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Biomechanical effects of four different configurations in salter harris type 4 distal femoral epiphyseal fractures

Salter harris tip 4 distal femoral epifiz kırıklarında dört farklı konfigürasyonun biyomekanik etkileri

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Salter Harris Tip 4 Distal Femoral Epifiz Kırıklarında Dört Farklı Konfigürasyonun Biyomekanik Etkileri

Araştırma Makalesi / Research Article

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ÖZ

Bu çalışmada, distal femurun Salter Harris (SH) Tip 4 epifiz kırığında redüksiyon sonrası stabilizasyon için kullanılan Parallel Kirshner telleri (K teli), Parallel vidalar, Üstte K teli-Altta vida, Üstte vida-Altta K teli olmak üzere 4 farklı konfigürasyonun, aksiyel, rotasyonel ve eğme kuvvetleri altında, biyomekanik etkilerini tanımlayıp hangisinin daha avantajlı olduğu araştırıldı. 4 farklı konfigürasyon SolidWorks programı ile modellendi ve bilgisayar destekli sayısal analizler sonlu elemanlar yazılımı ile gerçekleştirildi. Herbir konfigürasyon için, ağ süreci, sınır şartları ve malzeme modeli sonlu elemanlar yazılımında uygulandı. Buna ek olarak, epifiz plağının gelişimindeki von-Mises gerilme değerleri, vidalar ve K-tellerindeki gerilme değerleri hesaplanmıştır.Frontal, sagittal ve transvers düzlemde bükme (varus-valgus açılımı, ön-arka açısal kapanma) ve burulma kuvvetleri altındaki fizis çizgi üzerinde tüm konfigürasyonlarda gerilme değerlerinde genel olarak yakın bir eğilim vardır. Eksenel kuvvetler düşünüldüğünde, en yüksek gerilme, fisizte paralel K-telleri konfigürasyonunda bulunurken, en düşük gerilme paralel vida konfigürasyonunda bulundu.Paralel vida konfigürasyonunda fiksasyon tipinin kullanılması avantajlı bulunmuştur.Ek olarak, SH tipi 4 epifiz kırıklarında, K-teli konfigürasyonunda fiksasyon tipi dezavantajlı bulunmuştur.

Anahtar Kelimeler: Biyomekanik, SH tip 4 epifiz kırığı, kirshner teli, sonlu elemanlar analizi, epifiz plağı.

Biomechanical Effects of Four Different Configurations In Salter Harris Type 4 Distal Femoral Epiphyseal Fractures

ABSTRACT

In this study, the biomechanicaleffects of four different configurations (Parallel K wires, Parallel Screw, Upper K wire-Lower Screw, Upper Screw-Lower K wire), which are used for stabilizing Salter-Harris (SH) Type 4 epiphyseal fracture of distal femur after reduction process, on the epiphyseal plate has been investigated under axial, rotational and bendingforces in order to determine the most advantageous configuration. The fourdifferent configurations have been modeled by using SolidWorks and computer-aided numerical analyses were performed by finite element analysis software. The mesh process, boundary conditions and material model have been applied in finite element analysis software for each configuration. In addition, von-Mises stress values on epiphyseal plate, screws and K wires have been calculated. There is a general near trend on stress values in all configurations on physis line under bending (varus-valgus angulation, anterior-posterior angulation) and torsional forces in the frontal, sagittal and transverse plane respectively. Considering the axial forces, the highest stress was found on parallel K- wires configuration in physis while the lowest stress was found in parallel screw configuration. It has been found particularly advantageous to use fixation type in parallel screw configuration. In addition, in SH type 4 epiphyseal fracture, fixation type is found to be disadvantageous in K wire configuration.

Keywords:Biomechanics, Salter Harris Type 4, Kirschner wire, finite element analysis, epiphyseal plate.

1. INTRODUCTION

Classification for pediatric physeal fractures was proposed by Salter and Harris (SH) in 1963 [1].The classification of physeal plate injuries in 5 types, proposed in their report, is related to the mechanism of injury, the relationship of the fracture line to the various cellular layers of the physeal plate, and the prognosis concerning disturbance of growth [1, 2]. SH type 4 epiphyseal fracture of the distal femur has high risk especially in growth interruption and for other complications [1, 3-6]. There are some factors considered as the cause of this situation as follows. The age of the person, type of fracture, degree of axial loding or shear stress, sinuous structure of physis, quality of fracture reduction process and fixation shape [7-10]. It has been suggested that the main cause of angulation at the fracture line and growth complications is physeal bar

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formation by considering its histology [7, 11]. In recent studies, it has been shown that an injury with a 7-9 % ratio incross-sectional area of the physis line can disrupt the growth [12, 13]. Type 4 epiphyseal injuries carry a bad prognosis unless the epiphyseal plate is completely realigment (1). In this case, intraarticular SH type 4 fractures are almost always need surgical reduction to prevent deformity [14]. In the treatment of SH type 4 epiphyseal fracture of distal femur, the fixation with partially threaded screw or Kirschner wire (K wire) applied parallel to the joint and without passing through the physis line is recommended [10, 15, 16]. The size, number, location of the screws or K wires used depending on decision of the surgeoncan increase or decrease the physical injuries as well as the stability of fracture. Although it has been stated that the purpose of this type of fracture treatment is obtaining anatomic reduction and preventing additional injuries of the physis, the most reliable technique has not been identified yet [7, 11, 15, 17]. The aim of our study; was to investigate the different configurations of K wires and screws used in distal femur SH type 4 epiphyseal fracture, for stabilization after reduction; under axial, rotational and bending forces, and define the biomechanical effects on the epiphyseal plate and decide which one was more advantageous.The configuration with minimal stresson the epiphyseal plate was investigated.

