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Evaluation of Graft Harvesting Operations from Anterior and Posterior Iliac Donor Sites by Finite Element Analysis

Abdullah Tahir ŞENSOY[1], İsmail Hakkı KORKMAZ[2], Fatih MEDETALİBEYOĞLU[3], İrfan KAYMAZ[4]

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Öz

Greft donör bölgeleri, kemik rezervi ve fonksiyonel açıdan değerlendirildiğinde iliak bölgesi öne çıkmaktadır. Ancak, çeşitli iliak donör bölgelerinden gerçekleştirilen greft alım operasyonlarında karşılaşılan komplikasyonlar birçok araştırmacı tarafından raporlanmıştır. Bu komplikasyonları azaltmak, operasyon başarısını artırmak veya iliak bölgeyi biyomekanik açıdan derinlemesine tahlil etmek amacıyla literatürde çok sayıda modelleme ve Sonlu Elemanlar Analizi (SEA) çalışması gerçekleştirilmiştir. Ancak, anterior ve posterior iliak greft alımı cerrahi operasyonlarının biyomekanik açıdan karşılaştırılması literatürdeki eksiklerdendir. Bu çalışmanın amacı anterior ve posterior iliak donör bölgelerinden yapılan cerrahi operasyonların, hacim analizi ile sundukları kemik rezervi açısından ve SEA ile biyomekanik açıdan karşılaştırılmasıdır. Çalışmanın sonuçlarına göre, posterior iliak greft alımı, anterior operasyona göre %264 daha fazla trabeküler kemik rezervi sağlamaktadır. Bununla birlikte, kortikal kemik için bu oran %132'dir. Modeller biyomekanik açıdan karşılaştırıldığında ise, anterior osteotomi modelinde, posterior osteotomi modeline kıyasla %8,6 daha fazla maksimum von Mises gerilmesi elde edilmiştir. Elde edilen bulgular, posterior greft alımı operasyonunun morbidite oranı, eklem kırık riski ve greft rezervi açısından avantaj sunduğunu, anterior greft alımının ise eklem stabilitesi ve operasyon kolaylığı açısından tercih edilebileceğini göstermektedir.Ancak; alınan greft miktarı, hastanın kemik kalitesi, anatomik farklılıklar, yaş ve cinsiyet gibi faktörler, elde edilen sonuçları etkileyeceğinden, modelleme ve analizlerin hastaya özel olarak gerçekleştirilmesinin operasyon başarısını artıracağı değerlendirilmektedir.

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Abstract

When the graft donor areas are evaluated in terms of bone reserve and functional aspects, it can be said that the iliac site has outstanding properties. However, complications of graft harvesting operations performed from various iliac donor sites have been reported by many researchers. Numerous studies have been carried out in the literature to reduce these complications, and to increase the success of the operation. However, biomechanical comparison of anterior and posterior iliac graft

[1] Samsun University, Faculty of Eng., Dept. of Biomedical Engineering-Samsun/Turkey; e-mail: tahir.sensoy@samsun.edu.tr ; ORCID: 0000-0002-9371-8307 (Corresponding author)

[2] Erzurum Technical University, Faculty of Eng., Dept. of Mechanical Engineering-Erzurum/Turkey; e-mail: ismail.korkmaz@erzurum.edu.tr ORCID: 0000-0003-2440-0319

[3] Kafkas University, Faculty of Eng., Dept. of Mechanical Engineering-Kars/Turkey; e-mail: falibeyoglu@gmail.com; ORCID: 0000-0002-0323-3630

[4] Erzurum Technical University, Faculty of Eng., Dept. of Mechanical Engineering-Erzurum/Turkey; e-mail: irfan.kaymaz@erzurum.edu.tr

