Analysis of Biomechanical Functions of Non-Integrated Blade Plate: Finite Element Analysis

Abstract

Background: Axis deviation along a healthy bone is a common complication in orthopedic patients. Varus and Valgus angulation is one such deviation in the knee that may necessitate surgery with osteotomy and correct the deformity and fixation of the bone in its new position. There are numerous methods for osteotomy fixation The femoral valgus is typically located in the distal femur and is corrected via supracondylar osteotomy. The optimal fixation technique is debatable and is dependent on the device's ease and comfort of use. Historically, the blade plate has been an appealing option for fixation, although it may be more challenging for less-experienced surgeons. This study aims to redesign the blade plate with simplified instrumentation and evaluate it using finite element analysis to ensure the new device's effectiveness. The objective is to design a modular blade plate and compare its biomechanics to a conventional blade plate using finite elements. This paper aims to compare the biomechanical behavior of the two methods under quasi-static loading using a finite element model.

Methods: The CT scan images of a 37-year-old man were used axially and processed using Mimics software. Then, using the Abaqus software environment (abaqus19.0), the model was subjected to quasi-static biomechanical analysis. The bone was considered orthotropic to achieve the real model's properties, and the implant was made of stainless steel.

Results: The resulting stress in the femur in the modular state was closer to the healthy leg without implants and less stress was observed in both femur and tibia.

Conclusion: Compared to the tension in the blade plate and bone, the modular blade type reduces stress on both the plate and bone. The modular blade plate exhibited significantly less strain than older blade plates. However, the strain on the bone was more comparable to the placement of previous blade plates without the implant.

Keywords Bone Plates, Finite element analysis, Genu varum, Genu Valgum, Internal Fixators

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Abstract

Deviations in the healthy bone extension are a frequent occurrence in orthopedic patients. Geno varum and Geno valgum are two of these disorders that are specifically related to the knee. There are several reasonably clear indications for correcting these problems, such as surgery with osteotomy, deformation and repositioning the bone. There are numerous techniques in this field in terms of surgery, osteotomy type, and fixation tool type. Geno valgum is typically a distal femur disorder that can be repaired through osteotomy. The best fixation technique has always been a point of contention, and the surgeon's ability and the ease with which the surgery tool can be located are critical factors in selecting the tool. Historically, a blade plate is an attractive option for fixation, but it is more complicated than newer methods such as lockable plaques, especially for less-experienced surgeons. This research aims to present a new blade plate design that can facilitate tool installation and test the finite element to ensure the new tool's effectiveness. This research aims to create a modular sample of blade plates and compare the biomechanical properties of these two states using finite element analysis. The biomechanical behavior of these two methods under pseudo-static loading on a model developed using finite element software was investigated in this study. CT-Scan of a 37-year-old man obtained the cited images to ensure that the modeling and simulation accurately represent the real anatomy of the location under study.

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Mimics software was used to convert the CT-Scan images. The model for biomechanical analysis was then placed in a pseudo-static form in abaqus19.0 software. The bone was considered orthotropic, and a stainless-steel implant was used to create a characteristically real model. When the tension of the blade plate is compared to that of the bone, the tension on the plaque and bone is reduced in the modular blade plate, which may be related to the energy wasted in connecting the blade and plate. The strain on the modular blade plate is significantly less than that on the previous plate, but the strain on the bone without orthosis is much more comparable to that on the previous one.

Introduction

Valgus and Varus deformations, or disproportionate and hyper rotation, are two typical deformations of the knee. Valgus is a type of disorder in the natural direction of the underlying limbs in which the knees approach each other and the ankles separate. Adults' knees naturally deviate inward by 1 to 9 degrees. Valgus refers to a knee deviation of more than 9 degrees, most of which are caused by femur distal bone damage. When the valgus is severe enough to cause pain for the patient, there will be some distal femur fractures. The femur distal breakings consist of the femur distal metaphase and the femur distal joint surface (1,2).

Setting the joint surface anatomically, establishing the proper direction of the limbs, and quickly handling the patient are effective ways to manage femur distal breakings. Despite advancements in techniques and tools, treating femur distal breakings remains a problematic issue. Long-term disability can occur due to severe soft tissue damage, extensive joint cartilage damage, or significant bone-crushing (3,4).