2. COMPUTER AIDED FINITE ELEMENT ANALYSIS AND MODELLING

Three dimensional modelling (3D) of biologic models is very popular in nowadays. Data such as Magnetic resonance imaging (MRI) and multislice computed tomography (CT) can be processedby using 3D modelling.The computer aided numerical analysis to stabilization of the different configurations after reduction during fixation was performed using AnsysWorkbench software based on finite element method (FEM). FEM is very important to develop of new surgical techniques. It is also used as a reliable technique for validation of experimental or analytical results. In addition, several scientists similarly examined the optimal configuration, implant materials, fatigue behavior of implant materials, metal turning, bone drilling and bone screwing process using the computer aided FEA tool [18-24].

2.1. 3D Modelling

The human femoral model was scanned using 3D scanner and point cloud was obtained. After that, 3D model of femur was created using point cloud data by Geomagic Studio 10 program. This femur model was scaled for taking femur dimensions of a child into account, and SH Type 4 fracture for single configuration was created using SolidWorks program as seen in Figure1. The diameter of screwused in configuration wasØ4x1.75x22 cancellous screw (Figure 2).

2.2. Finite Element Analysis (FEA)

The computer aided numerical analysis used for stabilization of four configurations after reduction process during fixation was performed using AnsysWorkbench software. 3D CAD models of fourconfigurations (Figure 1) wereimported into AnsysWorkbench software to prepare the FEA. Load, boundary conditions and material models were defined in AnsysWorkbench.

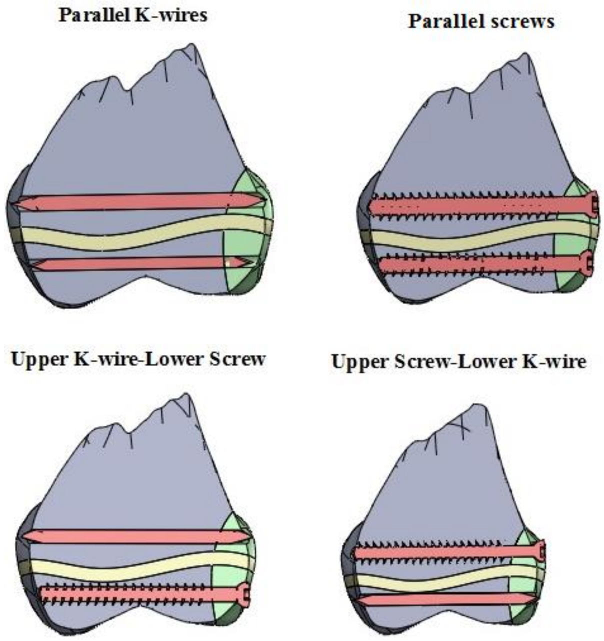


Figure 1. Four different configurations for SH Type 4 fracture

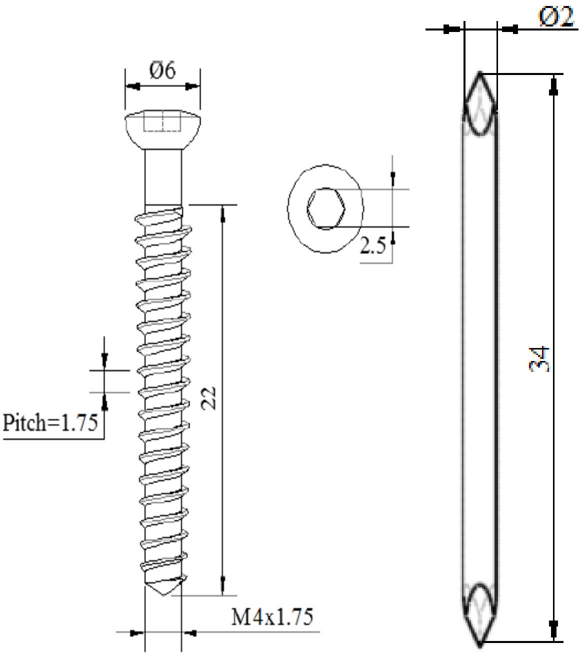
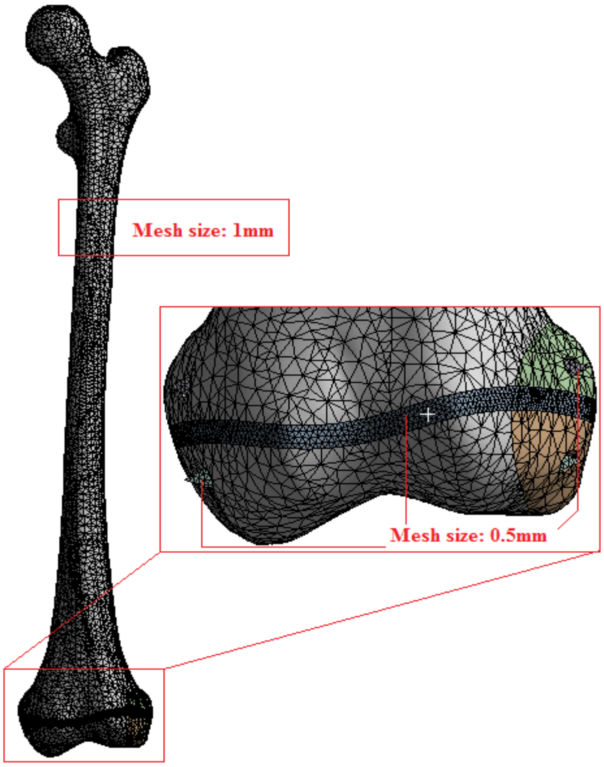


