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Research Paper

CAD Model and Finite Element Analysis of a Knee Brace for General Applications

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Abstract
One of the main problems in sports medicine in today's world is knee injuries. Champions of various sports fields often suffer from common knee injuries, such as injuries to the anterior cruciate ligament, middle cruciate ligament, medial collateral ligament of the knee, or meniscus. In this paper, a knee brace for general applications is modeled and its stress and strain analysis is calculated with the help of software. First, the displacement of the knee brace with ABAQUS software is investigated. By moving toward the top of the knee brace, the amount of displacement decreases. So that at least the amount of displacement is in the upper part of the knee brace. In the next part, the amount of strain and strain for this knee brace is investigated. The amount of stress in the upper part of the knee brace is higher than in other places. Additionally, the amount of strain for this knee brace is determined, the knee brace in the upper part, on the inner side of the knee brace, bears more strain. The results show that this knee brace can be easily produced and considered for different applications.

Keywords
CAD Model, Finite Element, Knee Brace, Simulation

1. Introduction

One of the most dominant and used joints of the human body is a knee, which is exposed to arthritis and diseases. The knee is a joint that consists of three bones, femur, tibia and patella, and two tibiofemoral joints and patellofemoral joint. [1-2]. There is joint capsule, synovial membrane and ligaments around of the knee joint [3]. In the structure of the knee joint, separate cartilaginous layers that are layered on top of each other in some places where the bones are located, the inner meniscus and the posterior (Lateral meniscus) and outer (Medial meniscus, Collaterals) five main ligaments, Posterior cruciate ligament (Patellar) and patellar (Anterior cruciate ligament) are very important [4-5].

Knee arthritis is one of the prevalent disorders of the knee joint. According to this, a knee brace can be considered the best help for the knee. Using medical knee braces including supportive knee braces is a solution for decreasing the intensity of injuries to the knee ligaments without limiting their range of motion and activity and treating knee arthritis [6]. Knee sleeve braces, prophylactic knee braces, functional knee braces, and postoperative braces are the four main types of knee braces. It should be

noted that knee sleeves are not practically knee braces and prophylactic knee braces are supportive or preventive as well as another name for postoperative braces is rehabilitation braces. Knee sleeves are the popular type of knee braces used by athletes around the world [7]. Medical knee braces work by controlling some movements of the knee joint and providing protection against extreme and abnormal movements of the knee ligaments. These knee braces are used both on injured knees that still have movement and on knees that have lost their ability to move. Knee braces have many different shapes and sizes, and their specific functions are also very diverse [8]. Understanding the anatomy of the knee is a great help in designing a knee brace. The knee consists of two ellipsoid joints that are hinged to each other. One of the ellipsoids is between each femoral condyle and the corresponding meniscus which is two C-shaped segments of the soft cartilage on each side of the knee that helps to absorb shock during movement and the other is the tibial condyle and the patella, which form a joint at the end of the femur [9]. The front and sides of the femur are covered by a large mass of flesh that is called the quadriceps. The quadriceps are the leg muscle group that is key in jumping, running, and walking. They behave as strong openers of the knee joint and are mandatory for the stability of the patella and knee joint in movement, especially in walking [10]. Another important muscle that is responsible for pulling down and back the knee is the hip extensors. By using the muscle, the flexor movement at the starting foot contact and hip extension are controlled. When the extensors miss their function, the trunk is bent backward in contact with the leg. The next group of muscles that are surrounded at the back of the thigh are the hamstrings that start from the femur to the knee. The hamstrings are used in knee flexion and hip extension because of crossing the hip and knee joint. When people run, their hamstrings move the leg in a downward direction and prevent trunk flexion at the hip joint [11]. The triceps are another muscle that loaches in the lower leg. The muscles are a pair and enter the heel bone of the human foot and make the key section of the calf muscle. The triceps muscles help to stabilize the ankle in the transverse plane and also stability during movement in the sagittal plane such as walking and running [12]. The walking cycle is defined as a way that humans walk. The mentioned muscles such as the quadriceps and hamstrings have important control over the knee during walking and locking the knee prevents unnecessary bending. One of the significant factors for ensuring stability in the knee joint is the ligaments and bony anatomy [13]. Indeed, the ligaments are employed to attach bone to bones that result in being strong and stable knee. The knee bones are connected by the articular capsule, anterior cruciate ligament, patellar ligament, posterior cruciate ligament, oblique popliteal menisci, medial and lateral menisci, tibial collateral, transverse, fibular, coronal [14]. The knee joint can be injured for several reasons. The first reason is that rapidly changing direction especially when lending from jumping in a sport such as basketball results in tearing the anterior cruciate ligament [15]. Another injury that can be nominated is a shin splint which is a direct impact on the outside of the knee. Finally, moving to the front of the knee may result in an injury to the posterior cruciate ligament. Knee injuries can result from meniscal tears due to twisting, shearing, rotation, deceleration, and impingement [16]. Another essential drawback in injuring the knee is vitamin D deficiency. This deficiency results in rickets that cause valgus deformity and also varus deformity. In the varus deformity, the tibia/fibula shifts towards the inside of the knee which causes the load-bearing axis to move inward and exert more pressure and force on the inner part of the knee on the cartilage and ligaments. However, the tibia/fibula shifts to outside the knee in the valgus deformity [16]. In this paper, a knee brace was modeled in Catia software, and