Various techniques for repairing these breaks have been proposed and implemented. The use of blade plates is one of these techniques. The next step is to determine the optimal method of repair and fixation with the least amount of soft tissue damage. Nowadays, it is recommended to use angled blade plates to stabilize the modification and strength of the bone at the proximal and distal humeral heads [5]. Access to the distal blade plates of the femur is possible at two angles of 95 and 130 degrees. The blade is precisely placed in three spatial directions in the Metaphysis-Epiphysis region, providing the device with high strength without removing the bone, and the side plate portion of the bone is modified (6).

The proper technique requires precise calculations regarding the operation at the time of hammering. Any calculation error or incorrect orientation of hammering in any spatial plan can result in the non-modification or creation of new deformations in the alignment of bones and joints. As a result, there is no need for replacement if the placement is incorrect, and a portion of its strength is lost at each stage. To this end, some blade plates are designed in this research with modular, rather than integrated, blade and plate components. The biomechanical functions of modular samples presented by common mechanisms were compared in this study using finite element analysis.

This research was conducted entirely through software, with no testing involving live people or animals.

Methods

Modeling and simulation were carried out as closely as possible to the actual anatomy of the foot. This is a subject that biomechanics researchers constantly consider. It is necessary to create geometric models of the knee bones for this model. CT-Scan images of a 37-year-old were used for this purpose. A total of 384 axial intersections were used to create these images, and the bones and soft tissues were separated before the processing was transferred to Mimics software (version 19.0) (7).

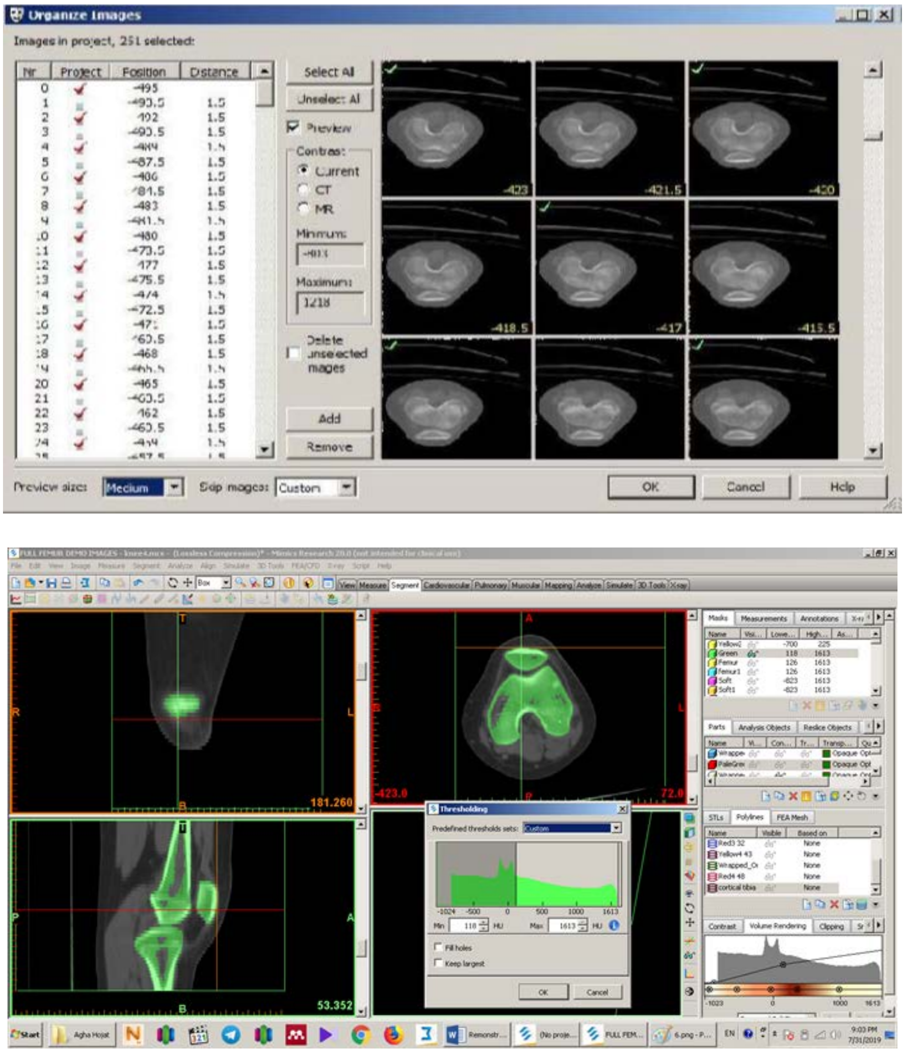


Figure 1. Geometric modeling in the Mimics software environment.