Figure 2. a) Ø4x1.75x22 cancellous screw, b)K wire

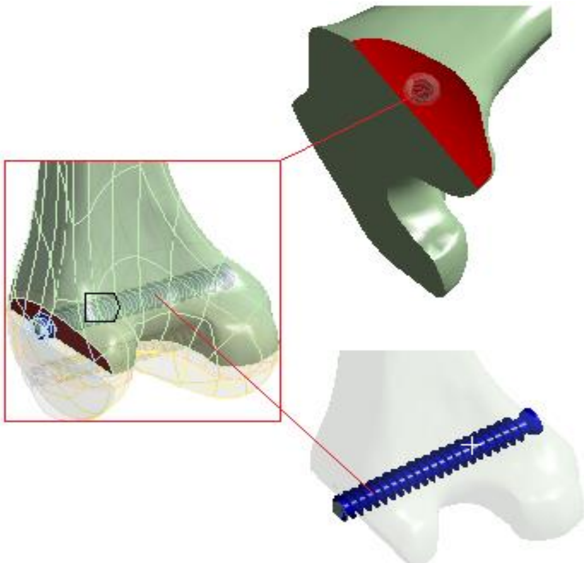
2.2.1. Loading and boundary conditions

The mesh operation was performed using tetrahedrons elements for FEA modeling after importing four different 3D model configurations into Ansys Workbench software (Figure 3a). The FEA model has 210378 nodes and 134305 elements.While the mesh density for femur and femur fragments were inputted as 1mm, K wires, epiphyseal plate and screw were inputted as 0.5mm. Axial, bending and rotational loading were applied within four configurations. A load of 350N in axial direction was applied to the femoral head and it was fixed from the distal femoral condylesfor axial loading as seen in Figure 4. According to this figure, bending forces were applied to the epiphyseal plate in varus and valgus directions, and femur was fixed from metaphysis and diaphysis part. Besides, bending forces were applied to the epiphyseal plate in anterior and posterior directions, and femur was fixed from metaphysis and diaphysis part. Finally, torsional force was applied to the epiphyseal plate around the z axis in CCW, and femur was fixed from metaphysis and diaphysis part.

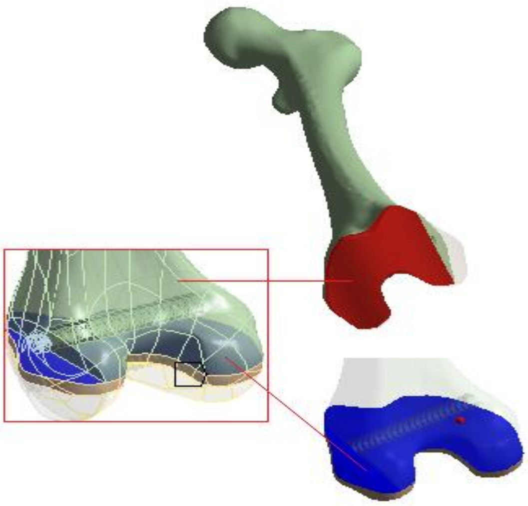
Contact types between bone and bone interaction, K wires and bone interaction or screw and bone interaction were defined as a frictional contact (Figure 3b). Friction coefficients were taken as 0.46 for bone and bone interactions and 0.42 for K wires and bone interaction or screw and bone interaction, respectively [25]. The contact type between epiphyseal plates was defined as a frictionless contact. Besides, the contact type between epiphyseal plate and bone was defined as bonded in Figure 3c[26]. Finally, as it can be seen in Figure 5, convergent analysis was conducted. The force convergence was commonly used in non-linear analyses. If solution is not convergent, there is a problem. For a good solution, purple line on the convergent graph should be acted on the cyan line. This status is dependent the boundary conditions such as friction, contact type and others.



a)



b)