ORCID: 0000-0002-9391-7218

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harvesting operations is one of the gaps in the literature. This study aims to assess both biomechanical behavior and bone graft reserve comparison of the two surgical operation alternatives. According to the FEA results of the study, posterior iliac graft harvesting provides 264% more trabecular bone reserve than anterior operation. However, this rate is 132% for cortical bone. When the models are compared, anterior osteotomy model has a 8.6% higher von Mises strain compared to the posterior osteotomy model. Results of the present study has shown that the region with the highest stress value in the cortical bone is the sacroiliac joint for both models. While posterior graft harvesting operation offers advantages in terms of morbidity rate, joint fracture risk and graft reserve, anterior operation can be preferred in terms of operational ease and the sacroiliac joint stability. However, since results obtained may be affected by the factors such as the amount of graft harvested, the patient's bone quality, anatomical differences, age and gender, it has been evaluated that the success of the operation may be enhanced by carrying out a patient-specific approach for modeling and analysis steps.

1. INTRODUCTION

Bone graft harvesting is a frequently used method for maxillofacial surgery and orthopaedic applications. If the adequate bone volume does not exist for dental implant fixation, harvested bone is used for reconstruction before the operation. Orthopaedic operations are other common usage areas of autologous bone transplantation in order to recover bone injuries. For the aforementioned surgical applications, the iliac crest is one of the most preferred regions due to its large trabecular bone reserve. There are two main options for iliac crest harvesting operations where can be from anterior and posterior sites. However, in the existing literature, many intraoperative and postoperative complications have been reported. It had been reported in a case report presented on iliac crest harvesting that iliac vessel injury was occurred due to the dislodgement of soft tissue retractor (Escalas & Dewald, 1977). In another study presented on the comparison of different graft reserve sites in terms of early postoperative complications, it was reported that iliac bone harvesting had shown more risk than of the rib. In intraoperative and early postoperative stages, complications such as gait disorders, more blood loss, and longer painful period were reported for iliac crest harvesting. However, even these complications, the iliac crest is one of the most popular bone harvesting sites due to its large trabecular bone reserve. Additionally, it was also documented that iliac graft harvesting showed much more advantages considering the late postoperative period (Laurie et al., 1984). Even though iliac crest bone harvesting is a frequently applied technique, it causes some serious problems such as pain, nerve and arterial injury, cosmetic deformity, blood loss and infection (Kurz et al., 1989). It was reported that the high complication rate of iliac harvesting (varies between 9.4% and 49%) could be reduced by developing a surgery protocol (Banwart et al., 1995). These complications can be mainly classified as posterior and anterior. The complications of posterior iliac graft harvesting had been reported as local hematoma, severe retroperitoneal blood loss, superficial infection and osteomyelitis, bowel hernia and perforation, sacro-iliac joint instability, ectopic bone formation, arterial and nerve injuries, etc. On the other hand, drawbacks of anterior graft operation had been documented as herniation of muscle and abdominal tissues,heterotropic bone formation, ilium fracture, pain, infection, etc.(Dosoglu et al., 1998). In the literature, some limits have been suggested in terms of graft harvesting operations. Anterior Superior Iliac Spine (ASIS) and Posterior Superior Iliac Spine (PSIS) points are two main references which are recommended for anterior and posterior operations, respectively (Kilinc et al., 2017). These reference points are of great importance in order to provide adequate distance between the osteotomy line and bone surface. In the posterior region where the iliac graft harvesting is mostly preferred, it has been stated that the sacro-iliac joint should not be damaged during the operation which causes decrease in stability of the pelvis. However, over-harvesting from the posterior region may cause pelvic instability due to ligament damage. Thus, pelvis fracture risk increases (Chan et al., 2001). In a clinical study, approximately one third of 92 patients who underwent iliac graft harvesting operation reported their complaints and minimally invasive surgery had been recommended by planning the osteotomy (Hill et al., 1999). It has been reported that the periosteum and muscle joints are exposed to a considerable dissection in the conventional iliac graft harvesting operations, and complications can be significantly reduced via less invasive methods such as trephine and bone abrasion techniques (Abdulrazaq et al., 2015; Burstein et al., 2000). In another study conducted on minimally invasive surgical techniques, it has been reported that it is necessary to improve surgical equipments in terms of clinical use (Steffen et al., 2000).