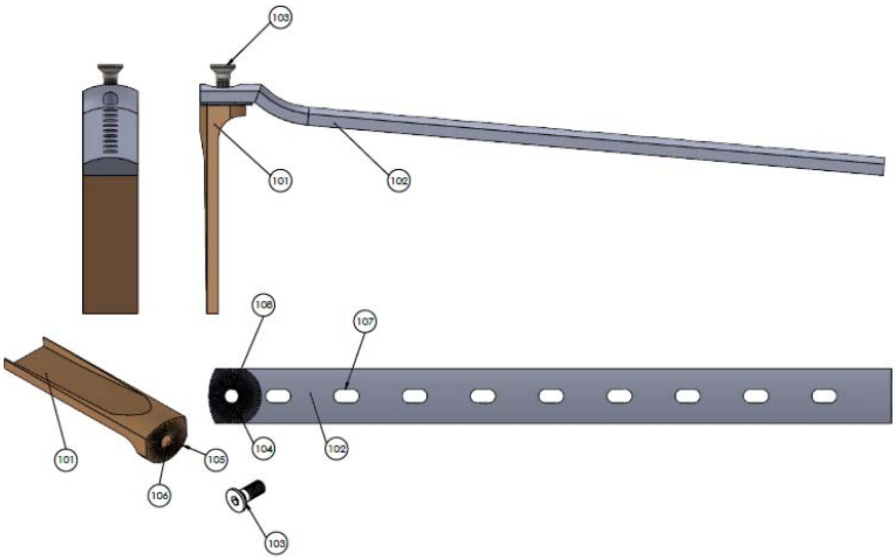


Figure 2. Design of the blade plate under consideration in this research using SolidWorks software (version 18.0).

Finally, the implant and bone were entered into the Abaqus software, and the commercial sample of blade plates and the modular sample were evaluated and compared using finite element analysis [9]. The elasticity of the cortical and spongy bone and orthotropic and hyperelasticity of the soft tissue are mechanical specifications, and the implant is made of stainless steel [10-12]. The analysis was performed as a pseudo-static load on the head of the proximal femur under the weight of a person weighing 69 kg. The resultant distribution of tension applied to the femur and tibia bones was calculated [13].

Results

According to the Abaqus software results, the resultant tension in the femur bone in the modular status is comparable to the tension in a healthy foot without an implant, and the tension in the femur and tibia is less than normal. The strain in the cortical bone integrated model is 5.1% greater than the strain in the modular model, 15% greater than the strain in the knee without any implant.

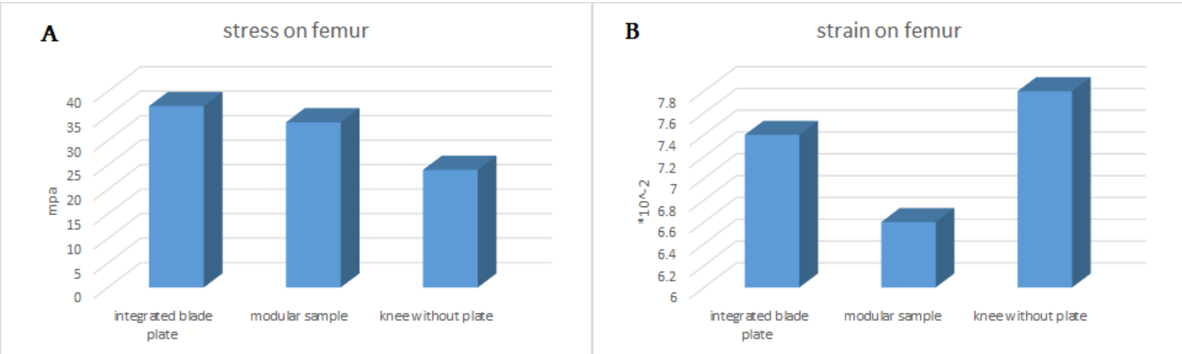


Figure 3. Comparison of tension and strain curves. A: stress on femur bone. B: strain on femur bone. According to the results of the curves, the integrated blade plate sample places the most stress on the femur, and the strain value in femur bone in the integrated blade plate sample is comparable to the without plate status.