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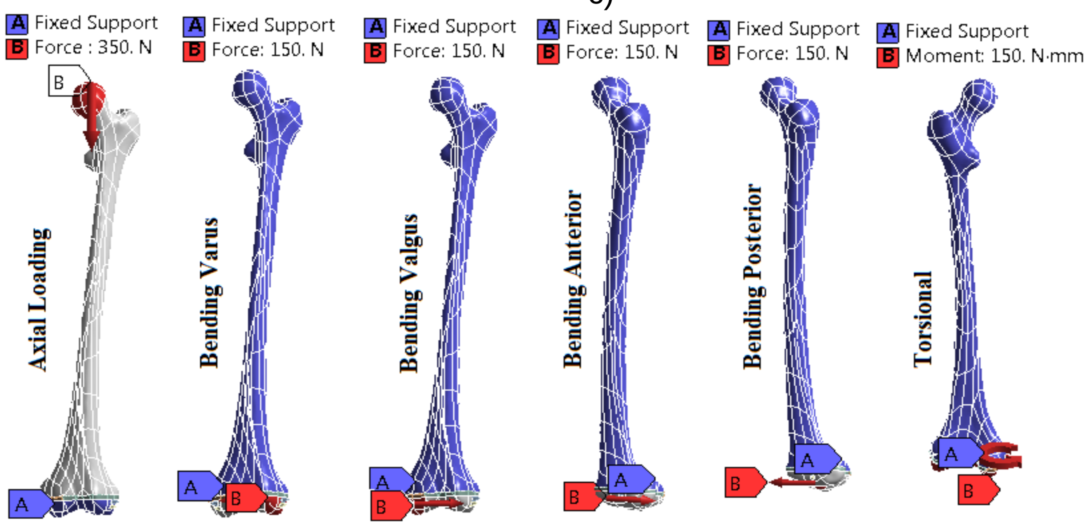

Figure4. Loading types for two configurations

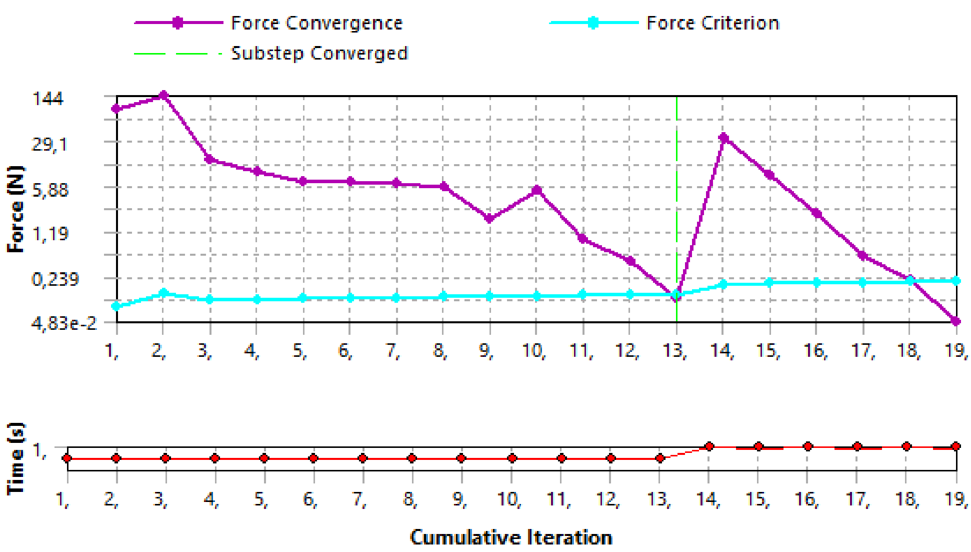

Figure 5. Convergence analysis

2.3. Material Model

Mechanical properties of bone andepiphyseal plate used in the Finite Element (FE) analyses were given in Table 1. The stainless steel was selected for K wires and screws used in FEA.The mechanical properties of K wires and screw were obtained from AnsysWorkbench Material Library [27]. Linear isotropic material model was used for mechanical behaviors of K wires, bone, epiphyseal plate and screw. The elasticity modulus of the epiphyseal plate was assumed as soft tissue when compared with other materials.

Table 1. Mechanical properties of K wires, screw, bone and epiphyseal plate used in FEA [28, 29]

Parameters	**Bone**	**Epiphyseal plate**	**Stainless Steel**
Density (kg m^{-3})	2100		7750
Young's Modulus (MPa)	17000	5	193000
Yield Strength (MPa)	135		207
Ultimate Strength (MPa)	148		586
Poisson's Ratio	0.35	0.46	0.31

3. RESULTS

After entering the loading and boundary conditions, FE analyseswere solved. According to FEA results, maximum stress values on epiphyseal plate upon FEA results, K wires and screw were given in Tables 2 and 3, Table 4, respectively.These stress values were evaluated according to von Mises criterion.The Von Mises model is generally used in ductile materials. As seen in Table 2, there is a general near trend on stress values in all configurations on physis line under bending(varus-valgus angulation, anterior-posterior angulation) and torsional forces in the frontal, sagittal and transverse plane respectively. Considering the axial forces, the highest stress was found on parallel K- wires configuration in physis while the lowest stress was found in parallel screw configuration.Stress distributions occurring in epiphyseal plate under axial loading in various configurations are seen in Figure 6. The deformations values on epiphyseal plate were given in Table 5. Figure 7 was presented images of deformations values on epiphyseal plate.