the results of stress and strain as well as its displacement were investigated. The obtained results show that this knee brace can be suitable for general applications.

2. Modeling

The proposed knee brace is designed in ABAQUS software and CAD modeling of the knee brace is shown in Figure 1. The upper leg has an outer diameter of 13.44 cm, an inner diameter of 11.6 cm, and a length of 15 cm. While the lower leg has an outer diameter of 12.5 cm and an inner diameter of 10.11 cm and a length of 15 cm. Flaps were placed on both legs with thick of 1 cm to restrict the knee movement of condyloid joints. Furthermore, they are made to fit on their respective legs and under their respective braces. Economical materials such as nylon or cotton can be used to make these flaps. The upper and lower braces are designed by the shell feature and the surface boundary in ABAQUS. They are modeled to fit on the corresponding flaps. Other materials such as neoprene, which is lightweight and elastic, can be employed to make a simple, inexpensive knee brace.

The hinges provide not only the degree of freedom of the knee brace but also the freedom of the knee. Also, the hinges are designed to provide a locking mechanism, with a ridge on the hinges to the knee which can help people regain the locking function lost due to knee problems and ensure never bending in unnecessary conditions. Some pins are used to attach the hinges to the braces. Hinges and pins should be light and withstand more fatigue cycles. Thus, aluminum can be an appropriate choice for pins. The mechanical properties of the materials used in the knee brace are listed in Table 1. Moreover, the CAD model of the knee brace is illustrated in Figure 1.

Table 1. Mechanical specifications of material employed in the proposed knee brace

Specifications	**Material**			
	Neoprene	Bone	Aluminum	Nylon
Elastic Modulus	81500	1.4×10^{10}	7.1×10^{10}	8.3×10^{9}
Poisson Ratio	0.499	0.31	0.33	0.31
Shear Modulus	27185	1.5×10^{8}	2.7×10^{10}	3.16×10^{9}
Mass Density	1292	1800	2770	1140

It should be noted that knee loading can increase up to 550 % body weight during sudden balance loss. It is well known that the medial compartment takes significantly more load than the lateral one, which is on average 60–70 % of the load during level walking [17].

3. Results

The obtained results are as follows. The modeled knee brace can be seen in Figure 1. First, the displacement of the knee brace with ABAQUS software is investigated, which, as can be seen, the maximum amount of displacement is at the bottom of the knee brace. By moving toward the top of the knee brace, the amount of displacement decreases. So that at least the amount of displacement is in the upper part of the knee brace in Figure 1.

