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Biomechanical comparision of femoral intramedullary nails for interfragmentary rotational stability

Kırık hattı rotasyonel stabilitesi için intramedüller femoral çivilerin biyomekanik yönden karşılaştırılması

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ABSTRACT

Objectives: This study aims to investigate which intramedullary nail is biomechanically better for establishing interfragmentary rotational stability.

Materials and methods: Thirty composite femurs were utilized in this study. We analyzed interfragmentary rotational arc displacements between 10 Nm external-6 Nm internal torques and 6 Nm external-6 Nm internal torques which imitate rotation torques while walking on a flat surface and descending stairs by administering 10 interlocking nails, 10 compression nails, and 10 Mehmet anti-rotation nails with tube compression.

Results: Maximum interfragmentary rotation arc displacement between 10 Nm external rotation and 6 Nm internal rotation torques was mean 1.64 mm in the Mehmet nail compressed by 7 Nm torque wrench. This value was lower by 309% (6.72 mm) from interlocking nail (p=0.000), 201% (5.42 mm) from compression nail compressed by 2.5 Nm torque wrench (p=0.000), and 26% (1.92 mm) from compression nail compressed by 7 Nm torque wrench (p>0.05).

Conclusion: In axially stable transvers and short oblique femur fractures, Mehmet nail is superior to other intramedullary nails with limited movement between locking screw and hole, more interfragmentary compression without locking screw deformation, and no proximal nail migration.

Keywords: Femoral nail; femur fractures; fracture union; interfragmentary distraction; interfragmentary rotation.

ÖZ

Amaç: Bu çalışmada hangi intramedüller çivinin biyomekanik olarak kırık hattı rotasyonel stabilitesini sağlamada daha iyi olduğu araştırıldı.

Gereç ve yöntemler: Bu çalışmada 30 kompozit femur kullanıldı. On kilitli çivi, 10 kompresyon çivisi ve 10 Mehmet tüp kompresyonlu anti-rotasyon çivisi uygulanarak düz zeminde yürürken ve merdiven inerken rotasyon torklarını taklit eden 10 Nm eksternal ile 6 Nm internal torklar ve 6 Nm eksternal ile 6 Nm internal torklar arasındaki kırık hattı rotasyonel ark yer değiştirmeleri analiz edildi.

Bulgular: 10 Nm eksternal rotasyon ve 6 Nm internal rotasyon torkları arası maksimum kırık hattı rotasyonel ark yer değiştirmesi 7 Nm tork anahtarı ile sıkılmış Mehmet çivisinde ortalama 1.64 mm idi. Bu değer kilitli çividen %309 (6.72 mm) (p=0.000), 2.5 Nm tork anahtarı ile sıkılmış kompresyon çivisinden %201 (5.42 mm) (p=0.000) ve 7 Nm tork anahtarı ile sıkılmış kompresyon çivisinden %26 (1.92 mm) daha düşüktü (p>0.05).

Sonuç: Kilit vida ile delik arası hareket azlığı, kilit vida deformasyonu olmadan kırık hattında daha fazla kompresyon olması ve proksimale çivi migrasyonu olmaması özellikleri ile aksiyel olarak stabil transvers ve kısa oblik femur kırıklarında Mehmet çivisi diğer intramedüller çivilere göre daha üstündür.

Anahtar sözcükler: Femoral çivi; femur kırıkları; kırık kaynaması; kırık hattı distraksiyonu; kırık hattı rotasyonu.

Interlocking nailing is a preferred treatment method for femur diaphysis fractures and nonunions. Interlocking nails are accused to stimulate secondary bone healing with excessive callus because they allow great macro motions between fragments.[1] It is reported that, with interlocking nails, great rotational

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motion (about 8 degrees) is observed in ovine tibia which is excessive for normal bone healing.[2]

It was reported that interlocking nails rotate totally 14.2 degrees with 4 Nm internal and external rotation torques in cadaveric femurs.[3] The narrowest diameter of adult femur shaft is about 29 mm and its periphery is about 91 mm.[4,5] About 14 degrees interfragmentary arc of rotation means about 3.5 mm rotational displacement on adult femur.[4,5]

The perfect nail should have wider screw holes than locking screws for comfortable locking screw placing. Also, it should have holes that are in the identical diameter with locking screws for snug fit to block toggling between holes and screws in order to decrease interfragmentary rotation motion.[3] For these reasons, we have developed a novel Mehmet anti-rotation nail that has key hole shaped screw holes (Figure 1). As its central compression screw is driven, the compression tube pushes the screws distally inside the narrow part of the key hole, which has identical diameter with the screws (Figure 2).