There are many finite element studies on this subject in the literature. Kawahara et al. (2003) applied 480 N vertical force to the half of the upper surface of the L3 vertebra in the spinopelvic finite element semi-model, and performed the analyzes by fixing it from the lower part of the pelvis. In another study, the effect of synovial state on force transmission in the sacroiliac joint was investigated using a FEA model fixed from the distal femur and 500 N force applied from the upper surface of the L3 vertebra. It was reported that to synovial state is a very effective factor (Shi et al., 2014). In another study related to the hip joint, the hemi-pelvis model was limited from the midline and fixed from the upper part, and analyzes were performed by applying hip force (Bachtar et al., 2006). In a Finite Element Model (SEM) established on the proximal femur and acetabulum, the ligaments were defined as spring elements and the model was fixed from the upper part and loaded from the femur shaft (Rudman et al., 2006). In a study showing that the boundary conditions significantly affect the FEA results, the behavior of the model was compared.under free and fixed boundary conditions of the ligaments (Li et al., 2007). Clinical and theoretical comparison of sacral fractures was made using the model in which force is applied from the upper part of the sacrum by fixing bilaterally from the acetabulum. Limitations of the study were noted as asymmetrical hip anatomy and neglected asymmetry-based muscle abnormalities (Linstrom et al., 2009). In the study on the application of cemented acetabular prostheses to the patient-specific pelvis bone, the pelvis was fixed from the upper part and hip force was applied (Zhang et al., 2010). It was noted that for FEM, where hip forces act through the acetabulum and are fixed from the upper part of the sacrum, the material properties should be determined individually and the forces that may cause pelvic fractures due to instability should be investigated (Bohme et al., 2012). In another study in which similar boundary conditions were preferred, a more detailed model was established by defining the ligaments. However, as the limitations, it was reported that the geometry and material properties of the pelvis and ligaments were modeled for a single situation, parametric studies were needed, and bone cartilage and ligament material properties were accepted as linear-elastic (Bohme et al., 2014). In a study where FEM boundary conditions were created by fixing the Distal Femur and by applying 600 N load to the upper surface of the Sacrum, pelvic fractures were theoretically evaluated and the importance of pelvic stability was emphasized (Lei et al., 2015).In a finite element study involving femoral and pelvis models, it was reported that small changes in the femoral neck angle can increase the loads balanced by the hip joint cartilage (Egea et al., 2014). It was stated that the method developed in the study, which was obtained with the mapping technique of the personal pelvis model without segmentation, was effective and reliable. As the boundary conditions, different forces were applied to the L5 vertebra from its upper surface (65 N, 115 N, 230 N, and 345 N) and the distal femur was fixed. The friction force between the femoral head and acetabular cartilage has been determined to be 0.01 (Salo et al., 2015).In a finite element study examining the effect of different boundary conditions on pelvic load transfer, the model with synovial connections (cartilages) and femoral contact yielded more realistic results compared to other simplified models, but the absence of muscle elements was the main limitation of the study (Hu et al., 2017). Although there are studies in the literature in which the lower extremity was completely modeled (Filardi, 2015; Mo et al., 2017), simpler models were mostly established and the boundary conditions were achieved by fixing the sacro-iliac and pubic joints (Cardiff et al., 2014; Hsu et al., 2007; Hsu et al., 2006; Liu et al., 2015; Mircheski & Gradisar, 2016; Nie et al., 2014; Phillips et al., 2006; Phillips et al., 2007).

However, in finite element studies conducted on the iliac bone, it is seen that the FEA boundary conditions used for the pelvic region vary. While some studies have established more detailed models in which many tissues interact, some publications have required the use of simpler models and boundary conditions for various reasons. Although certain simplifications are made in determining the FEM and boundary conditions, virtual surgery simulations should be specifically evaluated for each patient using comparative studies considering clinical issues. In this study, the mechanical behavior of the two different iliac harvesting surgery methods (anterior and posterior) was compared using Finite Element analysis and clinical recommendations were made according to the results obtained.

