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Research Paper

Finite element analysis of stress and wear characterization in total ankle replacements

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ABSTRACT

Total Ankle Arthroplasty is performed in order to reduce the pain and loss of ambulation in patients with various forms of arthritis and trauma. Although replacement devices fail by a number of mechanisms, wear in the polyethylene liner constitutes one of the dominating failure modes. This leads to instability and loosening of the implant. Mechanisms that contribute to wear in the liners are high contact and subsurface stresses that break down the material over time. Therefore, it is important to understand the gait that generates these stresses. Methods to characterize and decrease wear in Ohio Total Ankle Replacements (TARs) have been performed in this research. This research utilizes finite element analysis of Wright State University (WSU) patented TAR models. From the Finite element analysis (FEA) results, mathematical models of contact conditions and wear mechanics were developed. The maximum wear rate values obtained in the study (at 25.598 MPa, 3.74 mm^3/year) and maximum surface Mises stress obtained with new optimization model (11.52 MPa) seem to be comparable with the maximum wear values obtained in other similar studies. These models were used to determine the best methods for wear characterization and reduction. Furthermore, optimization models were developed based on geometry of the implants. These equations optimize geometry, thus congruency and anatomical simulations for total ankle implants.

1. Introduction

Cases of arthritis in the ankle joint are far less prevalent than those seen in other joints, such as the hip and knee. In fact, fewer than 7.5% of all patients suffer from some form of ankle arthritis (Saltzman et al., 2005). Still, degenerative conditions such as post-traumatic arthritis (PTA), rheumatoid arthritis (RA), and osteoarthritis (OA) can lead to pain, decreased range of motion in the gait, and general disability (Valderrabano et al., 2007). TARs are used to treat different types of disorders especially osteoarthritis, rheumatoid arthritis and post-traumatic arthritis (Michael et al., 2008). While TARs have been performed since the 1970s, they have been largely overshadowed in favor of more reliable procedures such as ankle

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fusions (Vickerstaff et al., 2007). This can be attributed to the fact that TARs generally have a lower survival probability when compared to hip and knee implants (Fevang et al., 2007). Cases of instability, excessive polyethylene wear, and mal-union between the bone and implant in first generation models raised questions to the viability of TARs. As a result, arthrodesis or fusion is considered the golden standard for treating ankle joint disorders. It was not until the early 1990s that a newfound interest for TARs caused researchers to again look toward ways of improving the devices. Stability, increased range of motion (ROM), improved wear characteristics for the polyethylene components, and improved union techniques were all concerns for the next wave of TARs.

Even with vast improvements made to TARs in the past two decades, revision rates continue to be higher than those seen in Total Hip Replacements (THRs) and Total Knee Replacements (TKRs). In fact, the average revision rate for total ankle implants was found to be nearly double that of hip and knee implants according to (Labek et al., 2011). This is in large part due to the drastically different biomechanical factors affecting the ankle joint, such as the small contact area between the talus and the tibia (Vickerstaff et al., 2007). Surface area of ankle joint constitutes only one-third that of hip or knee joints but the forces acting on ankle joint are relatively higher where, ankle joint experiences 64% more force than knee joint and 45% more force than hip joint (Michael et al., 2008). Force generation analysis revealed that ankle joint exposes to a force of four to seven times the body weight during normal walking and 9 to 13.3 times the body weight during stance phase of running (Michael et al., 2008). This small contact area, along with higher joint reaction forces compared to other joints, leads to very high contact stresses in TARs (Anderson and Pandy, 2001). Coupled with the relatively low yield point and wear resistance of ultra-high molecular weight polyethylene (UHMWPE), these stresses

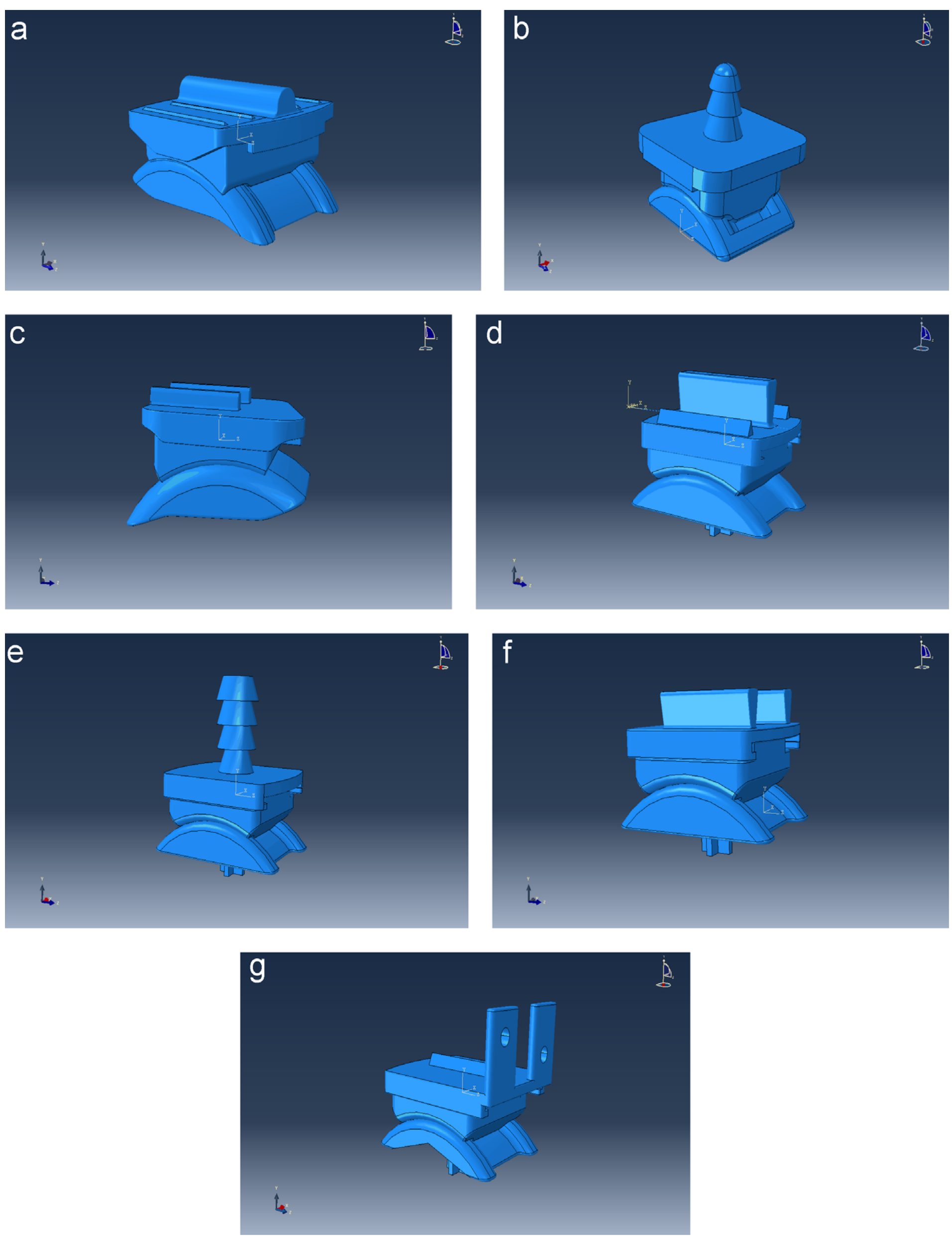

Fig. 1 – (a) Model M1, (b) Model M2, (c) Model M3, (d) Model N1, (e) Model N2, (f) Model N3 and (g) Model N4.