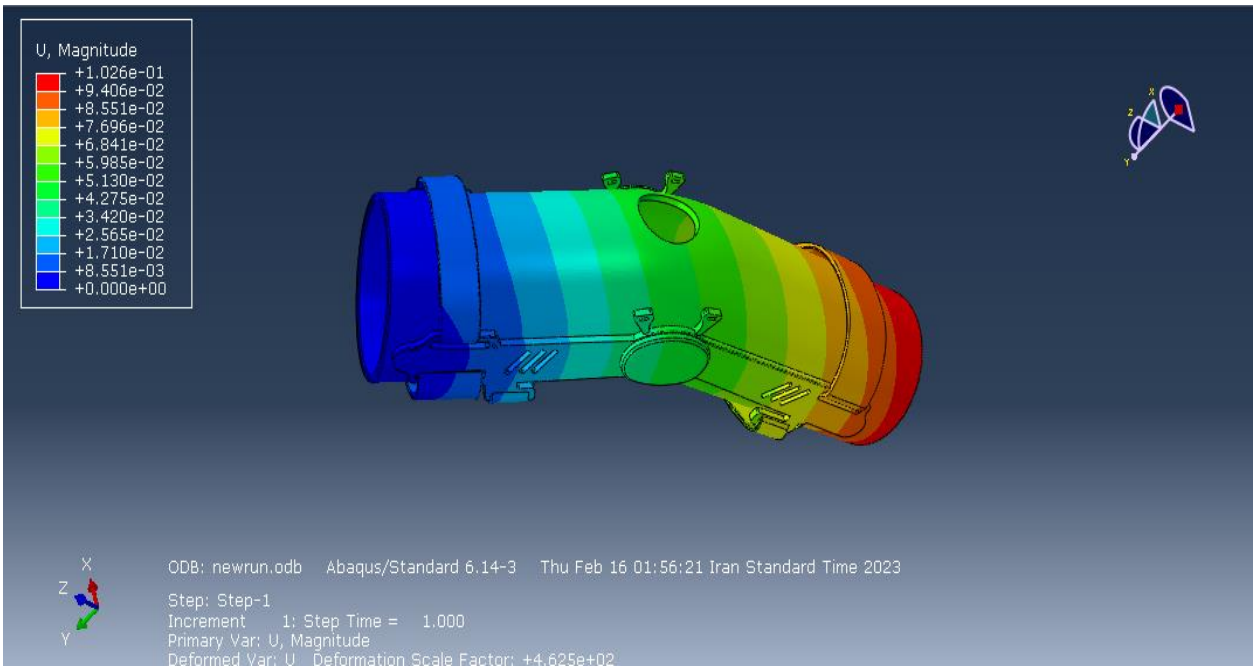

Figure1. The displacement of the proposed knee brace in ABAQUS

In the next part, the amount of strain and strain for this knee brace is investigated. As can be seen from Figure 2, the amount of stress in the upper part of the knee brace is higher than in other places. This shows that the knee brace is more likely to be injured in these places.