2. MATERIAL AND METHOD

Biomedical Modelling

Artificial hemi-pelvis bone was used in this study. Computed tomography (CT) images of the hemi-pelvis bone to be grafted were obtained in DICOM format and transferred to MIMICS 21.0 (Materialise, Leuven, Belgium) program. Three-dimensional models of cortical and trabecular bones were created by processing medical images (Figure 1.a, b). Then, virtual surgical simulations of anterior and posterior graft osteotomies were performed (Figure 1.c, d).

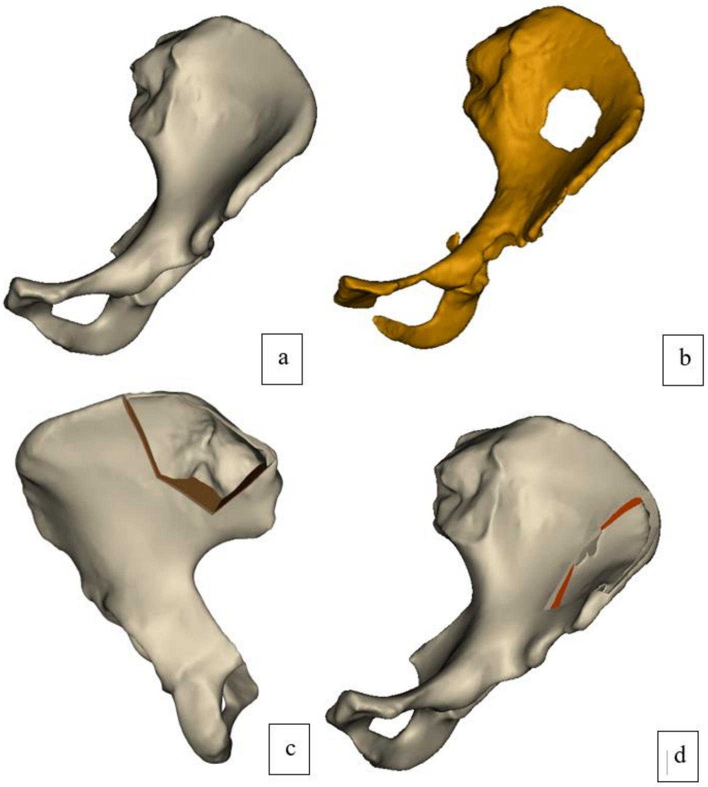

Figure 1. Hemi-pelvis bone model (a)Cortical bone (b)Trabecular bone (c)Posterior iliac graft harvested model (d)Anterior iliac graft harvested model

Finite Element Model

For the trabecular and cortical layers of the anterior and posterior models with virtual surgery, a volumetric mesh was constructed in the 3-Matic program and saved in *.cdb format. The volumetric mesh files were assembled in ANSYS FE modeler module, the regions where the boundary conditions will be applied were created as separate surfaces and the final geometry was obtained. The bone material properties are defined as linear isotropic by transferring the model to ANSYS "Static Structural" module. Elasticity modulus (E) and Poisson ratio (v) values were calculated as 15.1 GPa and 0.3 for the cortical segment, respectively, considering different values in the literature; for trabecular bone, it was accepted as 0.445 GPa and 0.22 (Cai et al., 2020; Guo & Li, 2020; Song et al., 2016). Anterior and posterior models have 407530 and 307191 10-node regular tetrahedral element (SOLID 187), respectively. The skewness ratio was obtained as 0.25 and 0.29 for the models, respectively. With reference to the many studies in the literature, the boundary conditions were applied by fixing the sacroiliac and pubic joints (Hsu et al., 2007; Hsu et al., 2006; Liu et al., 2015; Phillips et al., 2006; Phillips et al., 2007), and applying the average hip joint strength to 2236 N (Bergmann et al., 2016).