We were unable to detect any preceding reports of an intramedullary nail that decreases the toggling or of any nails that have key hole shaped screw holes for rotational interfragmentary stability. We intended to compare the maximum interfragmentary arc of rotation among the two most commonly used nails, namely interlocking nails and compression nails, and Mehmet anti-rotation nail.

We hypothesized that significant fracture site rotation takes place with standard interlocking nails and that Mehmet anti-rotation compression nail is superior to interlocking and compression nails for maximum interfragmentary rotational stability during daily activities. Therefore, in this study, we aimed to investigate which intramedullary nail is biomechanically better for establishing interfragmentary rotational stability.

MATERIALS AND METHODS

In this biomechanical experiment, we utilized 30 medium, left, fourth generation composite femurs (Model 3403; Sawbones Europe AB MALMOE, SWEDEN, cellular 20 pcf) of 455 mm length and 13 mm intramedullary canal diameter. We carried out reaming to 14 mm and reaming to 16 mm at the most proximal and the most distal 7 cm of composite femurs, making unrestricted rotation of nails possible. We performed a transvers osteotomy AO/OTA 32-A3 (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association 32-A3) at the midpoint, 21 cm distal to trochanteric fossa. We eliminated any spikes of the osteotomy surfaces.

We inserted 10 interlocking nails, 10 compression nails, and 10 Mehmet nails into 30 composite femurs. All of the nails were stainless steel 12x400 mm (Tıpsan Medical devices Company İzmir Turkey). In interlocking nails, locking screw hole diameters were 5.5 mm, one proximal and two distal. We placed one 5 mm unthreaded proximal screw and two distal 5 mm low threaded distal screws. In compression nails, there were one proximal 5.5x20 mm oblong hole and two distal holes 5.5 mm in diameter. We placed one 5 mm unthreaded proximal screw and two 5 mm low threaded distal screws.

In Mehmet nails, there were one proximal 26 mm long key hole shaped screw hole and two distal 14 mm long key hole shaped screw holes. The wider upper part of the holes were 6.5 mm in diameter and its slot part was 5.5 mm in diameter (Figure 1). We placed one 5.5 mm unthreaded proximal screw and two low threaded distal screws to the wider 6.5 mm upper part of all the key holes (Figure 1). While its central

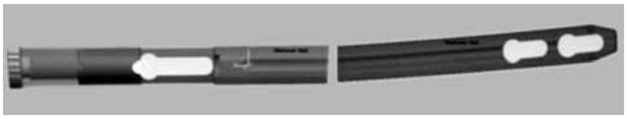

Figure 1. Key hole shaped proximal and two distal locking screw holes of Mehmet nail.

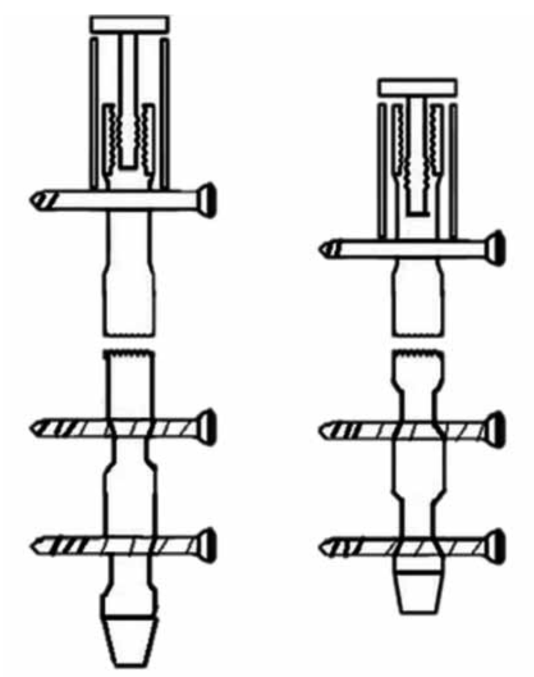

Figure 2. Mehmet nail compressed by proximal tube before compression and after compression.

compression screw is turned, the compression tube drives the locking screws distally to fit them snugly to the narrow distal edge of distal key holes and fracture site compression begins. As the distance between the proximal and the distal locking screws diminishes, a compression takes place at the fracture site and total length of the nail shortens by telescoping (Figure 2).

