemented or uncemented, especially considering the other uncemented stems are also made from titanium alloy and the cemented options are likely to be smaller in size.

One possible solution to this risk of stem fracture in overweight patients is to encourage exercise and weight loss prior to THR surgery. Studies have shown exercise therapy to improve pain and function in patients with osteoarthritis of the hip⁽⁴⁶⁾. Thus exercise and weight loss will not only help reduce the risk of stem fracture in these patients but in some cases may alleviate the need for a THR altogether.

CONCLUSION

Excluding the Corail size 6 uncemented femoral stem, there are currently no weight restrictions imposed by the manufacturing companies on any of the five most common cemented/ uncemented femoral stems used within the UK as documented by the NJR 10th annual report. However, there is clearly an association between excessive patient weight and fatigue failure of femoral stem implants THR patients. Based on the current literature, although the risk appears to be greater in those who have received a cemented component (particularly those manufactured from HNSS as compared to cobalt chrome) the risk is evident with both cemented and uncemented femoral stems. With the number of THR's performed in obese patients increasing, we suggest avoiding, where possible, the insertion of small stems (particularly cemented stems) and large offset stems (particularly those with a modular neck) in overweight patients. Furthermore, good proximal support is essential to reduce the cantilever bending forces acting on the stem. We therefore advocate particular attention is paid to achieving optimal proximal femoral support when undertaking THR surgery, especially in overweight patients.

REFERENCES

1. **No Authors Listed.** Obesity and Overweight. Factsheet No. 311. World Health Organisation. <http://www.who.int/mediacentre/factsheets/fs311/en/index.html>.
2. **No authors listed.** Report of a WHO Consultation on Obesity: obesity, preventing and managing the global epidemic. Geneva: World Health Organization, 1998.
3. **No Authors Listed.** Trends in obesity prevalence. Public Health England. http://www.noo.org.uk/NOO_about_obesity/trends.
4. **No Authors Listed.** Foresight Report 2007. <http://www.erpho.org.uk/Download/Public/16891/1/obesityKeymessages.pdf>.
5. **No Authors Listed.** National Joint Registry: 10th Annual Report. njrcentre. http://www.njrcentre.org.uk/njrcentre/Portals/0/Documents/England/Reports/10th_annual_report/NJR%2010th%20Annual%20Report%202013%20B.pdf.
6. **Martens M, Aernoudt E, de Meester P, Ducheyne P, Mulier JC, de Langh R and Kestelijn P.** Factors in the mechanical failure of the femoral component in 246 total hip prostheses. Report of six fatigue fractures of the femoral stem and results 247 of experimental loading tests. Acta Orthop. Scand 1974;45(5):693-710.
7. **Charnley J.** Fracture of femoral prostheses in total hip replacement. A clinical study. Clin Orthop Rel Res 1975;111:105-20.
8. **Pellicci PM, Salvati EA and Robinson HJ.** Mechanical failures in total hip replacement requiring reoperation. JBJS(Am) 1979;61(1):28-36.
9. **Wroblewski BM.** The mechanism of fracture of the femoral prosthesis in total hip replacement. Int Orthop 1979;3(2):137-39.
10. **Wroblewski BM.** Fractured stem in total hip replacement. A clinical review of 120 cases. Acta Orthop Scand 1982;53(2):279-84.
11. **Galante JO.** Causes of fractures of the femoral component in total hip replacement. JBJS(Am) 1980;62(4):670-73.
12. **Miller A, Shastri R and Shih C.** Fracture failure of a forged titanium prosthesis. JBJS(Am) 1982;64(9):1359-63.
13. **Fowler JL, Gie GA, Lee AJ and Ling RS.** Experience with the Exeter total hip replacement since 1970. Orthop Clin North Am 1988;19(3):477-89.
14. **Yates PJ, Quraishi NA, Kop A, Howie DW, Marx C, and Swarts E.** Fractures of modern high nitrogen stainless steel cemented stems. Cause, mechanism, and avoidance in 14 cases. J Arth 2008;23(2):188-96.
15. **Valle AGD, Becksac B, Anderson J, Wright T, Nestor B, Pellicci PM and Salvati EA.** Late Fatigue Fracture of a Modern Cemented Forged Cobalt Chrome Stem for Total Hip Arthroplasty. A Report of 10 Cases. J Arth 2005;20(8):1084-88.
16. **Woolson ST, Milbauer JP, Bobyn JD, Yue S and Maloney WJ.** Fatigue fracture of a forged cobalt-chromium-molybdenum femoral component inserted 252 with cement. A report of ten cases. JBJS(Am) 1997;79(12):1842-48.
17. **Van Doorn JW, Van Biezen FC, Prendergast PJ and Verhaar JAN.** Fracture of an Exeter stem 3 years after impaction allografting- a case report. Act Orthop Scand 2002;73(1):111-13.
18. **Davies BM, Branford White HA and Temple A.** A series of four fractured Exeter stems in hip arthroplasty. Ann R Col Surg Eng 2013;95(8):e130-32.
19. **Akinola B, Mahmud T and DeRoeck N.** Fracture of an Exeter stem-a case report. Int J Ortho Surg 2009;16(1): <http://ispub.com/IJOS/16/1/10279#>.

