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Proximal femoral fixation nail in proximal femoral fractures- study on biomechanical forces causing implant failure

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Abstract

Objective: Purpose of this study is to evaluate biomechanical factors working around hip which leads to implant failure. Knowledge of these biomechanical forces may help in some modification in implant design or developing new operative techniques[to avoid damage or to strengthen protecting forces working on implant] and it may also help in developing some new postop splint support for patient benefit.

Material and Methods: This is a prospective cum retrospective study. All *11 cases* with *proximal femoral fracture[# I/T & S/T included]* fixed with PFN.

Conclusion: To prevent implant failure biomechanical force-vectors has to be compensated by forces generated in opposite direction either by body itself or biomechanical properties of implant either due to its specific design or due to properties of material which is used. If not compensated implant failure may occure.

Keywords: Trochanteric fixation nail, Dynamic hip screw, Implant failure, Biomechanical forces around hip, Abduction Dynamic hip splint.

Introduction

Biomechanically PFN is better choice of implant for fixation of proximal femoral fractures[especially unstable type] compared to DHS and DCS. Has less mobility, provides more stability proximally as well as distally and is a load sharing device. Nail itself gives support as lateral trochanteric wall and itself resist collapse. Less intra-op bleed, less operative time less intra-op muscle damage, immediate post-op mobilization are key points that supports superiority of PFN over DHS. Still there are some pitfalls as implant failure does occur in PFN also; due to specific biomechanical forces acting on implant around hip joint.

One of complication of TFN is implant failure. Implant failure can be due to breakage of implant anywhere; cut-out of implant through bone or back-out of screws

Purpose of this study is to evaluate these biomechanical factors which lead to implant failure. Knowledge of these biomechanical forces may help in some modification in implant design or may help in developing new operative techniques [to avoid damage or to strengthen protecting forces working on implant] and it may also help in developing some new post-op splint support for patient benefit.

Biomechanics Around Hip: Centre of Gravity & Various forces acting around neck of femur:
[Fig. 1 & 2] [ref: biomechanics of hip by Mrrgareta Nordin, Victor H. Frankel]

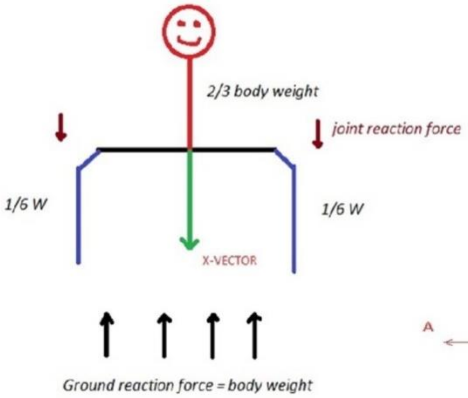
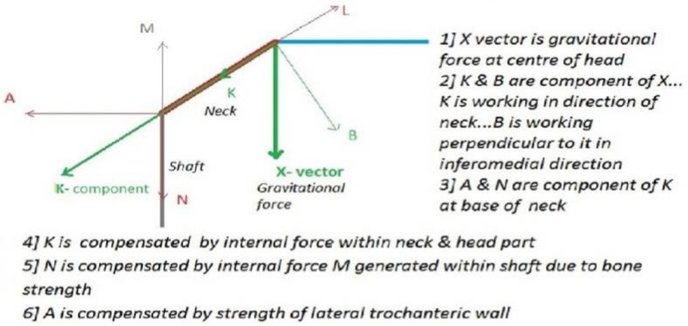


FIGURE 1

FIGURE 2



K-L is axis of neck of femur.

Vector X is the direction in which weight of half of body [mg] puts its force while standing.

K component of X vector is in direction of neck so it is compensated by force given by bone of neck of femur. If the bone is of not good quality then telescopic impaction occurs and this vector pushes the screws back and causes back-out.

B component of this X vector is not compensated and by this vector supero-lateral margin of acetabulum pushes head of femur in infero-medial direction.

This B component is the cause of breakage of screws or cut-through of screws in neck through supero-lateral part of head and neck of femur.

While standing on normal side the abductor lever arm [abductor muscles, neck femur] works to oppose the tilting force given by weight of opposite half of body.

While standing on affected hip with weak abductor mechanism [due to any reason may be injury related or postoperative] weight of opposite half of body works as rotatory torque. With vector of torque force tries to rotate head in relation to neck and shaft in varus position this force is also causative for cut-through of superior part of head in TFN patient and also may be causative factor in breakage of nail itself.

More lateral entry causes more deforming torque force.

K component of X vector divided in two vectors.

N component of Y vector compensated by counter force within the shaft of femur.