We managed the experiment in University of Dokuz Eylül, Institute of Health Science, Biomechanics Laboratory. We utilized SHIMADZU Autograph AG-5kNG universal test instrument (Shimadzu Corp., Tokyo, Japan) as distraction tool. The universal test machine was on the external torsion device (Figure 3). This apparatus fixed the proximal femur fragment and the distal femur fragment was attached into a steering wheel device that permits unrestricted rotation (Figure 3). We positioned optic markers right above and right below the osteotomy line at the lateral side of composite femurs. We gauged rotational movement at the osteotomy line with video extensometer (DVE-101-201, Shimadzu Corp., Tokyo, Japan). We preloaded with a load of 0.5 Nm in both sides.[6,7] In this experiment, the rotation torque loading rate was 0.30 degrees per second in displacement control mode similar to previous studies.[6,7]

We used three torque wrenches (2.5 Nm, 7 Nm and 8 Nm) to guarantee a constant torque for compression on compression nail and Mehmet nail. In the previous studies, the advised torque wrench was between 2 and 3 Nm for compression nails.[8,9] Also it was reported that higher interfragmentary rotational stability may be acquired by higher interfragmentary compression.[9]

We employed 6 Nm rotation intern (RI) torque to the distal fragment, around the center of its axis. Then, we employed 6 Nm rotation external (RE) torque to the distal fragment. We documented the maximum arc of rotation in the composite femur-nail construct between 6 Nm RI and 6 Nm RE. We also documented the maximum arc of rotation in the construct between 10 Nm RE and 6 Nm RI on all 30 constructs.

We applied 150 N distraction load after 100 N preload compression on 30 constructs because of the fact that there was 107 N distraction force on femur in a “hanging leg” situation.[10] We utilized SHIMADZU test machine for distraction tests of the composite femurs (Figure 4). The loading rate was 20 mm/minute in displacement control mode similar to previous research.[6]

Maximum arc of rotation and interfragmentary distraction gap values of three types of nails were compared using the Mann-Whitney U test. The level of significant difference was defined as $p<0.05$.

RESULTS

We observed locking screw deformation on compression nails compressed by 8 Nm torque wrench, but not by 7 Nm torque wrench. We observed no locking screw deformation on Mehmet nails compressed by 8 Nm torque wrench.

During stair descending activity, we found maximum arc of interfragmentary rotation motion with Mehmet nail compressed by 7 Nm torque wrench (mean 1.64 mm) to be 231% less than compression nails compressed by 2.5 Nm torque wrench (mean 5.42 mm) ($p=0.000$) and to be 309% less than interlocking nails (mean 6.72 mm) ($p=0.000$) between 10 Nm RE and 6 Nm RI torques (Table I).

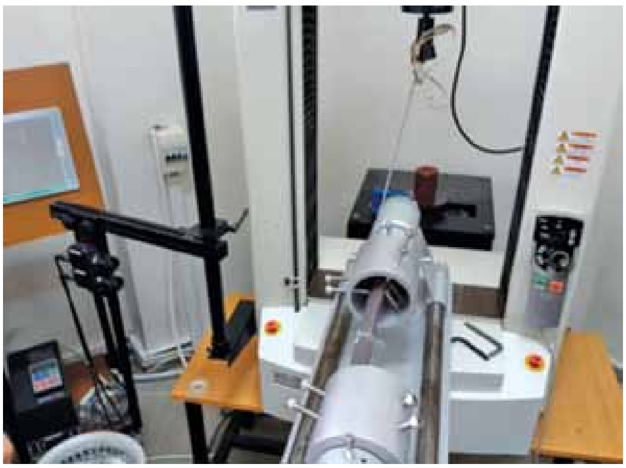

Figure 3. Video extensometer at left side and optic marker on composite femur in torsion apparatus.