Table 2. Stress values occurring in epiphyseal plate (MPa)

No	**Fixation Type**	**Epiphyseal plate**					
		Axial	**Bending (Varus)**	**Bending (Valgus)**	**Bending (Anterior)**	**Bending (Posterior)**	**Torsional**
1	**Parallel K wires**	4.24	1.17	1.19	1.28	0.98	0.09
2	**Parallel Screw**	4.01	1.20	1.22	1.27	0.97	0.09
3	**Upper K wire-Lower Screw**	4.02	1.20	1.23	1.28	0.97	0.09
4	**Upper Screw-Lower K wire**	4.15	1.20	1.21	1.24	0.88	0.08

Table 3. Stress values occurring in Upper K wires or screws (MPa)

No	**Fixation Type**	**Upper K wires or Upper Screw**					
		Axial	**Bending (Varus)**	**Bending (Valgus)**	**Bending (Anterior)**	**Bending (Posterior)**	**Torsional**
1	**Parallel K wires**	170.51	38.20	47.86	49.20	60.36	3.17
2	**Parallel Screw**	164.90	3.15	2.98	1.59	1.16	0.17
3	**Upper K wire-Lower Screw**	445.03	4.81	4.89	0.80	0.99	0.17
4	**Upper Screw-Lower K wire**	152.93	2.99	2.83	1.43	1.40	0.14

Table 4. Stress values occurring in Lower K wires orLower screws (MPa)

No	Fixation Type	Lower K wires or Lower Screw					
		Axial	Bending (Varus)	Bending (Valgus)	Bending (Anterior)	Bending (Posterior)	Torsional
1	Parallel K wires	6.50	31.89	35.50	24.25	24.18	1.22
2	Parallel Screw	10.50	44.75	52.93	27.20	27.83	1.99
3	Upper K wire-Lower Screw	10.69	44.46	51.05	27.27	27.82	1.63
4	Upper Screw-Lower K wire	4.85	41.27	38.01	30.34	32.42	1.20

Table 5. Deformation values occurring in epiphyseal plate (MPa)

No	Fixation Type	Epiphyseal plate
		Axial
1	Parallel K wires	0,71
2	Parallel Screw	0,72
3	Upper K wire-Lower Screw	0,72
4	Upper Screw-Lower K wire	0,69

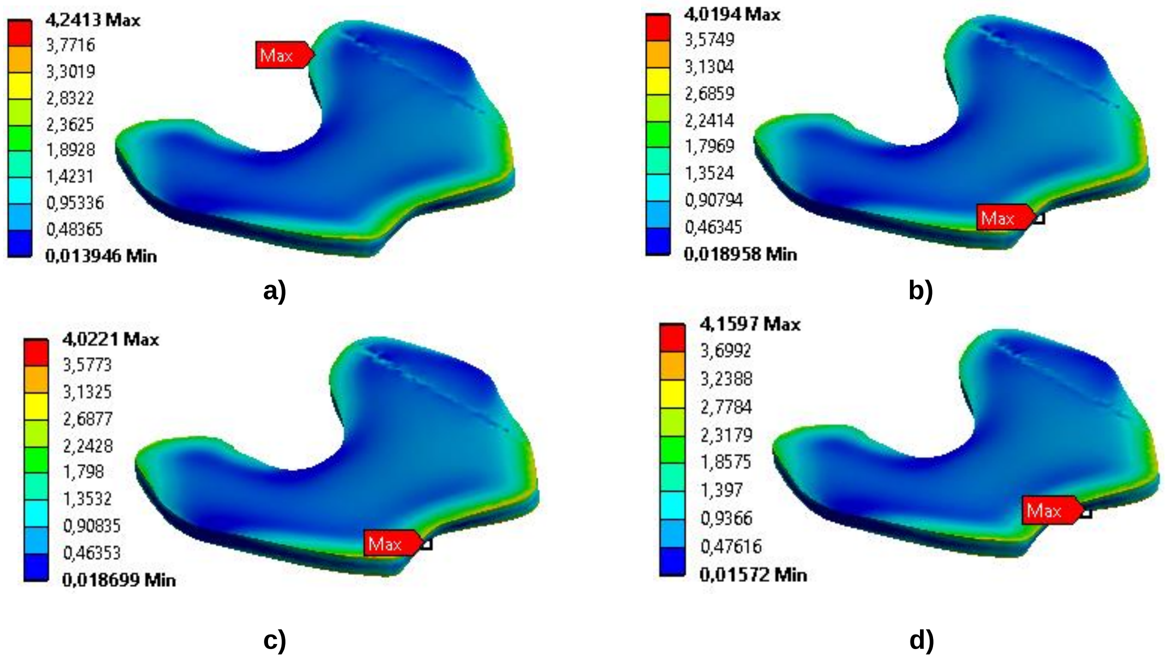

Figure 6. Stress values occurring at different configurations under the axial loading, a) Parallel K wires, b) Parallel screws, c) Upper K wire-Lower Screw, d) Upper Screw-Lower K wire