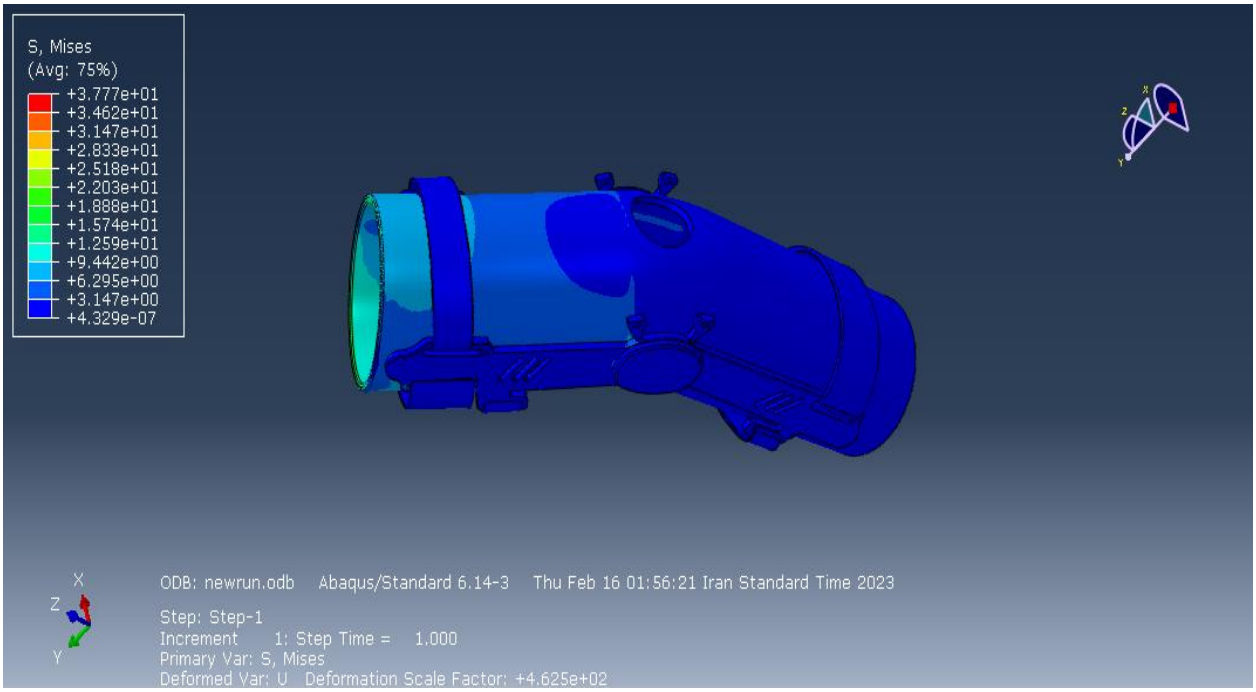

Figure 2. The stress of the proposed knee brace in ABAQUS

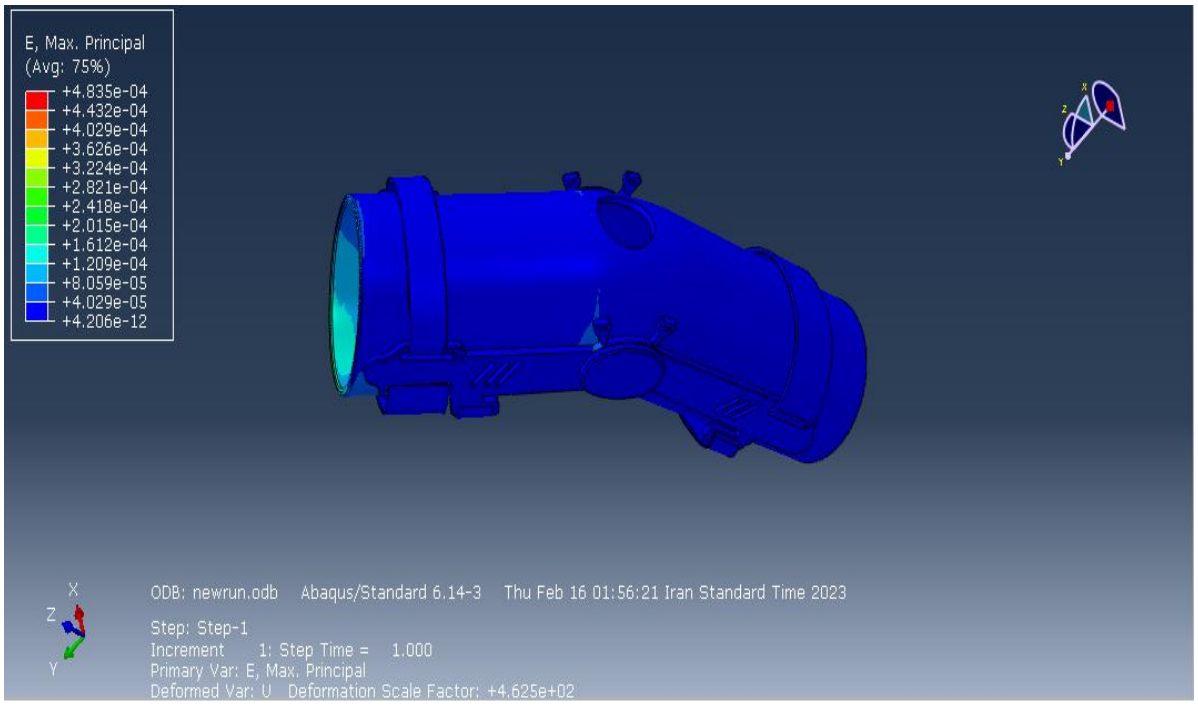

Figure 3. The strain of the proposed knee brace in ABAQUS

Figure 3 shows the amount of strain for this knee brace is determined. As can be seen in Figure 3, the knee brace in the upper part, on the inner side of the knee brace, bears more strain, which is proportional to the stress presented in Figure 2.

4. Discussions

Several important factors are considered for the proposed knee brace. The first factor is support. Knee braces are placed comfortably on the knee and compress the joint and provide support to its soft tissues (muscles and ligaments). The second factor, using a knee brace warms up the knee and increases the blood supply in it, helping to heal knee injuries faster. In addition to these cases, knee braces can be useful for people with arthritis by improving ligament damage, relieving knee patella pain, and strengthening the sense of caution and care. Also, the weight of the knee is less.

Bracing after ACLR has become a very common practice, as clinicians believed that it improves the post-operative knee outcome by decreasing the mechanical load, improving extension, decreasing asymmetry of the limb force, and limiting the excessive tibial rotation during pivoting [18-26]. In a study, the using a brace and delayed weight bearing after anterior cruciate ligament reconstruction (ACLR) make a negative impact on long-term functional outcomes [27]. However, the weight is less and can be used for the long term according to the employed material. Moreover, it has been observed in a study [28] that patients that are treated with braces were more likely to see increased compression on the soft tissues of the limb [28]. Nonetheless, the proposed knee brace is comfortable and makes reasonable compression in soft tissue. Other drawbacks related to knee brace consist of potential thigh atrophy, loss of flexion range of motion, and increased fatigability during sports [29]. Additionally, a knee brace may be a factor that increases the re-injury rate for patients who wear it for returning to sport. It should be noted that knee braces are for the rehabilitation phase not returning to sport [30-32]. For knee cruciate ligament injuries, the use of a suitable hinged knee brace can have a great effect