Figure 4. Video extensometer at left side and optic marker on composite femur in universal test machine.

TABLE I

Maximum arc of interfragmentary rotation of 30 composite femur-nail constructs in 10 Nm RE - 6 Nm RI torques and *p* values (Mann-Whitney U test) between Mehmet nail and other nails (n=30)

	Mean±SD	95% CI (mm)	Degrees	% (increase)	*p*
Mehmet nail compressed by 7 Nm torque wrench	1.64±0.68	1.15-2.13	6.5		
Interlocking nail	6.72±1.07	5.95-7.49	26.5	309	0.000
Compression nail compressed by 2.5 Nm torque wrench	5.42±1.55	4.31-6.53	21.4	231	0.000
Compression nail compressed by 7 Nm torque wrench	1.92±0.7	1.41-2.42	7.5	23	>0.05
Mehmet nail compressed by 8 Nm torque wrench	0.89±0.55	0.49-1.29	3.5		
Interlocking nail	6.72±1.07	5.95-7.49	26.5	655	0.000
Compression nail compressed by 2.5 Nm torque wrench	5.42±1.55	4.31-6.53	21.4	508	0.000
Compression nail compressed by 7 Nm torque wrench	1.92±0.7	1.41-2.42	7.5	54	0.004

SD: Standard deviation; CI: Confidence interval.

In these rotation torques, maximum arc of rotation with Mehmet nail compressed by 8 Nm torque wrench (mean 0.89 mm) was 54% less than compression nail compressed by 7 Nm torque wrench (mean 1.92 mm) (p=0.004) (Table I).

During level walking activity, we found maximum arc of interfragmentary rotation motion with Mehmet nail compressed by 7 Nm torque wrench (mean 1.13 mm) to be 277% less than compression nails compressed by 2.5 Nm torque wrench (mean 4.27 mm) (p=0.000) and to be 396% less than interlocking nails (mean 5.61 mm) (p=0.000) between 6 Nm RE and 6 Nm RI torques (Table II). In these rotation torques, maximum arc of rotation with Mehmet nail compressed by 8 Nm torque wrench (mean 0.56 mm) was 116% less than maximum arc of rotation with compression nail compressed by 2.5 Nm torque wrench (mean 1.21 mm) (p=0.023) (Table II).

Interfragmentary gap was 2.01±045; 1.68-2.33 mm between 150 N distraction and 100 N compression forces on the interlocking nails. There was no statistical difference between interfragmentary gap value at compression nail compressed by 2.5 Nm torque wrench (0.17±0.2; 0.03-0.32 mm) and Mehmet nail compressed by 2.5 Nm torque wrench (0.17±0.12; 0.08-0.26 mm). In the compression nails and Mehmet nails compressed by 8 Nm and 7 Nm torque wrenches, there was no interfragmentary gap between 150 N distraction and 100 N compression forces.

DISCUSSION

In this study, we compared maximum interfragmentary arc of rotation motion and distraction on the most commonly used nails, interlocking and compression nails, and the novel design Mehmet anti-rotation compression nails in daily activities. According to our results, Mehmet

TABLE II

Maximum arc of interfragmentary rotation of 30 composite femur-nail constructs in 6 Nm RE - 6 Nm RI torques and *p* values (Mann-Whitney U test) between Mehmet nail and other nails (n=30)

	Mean±SD	95% CI (mm)	Degrees	% (increase)	*p*
Mehmet nail compressed by 7 Nm torque wrench	1.13±0.72	0.61-1.65	4.4		
Interlocking nail	5.61±0.84	5-6.21	22.1	396	0.000
Compression nail compressed by 2.5 Nm torque wrench	4.27±1.74	3.02-5.52	16.8	277	0.000
Compression nail compressed by 7 Nm torque wrench	1.21±0.62	0.75-1.66	4.7	7	>0.05
Mehmet nail compressed by 8 Nm torque wrench	0.56±0.38	0.28-0.84	2.2		
Interlocking nail	5.61±0.84	5-6.21	22.1	901	0.000
Compression nail compressed by 2.5 Nm torque wrench	4.27±1.74	3.02-5.52	16.8	662	0.000
Compression nail compressed by 7 Nm torque wrench	1.21±0.62	0.75-1.66	4.7	116	0.023

SD: Standard deviation; CI: Confidence interval.

anti-rotation compression nail is superior to the other nails for maximum interfragmentary rotational stability in daily activities like stair descending or level walking. We demonstrated that Mehmet nails and compression nails are superior in preventing interfragmentary distraction gap.