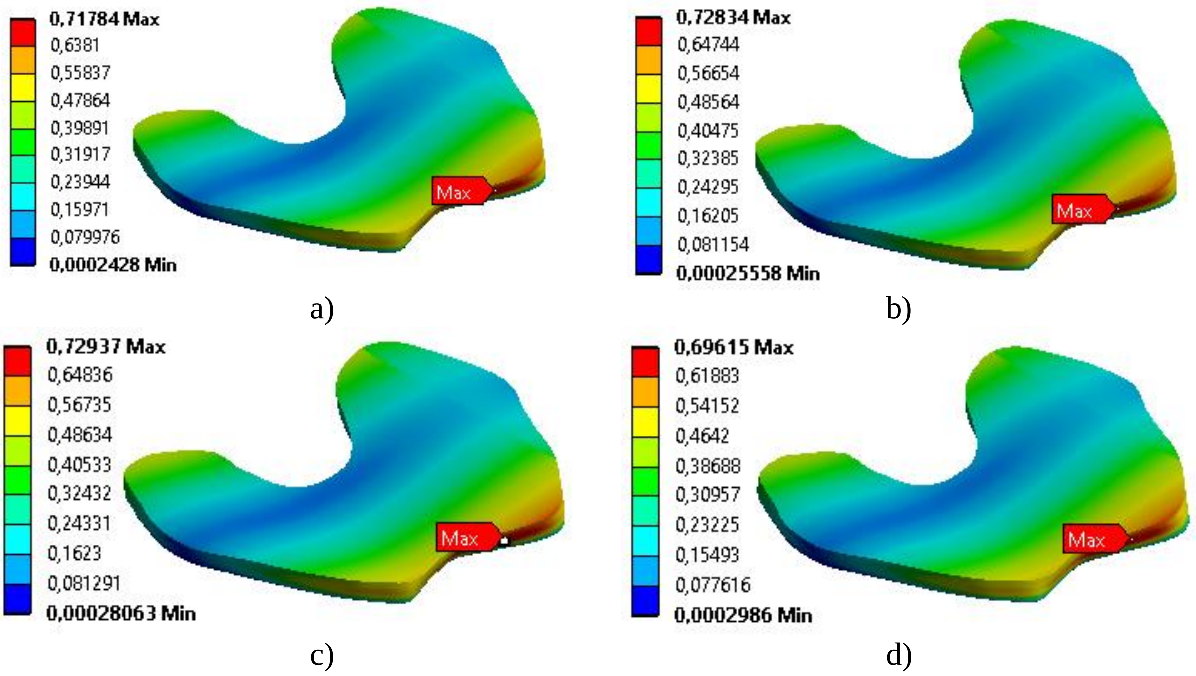

Figure 7. Deformation values occurring at different configurations under the axial loading, a) Parallel K wires, b) Parallel screws, c) Upper K wire-Lower Screw, d) Upper Screw-Lower K wire

Table 6 and Table 7 show the contact pressure distributions of medial and lateral epiphyseal plates. The contact pressure values occurring in parallel screw configuration is found lower than other configurations for different loading conditions.

Table 6. Contact pressure of medial epiphyseal plate (MPa)

No	Fixation Type	Epiphyseal plate					
		Axial	Bending (Varus)	Bending (Valgus)	Bending (Anterior)	Bending (Posterior)	Torsional
1	Parallel K wires	8,57	1,69	3,04	3,41	2,24	0,13
2	Parallel Screw	8,10	1,56	1,24	1,82	1,59	0,13
3	Upper K wire-Lower Screw	11,35	1,57	1,25	1,84	1,72	0,13
4	Upper Screw-Lower K wire	8,93	1,78	1,20	2,22	1,61	0,14

Table 7. Contact pressure of lateral epiphyseal plate (MPa)

No	Fixation Type	Epiphyseal plate					
		Axial	Bending (Varus)	Bending (Valgus)	Bending (Anterior)	Bending (Posterior)	Torsional
1	Parallel K wires	32	2,96	3,07	2,21	5,20	0,10
2	Parallel Screw	8,02	0,10	2,80	1,37	0,62	0,10
3	Upper K wire-Lower Screw	16,19	0,10	2,89	1,37	0,73	0,10
4	Upper Screw-Lower K wire	8,43	0,19	2,85	1,44	0,69	0,08

4. DISCUSSION

The Salter-Harris (SH) classification of growth plate injuries aids in estimating both the prognosis and the potential for growth disturbance [1, 30]. SH type 4 fractures are usually caused by axial loading or shear stress [31]. Intra-articular SH type 4 fractures are rare, carry a poor prognosis, and almost always need surgical reduction to prevent deformity [14]. In the treatment of femur distal epiphysis SH type 4 fractures, parallel screw or K wires between physis and joint can be used [10, 11, 16].However, there is no biomechanic evidence showing that which one is stronger in fracture stability in fixations done with screw or K wires. In addition, in these fixations, issue about in which technic stress load applied on the physis under force is less or more is still not very clear [17].In our study, when displacive forces reflected to fracture in physis line evaluated; the lowest stress values in axial forces in longitudinal plan were found by using parallel screw configuration in physis line. When we look at the literature there was no study about the physis after which fixation at which rate it was carrying the stress load [17].