in speeding up the recovery of the knee. Treatment of anterior cruciate ligament tears often requires surgery. Usually, after this surgery, the doctor or physical therapist prescribes a hinged knee brace that can be locked to keep the knee stable and unlocked to flex the knee during the postoperative recovery period [33]. When the degeneration and softening of the cartilage under the kneecap causes knee pain, the use of knee braces made of neoprene, which has a cut in the place of the kneecap, is used. It can effectively help keep the patella bone in place and relieve the pain caused by the complication. Using this type of knee brace makes it easier to perform specific exercises to strengthen the quadriceps muscles. [34]. Many people who have used simple knee braces or knee sleeves available at drugstores and sporting goods stores have found the use of these knee braces to be very effective in relieving their knee pain. Experts agree that these knee braces can be effective in removing swelling and relieving knee pain by heating and compressing the joint. But perhaps the main benefit of using these knee braces is related to psychological factors [35].

5. Conclusions

The knee is one of the most important and most used joints of the human body, which is exposed to arthritis and diseases. In this paper, a knee brace was modeled in ABAQUS software for public use. To this end, the displacement of the knee brace with ABAQUS software is considered and the amount of the displacement decreases by moving towards the top of the knee brace. In the next part, the amount of strain and strain for this knee brace is investigated and the amount of stress and strain in the upper part of the knee brace is higher than in other places. The results show that this knee brace can be easily produced and considered for different applications.

6. References

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