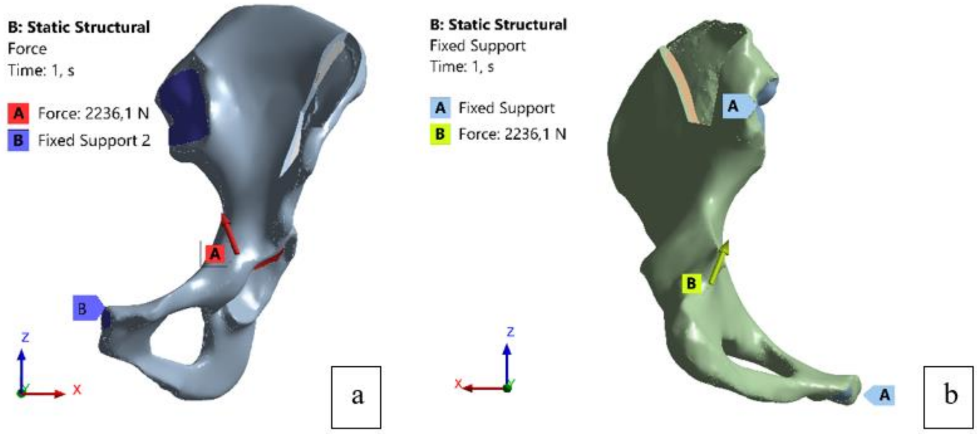

Figure 2. Boundary conditions of Finite Element Models (a)Anterior Osteotomy Model (b)Posterior Osteotomy Model

3. THE RESEARCH FINDINGS AND DISCUSSION

The bone volume amounts obtained as a result of virtual bone graft removal are given in Table 1. According to the results, the total amount of grafts taken for anterior and posterior osteotomy was calculated as 18.81 ml and 60.03 ml, respectively. In both models, the trabecular bone reserve is greater than the cortical bone. In addition, the trabecular bone obtained as a result of posterior osteotomy offers 264% more reserve compared to the other model. For the cortical bone, this rate was calculated as 132%.

Table 1. Graft Amounts Harvested From Anterior and Posterior Osteotomies

	Bone Volume (cm^3)	
	Anterior Osteotomy	Posterior Osteotomy
Cortical Bone	6,02	14,01
Trabecular Bone	12,61	46,02

According to Finite Element Analysis (FEA) results, when the stress values in the cortical bone in the models applied with the same boundary conditions were examined, it is seen (in Figure 3. a,b) that the anterior osteotomy model (AOM) has shown 8.6% more maximum von Mises stress value compared to the posterior osteotomy model (POM). However, the opposite is true in trabecular bone. The AOM has shown 48.57% less maximum von Mises stress in trabecular bone compared to the POM (Figure 3. c,d).