If we think that the worst prognosis of epiphyseal fracture was oppression in physis line, we can think the worst configuration was the most axial stress in physis line [32]. Therefore, the parallel screw configuration has been found to have the best balancing advantages of minimal stress on the physis.The growth interruption may depend on the type of the fracture, or differences material used and also fizeal bar formation was said to be responsible from this conditions [11, 15]. Excessive stress on the physis can support bone formation. In our study, when displacive forces reflected to fracture in physis line evaluated; the highest stress values in axial forces in longitudinal plan were found by using parallel K wire configuration in physis line. In this study, the fixation shape of K wire on the upper and lower configuration was found to be disadvantageous compared to other fixation configurations in the SH type 4 epiphyseal fractures.In another paper by Gok et al [17], they have been found particularly advantageous to use fixation type in screw configurationin SH type 3 epiphyseal fracture.The distal epiphyseal fractures of femur have a high risk of especially growth delay and other morbidities [3-6]. There are some factors considered as the cause of this situation as follows. The age of the person, type of fracture, degree of shear, sinuous structure of physis, quality of fracture reduction process and fixation shape [7-10].Thereis no final proof of evidence or biomechanical research that highlight which factors were effective in the formation of iatrogenic epiphysiodesis (bar formation and consequently growth interruption) in this area [17]. In contrast, in many studies growth retards was related to the fracture fixation of this type of fracture [33].According to our results, it has been found particularly advantageous to use fixation type in parallel screw configuration.

The most important point in the treatment of the bone fractures is the elimination of the stress shielding [34]. The event that implant undertakes to carry the load on the structure, that is, the stresses and deformations occurring in the bone callus structure are reduced and the weakening of the bone is called the stress shielding effect [34-36]. It is suggested that this effect should be kept to a minimum for the healing process not to be delayed. However, in the initial stages of the healing process, bone implant structure is required to be sufficiently strong in contrast to this condition[34].

5.CONCLUSION

In this study, the biomechanical behaviors of four different configurations (K wire, screw) used for stabilization after reduction in SH type 4 epiphyseal fracture of distal femur under axial, rotational and bending forces on epiphyseal plate are investigated, and we tried to find out which of the configurations is more advantageous to use.According to our results, it has been found particularly advantageous to use fixation type in parallel screw configuration. In addition, in SH type 4 epiphyseal fracture, fixation type is found to be disadvantageous in K wire configuration. The contact pressure values occurring in parallel screw configuration is found lower than other configurations for different loading conditions.

Conflict of interest

There is no conflict of interest.

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REFERENCES

[1] SALTER RB, HARRIS WR. "Injuries Involving the Epiphyseal Plate", ***JBJS***, 45(3): 587-622, (1963)

[2] Sferopoulos NK. "The Classification of Physeal Injuries", ***ARC Journal of Orthopedics*** 1(1): 23-7, (2016)

[3] D.C. Mann , Rajmaira S. "Distribution of physeal and nonphyseal fractures in 2,650 long-bone fractures in children aged 0-16 years", ***J Pediatr Orthoped***, 10(6): 713-6, (1990)

[4] Peterson HA, Madhok R BJ, Ilstrup DM, Melton LJ. "Physeal fractures: Part 1. Epidemiology in Olmsted County, Minnesota, 1979-1988", ***J Pediatr Orthoped***, 14(4): 423-30, (1994)

[5] Basener CJ, Mehlman CT, TG D. "Growth disturbance after distal femoral growth plate fractures in children: a meta-analysis", ***J Orthop Trauma***, 23(9): 663-7, (2009)

[6] Eid AM, Hafez MA. "Traumatic injuries of the distal femoral physis. Retrospective study on 151 cases", ***Injury***, 33(3): 251-5, (2002)

[7] Dahl WJ, Silva S, Vanderhave KL. "Distal Femoral Physeal Fixation: Are Smooth Pins Really Safe?", ***J Pediatr Orthoped***, 34(2): 134-8 10.1097/BPO.0000000000000083, (2014)

[8] Liu RW, Armstrong DG, Levine AD, Gilmore A, Thompson GH, Cooperman DR. "An Anatomic Study of the Distal Femoral Epiphysis", ***J Pediatr Orthoped***, 33(7): 743-9 10.1097/BPO.0b013e31829d55bf, (2013)

[9] Lombardo S, Harvey JJ. "Fractures of the distal femoral epiphyses. Factors influencing prognosis: a review of thirty-four cases", ***JBJS***, 59(6): 742-51, (1977)

[10] Beaty JH, Rockwood CA, Kasser JR. *Rockwood and Wilkins' Fractures in Children*: Wolters Kluwer/Lippincott, Williams & Wilkins, 2010.

[11] JA. H. Lower extremity injuries. *Tachdjian's Pediatric Orthopaedics*: USA: W.B. Saunders Company, 2002, p. 2327-34.

[12] Garcés GL, Mugica-Garay I, López-González Coviella N, E G. "Growth-plate modifications after drilling", ***J Pediatr Orthop*** 14(2): 225-8, (1994)

[13] Janarv P-M, Wikström B, Hirsch G. "The Influence of Transphyseal Drilling and Tendon Grafting on Bone Growth: An Experimental Study in the Rabbit", ***J Pediatr Orthoped***, 18(2): 149-54, (1998)

[14] Buch BD, Myerson MS. "Salter-Harris type IV epiphyseal fracture of the proximal phalanx of the great toe: a case report", ***Foot & ankle international***, 16(4): 216-9, (1995)

[15] Zionts. LE. Fractures and dislocations about the knee. *Skeletal Trauma in Children*: USA: Saunders, 2003, p. 443-9.