Between 10 Nm external and 6 Nm internal rotation torques, we detected a mean 0.89 mm maximum interfragmentary arc of rotational displacement with Mehmet nail compressed by 8 Nm torque wrench. We showed the insufficiency of interlocking nail due to its mean 6.72 mm maximum arc of rotational displacement. We also determined that compression nail compressed by 2.5 Nm torque wrench is insufficient due to its mean 5.42 mm maximum arc of rotational displacement. In the literature, it was advised to use 2-3 Nm torque wrench with compression nail.[8,9]

We detected 22.1 degrees maximum arc of rotation movement at 6 Nm RE - 6 Nm RI torques with interlocking nails. It is reported that the static interlocking nails rotated totally 14.2 degrees with 4 Nm RI and 4 Nm RE torques which are under physiologic load in cadaveric femurs reported by Citak et al.[3] In that experiment, no information was provided about the diameters of locking screws and locking screw holes.

A great number of factors may affect fracture site rotation displacement of long bones. One of these factors is a toggling between hole and locking screw leading to interfragmentary rotation displacement between the ultimate rotation external and internal torques.[3] Mehmet nail offers key hole shaped screw holes and distal slot part of these holes are in the same diameter with locking screws.

Taylor et al.[11] and Taylor and Walker[12] stated that the RE torque reached its peak at 0.8 BW cm (6 Nm) in early stance, changing route in mid-stance on femur in level walking and that the axial torque reached its peak at 1.3 BW cm (about 10 Nm) RE, followed by 0.73 BW cm (about 6 Nm) RI torques in stair descending and quickstep. In daily activities, only the level walking ability is inadequate for independent motion. Activities like getting off the car, getting off the chair or wheelchair and getting up from the toilet are similar to the activity of stair descending. The perfect femur nail should resist to the torques of interfragmentary rotation of these daily activities (between 10 Nm RE and 6 Nm RI).

It was shown that fracture site compression more effectively reduces interfragmentary rotation displacement on the osteotomy line.[9] Also, it was demonstrated that a higher interfragmentary rotational resistance is accomplished by compressed intramedullary nailing compared to uncompressed systems.[1,9]

Combination of anatomical locking plate and retrograde intramedullary nail in distal femoral fractures was reported to increase the rotational stability of bone-implant complex. Their combined use may be a choice of treatment in patients with osteoporosis or high-energy trauma.[13]

A limitation of our study is the utilization of composite femurs that could not accurately reproduce in vivo environments. Nevertheless, the composite femurs have been utilized successfully in biomechanical tests and produced more constant outcomes than cadaveric femurs which possibly have different bone mineral density and different biomechanical resistance.[14] It was stated that the composite bones demonstrated the same rotation patterns as the cadaveric bones.[9] Another limitation of our study is the lack of cyclic tests for fatigue life of nail-femur constructs. Some researchers also investigated fatigue life of implant-femur constructs with cyclic tests.[13]

For interlocking nails, numerous proximal nail migration cases were reported.[15,16] Proximal end of the compression nail may migrate more proximally as compression is performed during operation. Differently from the compression nails, the proximal end of the Mehmet nail does not change its position proximally during compression since the whole length of the nail compressed by tube shortens with compression by telescoping.

In conclusion, Mehmet anti-rotation compression nail is superior than other femoral nails for maximum rotational stability by no toggling of the locking screws, with more interfragmentary compression, and without locking screw failure, interfragmentary distraction gap, and superior nail migration in transvers and short oblique femur fractures for daily motions like stair descending or level walking.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

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