A component of Y works in lateral direction and tries to push lateral wall of upper 3rd of femur laterally. This vector may be the cause of implant failure due to breakage of nail itself. Because usually in distal part of shaft; nail is impacted in the medullary canal and in proximal part nail have some space around it to move due to broad size of trochanter. Vector A causes movement of movable proximal part in relation to fixed distal part. And this may cause breakage of nail.

B component & Effect of B & K components:

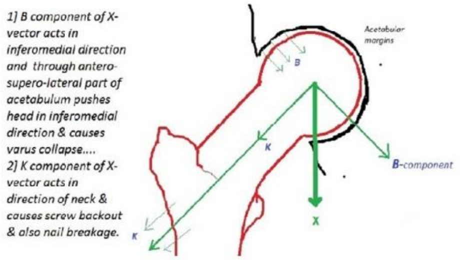
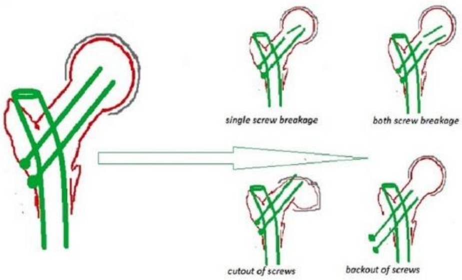


FIGURE 3

FIGURE 4



Torque force vector & Effect of torque vector:-
[ref: biomechanics of hip by MrrgaretaNordin, Victor H. Frankel]

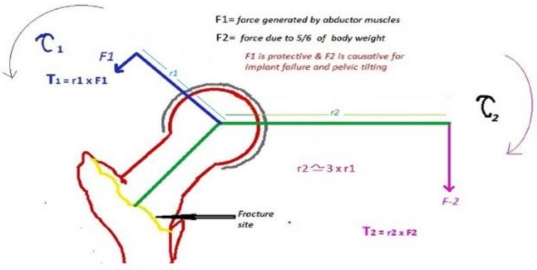
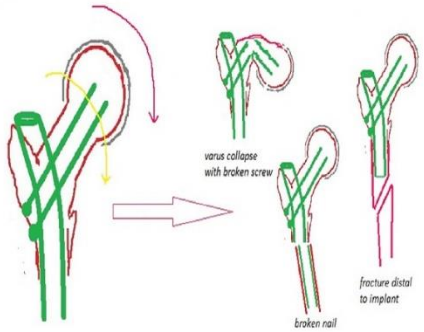


FIGURE 5

FIGURE 6



Materials and Methods

This is a prospective cum retrospective study. All *11 cases* below 80 year of age with *proximal femoral fracture [fracture Inter-trochanteric & Sub-trochanteric included]* fixed with PFN *irrespective of the centre* where surgery was performed attending routine out-door of department of orthopaedics in M. Y. Hospital associated to M.G.M. Medical college INDORE with implant failure since June 2010 are being registered for the study.

Cases with infection; poly-trauma and disability in other limb were excluded from study.

Cases included in study were evaluated on following points-

1. History was taken from patient and close relatives regarding rehabilitation protocol, mode of failure, duration between injury and operation.
2. Information about surgical procedure, approach & implant details from patient records and if necessary from hospital records.
3. Radiological evaluation from series of X- rays both pre-op and post-op and follow-up X- rays obtained from patient.
4. Biomechanical force study in reference to implant placement & fixation strength; protocol for rehabilitation in different fracture patterns with the help of available literature.

Till date our study includes 11 cases of proximal femoral fractures fixed with PFNs with implant failure.

Observation

Based on following points:

1. Age
2. Sex
3. Duration between injury & operation
4. Duration between operation and implant failure
5. Geometry pattern of fracture
6. Post-op rehabilitation protocol
7. Surgeon's experience [entry point, angle of fixation, TAD index]
8. Patient factors [overweight, compliance, nutritional status/immune status, osteoporosis]
9. Pattern of implant failure.

Observation in our study is summarized in following table

Case No.	Age/sex	Fracture pattern A.O. type	Pattern of Implant failure	Non union	Duration between Injury & Operation
1	60yr/m	A-2.2 unstable	Both screw breakage	present	20 days
2	65yr/m	A-3.2 Unstable	Broken nail	present	4 days
3	62yr/m	A-2.2	Single screw	present	3 days

		Unstable	breakage		
4	48yr/m	A-2.1 Unstable	Z- effect	absent	1 days
5	68yr/m	A-2.2 Unstable	Z-effect, cutout, infection	present	2 days
6	80yr/f	A-2.1 Unstable	Reverse Z-effect	absent	2 days
7	58yr/m	A-3.3 Unstable	Broken nail	present	2 days
8	66yr/m	A-3.1 Unstable	Reverse Z-effect	present	4 days
9	72yr/m	A-3.1 Unstable	Reverse Z-effect	present	3 days
10	48yr/m	A-1.2 stable	Spiral shaft Femure fracture	absent	2 days
11	63yr/f	A-2.2 Unstable	Reverse Z-effect	absent	4 days

In our study we registered total of 11 cases with 9 cases of true implant failure & 2 cases of post-op spiral fracture femur just distal to tip of PFN explained by biomechanical forces.