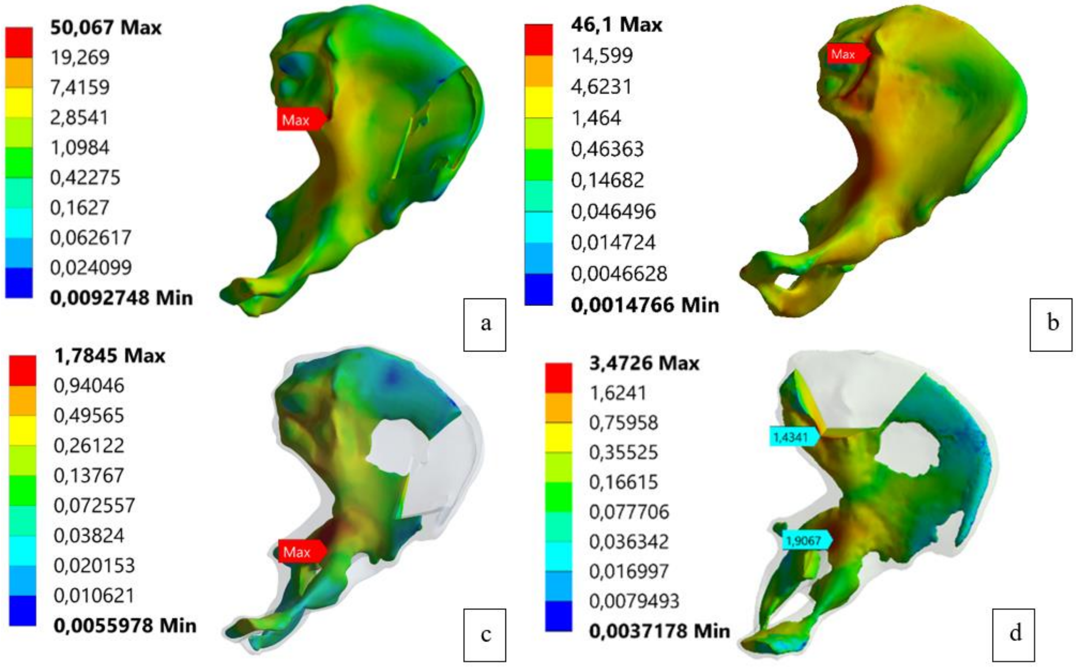

Figure 3. Von Mises stress distribution of cortical and trabecular bones (a,c) Anterior Osteotomy Model, (b,d) Posterior Osteotomy Model

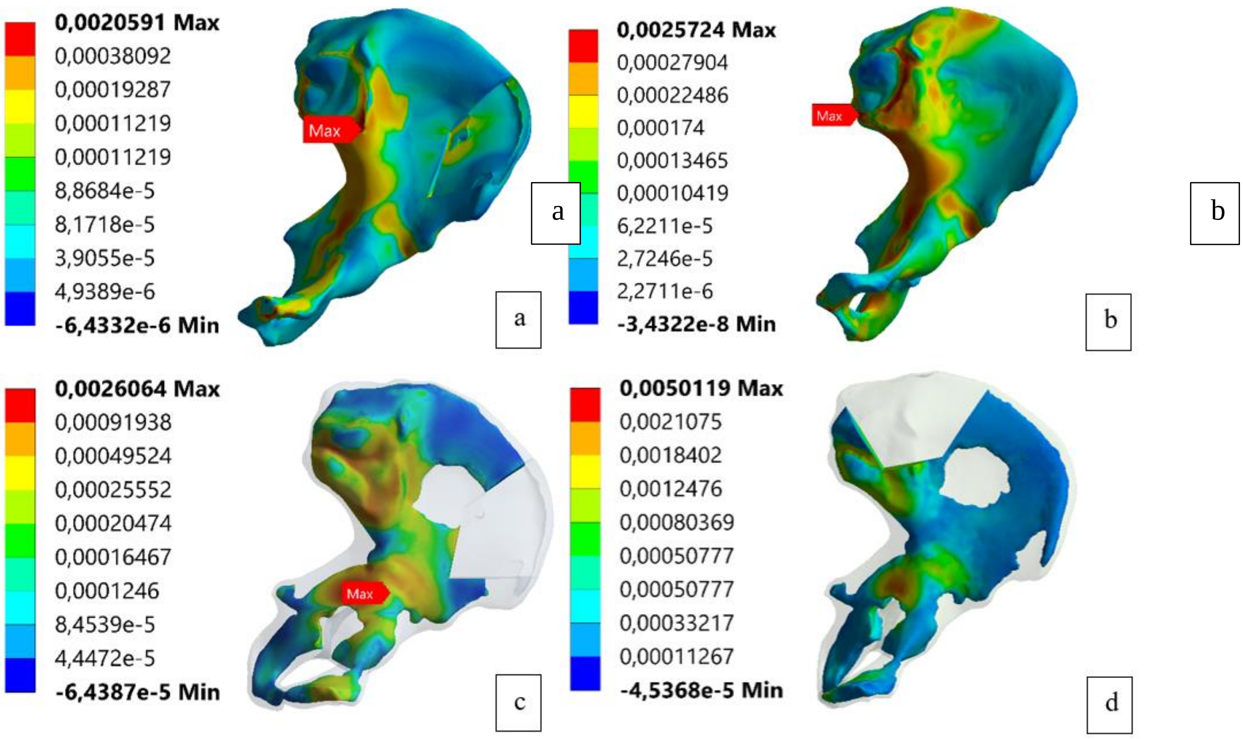

Figure 4. Principal strain distribution of cortical and trabecular bones (a,c) Anterior Osteotomy Model, (b,d) Posterior Osteotomy

When the models were examined in terms of maximum principal strains, its value in cortical bone in AOM was obtained as 2059.1 με, while it was found as 2572.4 με in POM. The maximum principal unit shape change values obtained in trabecular bone were 2606.4 με and 5011.1 με, respectively.