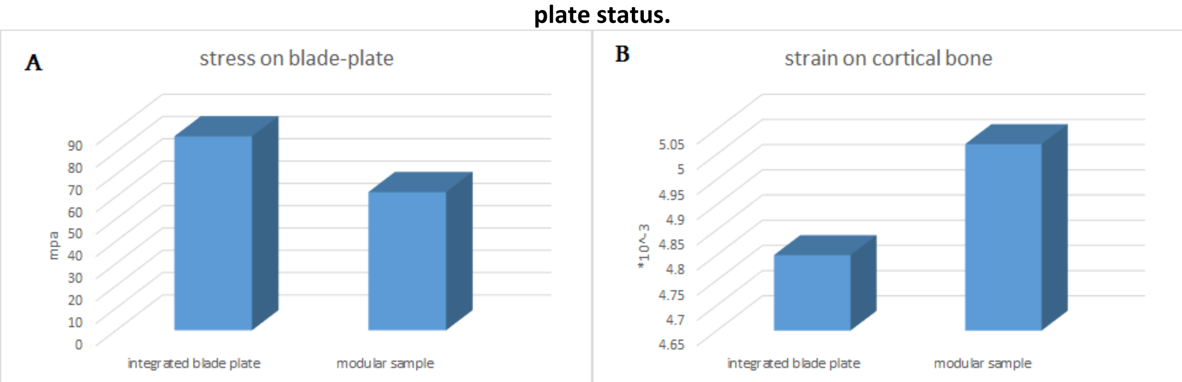


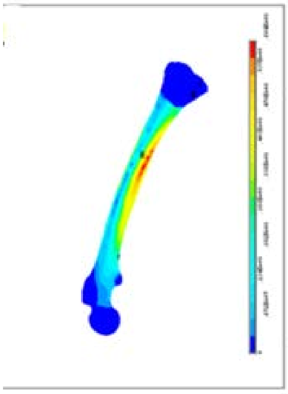
Figure 4. a: stress on the blade plate, b: strain in the blade plate. According to the results of the curves, the integrated blade plate sample exhibited the most significant amount of stress on the femur and blade plate.

Discussion

For many years, using blade plates has been one of the most effective methods for stabilizing distal and proximal femur osteotomies, demonstrating the practical effectiveness of this type of device for orthopedists. However, due to the challenges of resolving this issue and the difficult replacement technique for these devices, their use has gradually declined [14, 15]. In the comparison conducted in this research, we attempted to create a deformed shape for this device that is simple to use and reduces surgery time.

The purpose of studying tensions is to calculate a yielding safety factor. With the assumption that stability is greater than the safety factor, the tension was determined as a proxy for identifying the safety factor caused by the loads applied to the bones and implant to avoid reaching the yield point.

A healthy knee was loaded with an implant and compared to a previous study to evaluate the study's validity [13]. The pattern of tension distribution under similar loading was similar in both investigations, as demonstrated by the findings, and the maximum tension under similar loading (69 Kg) varied by approximately 2.3% (Figure 5).



Loading (Kg)	Max. Stress (Axial)-MPa	Max. Stress (Bending)-MPa
25	6.04	36.31
35	9.31	51.22
69	24.23	100.30*
150	36.41	217.93
250	60.01	363.11
414	99.83*	601.93
500	121.12	733.31

B

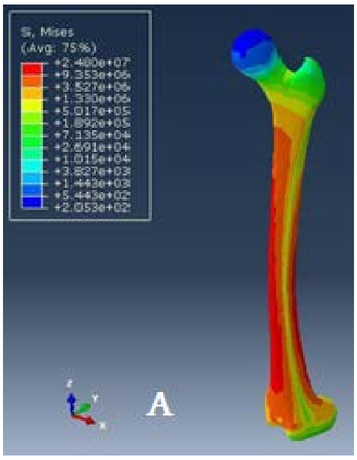


Figure 5. The validation of the research. A: The sample under study in the reference article b: The sample under study in the present study.

We assumed that when comparing the tensions in the blade plate and the bone, the maximum applied tension to the bone in both states is an index of the total applied tension to the bone in that state. The tension on both the plaque and the bone has been reduced in modular blade plates, possibly due to energy loss at the blade-plate joint. On the other hand, Von Mises's stress on the cortical bone of the modular model is only 4.1% greater than the cortical bone without a plaque. As a result, this is more appropriate than the integrated method (Figure 3, a & b).