[16] http://www.wheelessonline.com/. 2014.

[17] Gok K, Inal S, Gok A, Pinar AM. "Biomechanical effects of three different configurations in Salter Harris type 3 distal femoral epiphyseal fractures", ***Journal of the Brazilian Society of Mechanical Sciences and Engineering***, 39(4): 1069-77, (2017)

[18] Gok K, Inal S, Gok A, Pinar AM. "Biomechanical effects of three different configurations in Salter Harris type 3 distal femoral epiphyseal fractures", ***Journal of the Brazilian Society of Mechanical Sciences and Engineering***, 1-9, (2016)

[19] Gok K. "Development of three-dimensional finite element model to calculate the turning processing parameters in turning operations", ***Measurement***, 75(57-68, (2015)

[20] Inal S, Taspinar F, Gulbandilar E, Gok K. "Comparison of the biomechanical effects of pertrochanteric fixator and dynamic hip screw on an intertrochanteric femoral fracture using the finite element method", ***The International Journal of Medical Robotics and Computer Assisted Surgery***, 11(1): 95-103, (2015)

[21] ERDEM M, GOK K, GOKCE B, GOK A. "NUMERICAL ANALYSIS OF TEMPERATURE, SCREWING MOMENT AND THRUST FORCE USING FINITE ELEMENT METHOD IN BONE SCREWING PROCESS", ***Journal of Mechanics in Medicine and Biology***, 1750016, (2016)

[22] Gok A, Inal S, Taspinar F, Gulbandilar E, Gok K. "Fatigue behaviors of different materials for schanz screws in femoral fracture model using finite element analysis", ***Optoelectroin and Adv Mater Rapid Commun***, 8(5-6): 576-80, (2014)

[23] Afsar E, Taspinar F, Calik BB, Ozkan Y, Gok K. "Use of the finite element analysis to determine stresses in the knee joints of osteoarthritis patients with different Q angles", ***Journal of the Brazilian Society of Mechanical Sciences and Engineering***, 1-7, (2016)

[24] Gok K, Taspinar F, Inal S, Gulbandilar E. "IMPORTANCE OF SIDEBAR-BONE SPACING DURING THE APPLICATION OF PERTROCHANTERIC FIXATOR ON FEMORAL INTERTROCHANTERIC FRACTURE MODEL; COMPARISON OF THE BIOMECHANICAL EFFECTS USING FINITE ELEMENT METHOD", ***Biomedical Engineering: Applications, Basis and Communications***, 27(03): 1550030, (2015)

[25] Goffin JM, Pankaj P, Simpson AH. "The importance of lag screw position for the stabilization of trochanteric fractures with a sliding hip screw: A subject-specific finite element study", ***J Orthopaed Res***, 31(4): 596-600, (2013)

[26] Atmaca H, Kesemenli C, Memişoğlu K, Özkan A, Celik Y. "Changes in the loading of tibial articular cartilage following medial meniscectomy: a finite element analysis study", ***Knee Surg Sports Traumatol Arthrosc***, 21(12): 2667-73, (2013)

[27] AnsysWorkbench. Material Library. 2014.

[28] Yuan-Kun T, Yau-Chia L, Wen-Jen Y, et al. Temperature Rise Simulation During a Kirschner Pin Drilling in Bone. *Bioinformatics and Biomedical Engineering , 2009 ICBBE 2009 3rd International Conference on*. Beijing 2009, p. 1-4.

[29] Peña E, Calvo B, Martínez MA, Palanca D, Doblaré M. "Finite element analysis of the effect of meniscal tears and meniscectomies on human knee biomechanics", ***Clin Biomech***, 20(5): 498-507, (2005)

[30] Brown JH, DeLuca SA. "Growth plate injuries: Salter-Harris classification.", ***American Family Physician*** 46(4): 1180-4, (1992)

[31] Eiff MP, Hatch R, Calmbach WL. *Fracture Management for Primary Care*: Saunders, 1998.

[32] SEYHAN F, GÖKSAN SB. Çocuk Kırıkları. *Ortopedik Travmatoloji*: Nobel Tıp Kitabevleri 89-101, (2002).

[33] Wall EJ, May MM. "Growth plate fractures of the distal femur", ***Journal of Pediatric Orthopaedics***, 32(S40-S6, (2012)

[34] Çelik A, Kovacı H, Saka G, Kaymaz İ. "Numerical investigation of mechanical effects caused by various fixation positions on a new radius intramedullary nail", ***Computer Methods in Biomechanics and Biomedical Engineering***, 18(3): 316-24, (2015)

[35] Kujala S, Ryhänen J, Jämsä T, et al. "Bone modeling controlled by a nickel–titanium shape memory alloy intramedullary nail", ***Biomaterials***, 23(12): 2535-43, (2002)

[36] Cheung G, Zalzal P, Bhandari M, Spelt JK, Papini M. "Finite element analysis of a femoral retrograde intramedullary nail subject to gait loading", ***Medical Engineering & Physics***, 26(2): 93-108, (2004)