Mean age of registered cases was 62.72 year with 7 patients [63.33%] in our study were from age group between 50 to 70 yr. Two patients [18.18%] were <50 yr of age & two [18.18%] were >70yr of age presented.

9 patients were male and 2 were females.

Effect of Duration between injury and operation could not be studied because there was only 1 patient in which it was 3 weeks in other 10 patients itwas <1 week.With mean duration betwen injury and operation was 4.09 days.

Except 1 all cases of implant failure in our study were categorized as unstable type according to EVAN's & A.O. classifications preoperatively.

Out of 11 cases registered pattern of implant failure in our study were four cases had implant failure pattern of reverse Z-effect; two had breakage of nails; one case had both screw breakage with varus collapse; one had single upper proximal screw breakage; one had implant failure pattern of Z-effect & two cases were associated with spiral fracture femur just distal to the tip of PFN.

Result/ Discussion

In our study most of the patients [63.33%] were between age 50 to 70 year could be explained due to the fact that incidence of fracture inter-trochanteric femur is increases with age [ref Campbell 11thedition page 3238]so no. of cases in >50year age is more compared to no. of cases in <50 year of age. Along with this in our society usually >70 year aged people do not indulge in heavy activities & suffers from reluctances for further treatment from family members in case of implant failure. And also 50- 70 year age group usually have burden to earn to run family so this group has mindset not to be bedridden and to earn.

Incidence of fracture inter-trochanteric femur is more in females as compared to male [ref Campbell 11th edition page 3238] instead of this there was 9:2 ratio with male predominance. This could be due to the fact that in fracture pattern in females is usually is stable type due to low velocity traumatic injury. In males incidence of unstable fracture is more. Also in Indian families females usually do-not have to do heavy work. They only have to do light household activities that avoid repeated stress on implant caused by heavy activities in males.

In our study we could-not established effect of duration between injury & operation time on chances of implant failure because of small cohort. But disuse atrophy of abductor muscles while waiting for surgery, accepting in compromised fracture reduction rather than anatomical due to delay in operation &more intra-op soft tissue damage because of delayed intervention might be the factors which could lead to increased chances of implant failure. It has been established that delaying fixation for more than 2 days increases immediate mortality by 15% & more than 3 days by doubles the mortality rate [ref Campbell 11th edition page 3238].

Unstable fractures have tendency to displace. Usually these have postero-medial wall comminution. Instability of fracture may predispose to varus collapse, tendency of distal fragment to displace medially. Instability of fracture pattern increases strength of uncompensated destructive biomechanical forces that leads to implant failure.

Also the blood supply is maximum at inter-trochanteric line so fractures away from this have increased chances of non union. [Ref Campbell 11thedition page 3238]

Case 1 [Fig. 7] had both screw breakage in neck with slight back-out of inferior proximal screw with some degree of varus collapse. And in case 3 breakage of single screw occurred. Breakage of screw and varus collapse caused by both uncompensated torque force vector-2 & B-component of X- vector. Breakage of inferior screw caused by uncompensated A-component of K-vector. Case 1 needed re-fixation with cobra plate. Case 2 had union at fracture site and treated conservatively also trained for precautions to avoid further damage. In case 2 & 7 [Fig. 8] breakage of nail occurred with varus collapse of proximal fragment. Nail breakage with varus collapse explained by both uncompensated Torque-2 and B-component

Case 4 & 5 [Fig. 9] had back-out of inferior proximal screw typical of Z-effect. Case 5 also had back out of superior screw. Cases 6, 8, 9 [Fig. 10] had back-out of superior proximal screw typical of reverse Z-effect. In all these cases back-out is caused by uncompensated K-component of X and varus collapse by torque vector-2 and uncompensated B-component of X-vector.


FIGURE-7


FIGURE-8

FIGURE-9

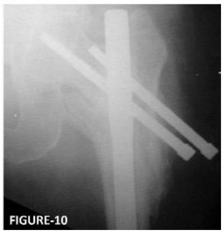


FIGURE-10

Case 10 & 11 had spiral fracture shaft femur just distal to tip of PFN. Here in this type of failure uncompensated B-component and uncompensated Torque vector are responsible for fracture and varus angulations

Surgeon's experience & accuracy of procedure is of great importance in preventing implant failure. Varus sitting of implant; lateral entry & short screws [TAD> 25mm] increases strength of deforming forces and increases the chances of implant failure. Lateral entry causes long lever arm that leads to more damaging torque force acting on implant.