More accessibility of the anterior iliac crest may be a reason for preference, but it has been reported in the literature that the morbidity rate in the anterior donor site is higher than the posterior donor site and the posterior graft harvesting carries less risk of complications (Ahlmann et al., 2002; Kessler et al., 2005). The findings obtained within the scope of this study support these reports. In both models, the region with the highest stress value in the cortical bone is the sacroiliac joint. This can be explained by joint fracture, which is a complication of iliac graft operation (Suda et al., 2019). In addition, it can be said that osteotomy planes are associated with the possibility of damage in terms of intersection points. Especially, these intersection lines to be obtained close to the ASIS and PSIS references include stress concentrations and increase the probability of damage. On the other hand, in terms of maximum principal unit shape changes, values obtained in the same region can be associated with sacroiliac joint instability (COVENTRY & TAPPER, 1972). Pain, a common postoperative complication (Cansiz et al., 2019; Kono et al., 2018), can be reduced by reconstructing the graft site with bone cement (Zhang et al., 2018).

Since the study is conducted under certain constraints, a more comprehensive biomedical model can increase the sensitivity of the results obtained. Using the references of the biomechanical studies in the literature (Henyš & Čapek, 2019; Sensoy et al., 2018; Şensoy et al., 2019; Şensoy et al., 2020; Wang et al., 2019) the bone material model used in this study assumed as linear isotropic and homogeneous, which is one of the limitations in the present study. Another limitation is the absence of a soft tissue model and direct application of muscle strength to the model. In future studies, establishing the material model as heterogeneous and anisotropic (Enns-Bray et al., 2016; Guo & Li, 2020; Kharmanda et al., 2020; Latypova et al., 2017) will better reflect the actual tissue properties of the patient, thus the accuracy of the results can be increased. Since the results obtained will be affected by factors such as the amount of grafts harvested, the bone quality of the person, anatomical differences, age and gender, it is considered that the success of the operation can be increased patient-specific modeling, patient-specific virtual surgery as well as the patient-specific FEA. On the other hand, the osteotomy guideline-assisted surgical approach suggested in the literature for different anatomical regions (Sensoy et al., 2018; Zhang et al., 2019) can also be applied for this operation. Therefore, the minimally invasive operation to be performed can reduce the pain and the risk of pelvic fracture after the operation. In future studies, considering the aforementioned limitations and the actual surgical facts, it is planned to evaluate the proposed osteotomy guideline-supported graft operation with FEA, both with in-vitro experiments.

4. RECOMMENDATIONS

When anterior and posterior osteotomy alternatives are evaluated, it is seen that both methods have prominent advantages and risks. While anterior graft removal offers advantages in terms of ease of operation and joint stability, posterior graft removal operation can be preferred in terms of joint fracture risk and graft reserve. ASIS and PSIS reference points play an important role in relation to the amount of graft to be used in this choice. Because the osteotomy starting point, which can be preferred close to these points, will cause the iliac bone to be damaged by the inguinal and iliolumbar ligaments. However, since the operations are performed individually, the geometry of the incision line and the amount of grafts taken are parameters that can affect the results. Here, determining the method with minimum risk for the patient as a result of personal analyzes may be an approach that increases the success of the operation. In addition, since the presence of sharp edges at the intersection areas of the osteotomy plane causes stress accumulation, obtaining the corner regions in curvilinear form with a personalized surgical guide in these areas may be an approach to reduce the risk of fracture.

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