When comparing the strains in the blade plate and bone, we assumed that the maximum applied strain to the bone in both states is an index of the total applied strain to the bone and blade plate in that state. The modular blade plate strain is significantly less than older blade plates, but the bone strain is more comparable to that of previously integrated blade plates. Thus, biomechanical tests should be used to determine the effectiveness of these devices. The integrated model is more accurate than the modular method, with a difference of 5.1% between the cortical without plaque and the cortical with plaque.

Recent studies [20] have assumed that bone is isotropic, and the role of muscle in loading has been overlooked. However, in the current study, bone and soft tissue were considered orthotropic, and the maximum axial tension was calculated with a 2.3 percent error compared to the previous study. This analysis was conducted statistically using the previously studied and validated issue. It is suggested that future research should be conducted dynamically. Given that the properties of soft tissues were considered hyperelastic in this study, it is proposed that it is preferable to study soft tissues as viscoelastic in order to obtain a more accurate representation of their actual properties.

It should be noted that we considered the biomechanical effects of the plaque's interaction with the physiologic structure and their impact on the mechanical parameters generated. In future studies, we can examine additional factors such as the effect of the interaction of soft tissue and muscular forces on the function of the plaques. It should be considered that this issue can significantly complicate modeling, with some aspects being impossible or challenging to access

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using existing facilities. However, due to the skeletal system's role in transporting a significant portion of the body's weight to the region under study, and the relatively small proportion of soft tissues and even muscular forces in the stable state in comparison to the majority of previous studies, the skeletal elements have been considered for avoiding the complexities above (12,13,21).

The safety factor of greater than three was determined through extensive calculation. Biomechanically, this safety factor is appropriate because it accounts for any increment caused by unknown loads. Thus, the possibility of failure in this region is close to zero in terms of the static solution. The study of fatigue and failure mechanisms under dynamic loading is not the purpose of this research, as this can be accomplished independently in other articles. However, it is worth noting that due to the low frequency of dynamic loading in the region as mentioned above, which is naturally caused by walking, this loading cannot be expected to have a significant effect on the calculated safety factor.

It should be noted that the integrated blade plate samples used today are not adjustable, which can delay the installation process and result in unintended injuries to the patient due to the repeated installation process required to align the blade with the patient's bone. Nonetheless, current research indicates that the blade portion can be adjusted on the plate implanted in the bone via a grooved connection, potentially avoiding additional injuries to the patient.

One of the limitations of current research is the absence of consideration of other factors, such as the effect of the interaction of soft tissue and muscular forces on the plaque's function. Additionally, we can consider the bone's viscoelastic properties and dynamic loading during various phases of walking to arrive at a more realistic model, which was not considered in this study.

This study demonstrates that the plaque's modular structure may facilitate placement during surgery. If biomechanical tests indicate that this device is superior to the previous blades, it may be used instead.

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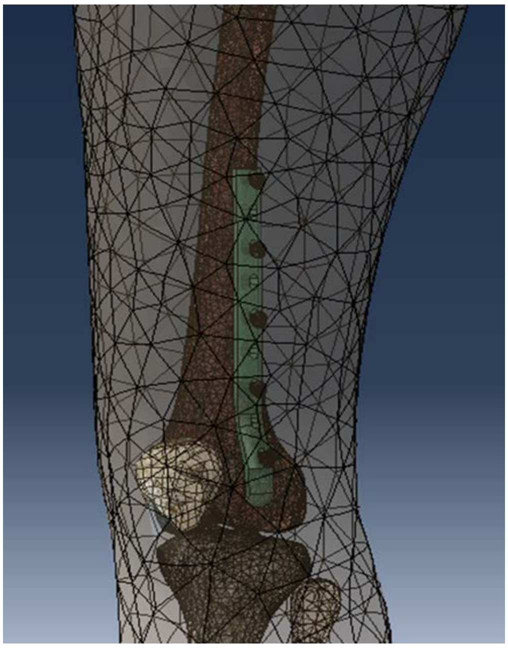
Attachment

The definition of the numerical model in this research entails determining the material properties, determining the coefficients, determining the simulation type, defining the simulation conditions, and defining the meshing in the Abaqus software environment (16-19).



Loading

A 69 Kg weight was applied to the top of the proximal femur in the coupled location to load the stress.