20. **O'Neill GK, Maheshwari R, Willis C, Meek D and Patil S.** Fracture of an Exeter 'cement in cement' revision stem: a case report. *Hip Int* 2011;21(5):627-29.
21. **Wright DM, Alonso A, Lekka E and Sochart DH.** Fracture of the CDH C-stem. A report of two cases. *JBJS(Br)* 2006;88-B(supp II):245.
22. **Morley D, Starks I and Lim J.** A case of a C-stem fracture at the head-neck junction and review of the literature. *Case Reports in Orth* 2012;2012: <http://dx.doi.org/10.1155/2012/158604>.
23. **Tiberi JV, Spitzer A, and Paiement G.** Fracture of a cemented, highly polished, collarless, triple-tapered, high nitrogen stainless steel femoral stem. A case report. *JBJS(Am) Case Connector* 2013;3(4):e103.
24. **Trigkilidas D, Anand A, Ibe R, Syed T and Floyd A.** A fracture through the neck of a Charnley Elite Plus Femoral component: a case report. *Int J of Orth Surg* 2009;16(1): <http://ispub.com/IJOS/16/1/9262> .
25. **Raj D, Coupe BD and Keene GS.** Stem fracture of a collarless, polished, double taper cemented femoral prosthesis: a case report. *Acta Orthop Belg* 2008;74(5):697-99.
26. **Jazrawi LM, Della Valle CJ, Kummer FJ, Adler EM and Di Cesare PE.** Catastrophic failure of a cemented, collarless, polished, tapered cobalt chromium femoral stem used with impaction bone grafting. A report of two cases. *JBJS(Am)* 1999;81(6):844-47.
27. **Lee EW and Kim HT.** Early fatigue failures of cemented, forged, cobalt-chromium femoral stems at the neck-shoulder junction. *J Arth* 2001;16(2):236-38.
28. **Jaques, H.** Number of doctors facing medico-legal claims increases by 15%. *BMJ Careers*. 14th August 2013. *BMJ Careers*: <http://careers.bmj.com/careers/advice/view-article.html?id=20014004>.
29. **Galante JO, Rostoker W and Doyle JM.** Failed femoral stems in total hip prostheses. A report of six cases. *JBJS(Am)* 1975;57(2):230-36.
30. **Hook S, Moulder M, Yates, PJ, Burston B, Whitley E and Bannister GC.** The Exeter universal stem. A minimum 10-year review from an independent centre. *BJJ(Br)* 2006;888(12):1584-90.
31. **Ling RS, Charity J, Lee AJ, Whitehouse SL, Timperley AJ and Gie GA.** The long term results of the original Exeter polished cemented femoral component: a follow up report. *J Arth* 2009;24(12):511-17.
32. **Gie GA, Ling RS and Timperley AJ.** Stem fracture with the Exeter prosthesis. *Acta Orthop Scand* 1996;67(2):206-7.
33. **Rokkum M, Bye K, Hetland KR and Reigstad A.** Stem fracture with the Exeter prosthesis. 3 of 27 hips followed for 10 years. *Acta Ortho Scan* 1995;66(5):435-39.
34. **Miller EH, Shastri R, Shih AC and Ohio C.** Fracture failure of a forged vitallium prosthesis. A case report. *JBJS(Am)* 1982;64-A(9):1359-63.
35. **No Author Listed.** Product information for the stainless steel CPT hip system. Zimmer Inc. Warsaw. Ind. 87-6203-901-22.
36. **Morgan-Hough CVJ, Tavakkolizadeh A and Purkayastha S.** Fatigue failure of the femoral component of a cementless total hip arthroplasty. *J Arth* 2004;19(5):658-60.
37. **Sharma DK, Brooks S, Creasey S and Lewis B.** Fracture of fully hydroxyapatite-coated titanium femoral stem of a total hip replacement: a report of three cases. *Acta Ortho Scand* 2004;75(6):768-71.
38. **Harvie P, Haroon M, Henderson N and El-Guindi M.** Fracture of the hydroxyapatite-ceramic-coated JRI-Furlong femoral component. Body mass index and implications for selection of the implant. *BJJ* 2007;89-B(6):742-45.
39. **Vatani N, Comando D, Acune J, Prieto D and Caviglia H.** Faulty design increases the risk of neck fracture in hip prosthesis. *Acta Ortho Scand* 2002;73(5):513-17.

40. **Kop Am and Swarts E.** Corrosion of a hip stem with a modular neck taper junction: a retrieval study of 16 cases. *J Arth* 2009;24(7):1019-23.
41. **Gill HS, Alfaro-Adrián J, Alfaro-Adrián C, McLardy-Smith P and Murray DW.** The effect of anteversion on femoral component stability assessed by radiostereometric analysis. *J Arth* 2002;17(8):997-1005.
42. **Wright G, Sporer S, Urban R and Jacobs J.** Fracture of a modular femoral neck after total hip arthroplasty: A case report. *JBJS(Am)* 2010;92(6):1518-21.
43. **Wilson DAJ, Dunbar MJ, Amirault JD and Farhat Z.** Early failure of a modular femoral neck total hip arthroplasty component: a case report. *JBJS(Am)* 2010;92(6):1514-17.
44. Femoral stem fractures in Zimmer modular revision (ZMRO) hip systems. . 20, *TGA News*, 2003, Vol. 40.
45. **Lakstein D, Eliaz N, Levi O, Backstein D, Kosashvili Y, Safir O and Gross AE.** Fracture of cementless femoral stems at the mid-stem junction in modular revision hip arthroplasty systems. *JBJS(Am)* 2011;93(1):57-65.
46. **French HP, Cusack T, Brennan A, Caffrey A, Conroy R, Cuddy V, FitzGerald OM, Fitzpatrick M, Gilenan C, Kane D, O'Connell PG, White B and McCarthy GM.** Exercise and manual physiotherapy arthritis research trial (EMPART) for osteoarthritis of the hip: a multicenter randomized controlled trial. *Arch Phys Med Rehabil* 2013;94(2):302-14