Older theories about screw placement favored a low and occasionally a posterior position of the lag screw, thereby leaving more bone superior and anterior to the screw. This effectively lengthens the tip-to-apex distance andshould be avoided. The ideal position for a lag screw in both planes is deep and central in the femoral head within 10 mm of the sub-chondral bone. A tip-to-apex distance of <25 mm has been shown to be generally predictive of a successful result; however, most traumatologists aim for a tip-to-apex distance of <20 mm.[ref *J Bone Joint Surg Am.* 2009;91:712-719. George J. Haidukewych]. If screw remains short [TAD>25mm] it leads to decreased resisting force of implant against torque force. If tip ofscrew is till near sub-chondral area of head [TAD< 25mm] then internal strength of bone and screw both tries to resist varus collapsing forces in addition to abductor muscle forces. But if TAD>25mm then it will lead to situation in which internal strength of only bone of head of femur will resist along with abductor muscles and it increases chances of varus collapse; screw breakage; screw cut-out; nail breakage etc.

To prevent varus collapse following forces must be compensated-

Abductor muscle force + internal strength of implant & bone = or > torque force due to body weight + B component of X- vector + adductor muscle torqueforce

Here due to short lever arm adductor muscle torque force is not much of significance

It was also observed that 10 out of 11 implant failure occurred in fractures that were classified as unstable type with loss of medial wall support. It may be one of the important reasons for occurrence of implant failure. If with some modification in operative procedure or modification in implant design we make ourselves able to fix medial wall support then it may decrease no implant failure.

To prevent implant failure Following points must be kept in mind while doing proximal femoral nailing- [ref *J Bone Joint Surg Am.* 2009;91:712-719. George J. Haidukewych]-

1. Tip-to-Apex Distance [TAD]should be between 5 & 25mm
2. Be-aware of the Anterior Bowing of the Femoral Shaft while doing nailing.
3. When Using a Trochanteric Entry Nail, Start Slightly Medial to the Exact Tip of the Greater Trochanter
4. Do Not Ream an Unreduced Fracture
5. Be Cautious About the Nail Insertion Trajectory, and Do Not Use a Hammer to Seat the Nail
6. Avoid Varus Angulations of the Proximal Fragment—Use the Relationship Between the Tip of the Trochanter and the Center of the Femoral Head
7. Avoid Fracture Distraction When Nailing

Conclusion/ Summery

Various complicated forces are there that acts on hip joint in different direction. Each force [whether it is tractional, compression or rotational force] has its own direction. These biomechanical forces are due to body-weight while standing and walking. To minimize damage to joint & implant[to prevent implant failure] these forces vectors has to be compensated by forces generated in opposite direction either by body itself [abductor muscle strength etc] or biomechanical properties of implant either due to its specific design or due to properties of material which is used. If not compensated implant failure may occur.

We suggest **Abductor Dynamic Hip Splint**[Fig. 11 & 12] at our centre postoperatively. This splint may strengthen abductor mechanism while standing on diseased hip and oppose pelvic tilt forces so it may be a useful splint to prevent implant failure but long-term study has to be done to show beneficial effect if any of this splint.

Modification of implant design [Fig. 13] by making nail with screw that also fixes medial wall also can be done. Also holes for screws should be either locking or they should be oval to prevent back-out of screws.

FIGURE-11

FIGURE-12

FIGURE-13

Modification in surgical procedure by inserting cement by injection technique under imaging machine guidance to make cemented calcar [medial wall] and then inserting nail can be done. Also entry should be made medial to tip of greater trochanter not through it.

There is also need for study that reveals importance of preoperative CT-SCAN in proximal femoral fractures.

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26. Corresponding author. Orthopaedic Department, National Cheng Kung University Medical Center, No. 138, Sheng-Li Road, Tainan, Taiwan. Fax: +886 6 2766189. E-mail address: laikuoan@mail.ncku.edu.tw (K.-A. Lai). 1 Present affiliation: Department of Emergency Medicine, The Johns Hopkins University School of Medicine, Baltimore, Maryland, USA. 8756-3282/$ – see front matter © 2008 Elsevier Inc. All rights reserved. doi:10.1016/j.bone.2008.09.004 Contents lists available at ScienceDirect Bone journal homepage: www.elsevier.com/locate/bone.
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