Effect of Body Mass Index (BMI) on Gait Biomechanics

Asfour, S,[1,2] Cami, S,[1] Eltoukhy, M,[1] Latta, L[1,2]
[1]Dept. Industrial Engineering, Univ. Miami, Coral Gables, FL [2]Dept. Orthopaedics, Univ. Miami, Miami, FL & Max Biedermann Institute for Biomechanics Research, Mount Sinai Medical Center, Miami Beach, FL

INTRODUCTION: According to the data published by the CDC, obesity has steadily increased, from 19.4% in 1997, to 26.6% in 2007, to 33.8% (adults) and 17% (children) in 2008. In 2010, the CDC reported higher numbers once more, counting 35.7% of American adults as obese, and 17% of American children. According to a study published in the Obesity Journal, the direct medical cost of obesity and indirect economic loss to obesity has been estimated to be as high as $51.64 billion and $99.2 billion in 1995, respectively; this rose to $61 billion and $117 billion in 2000.

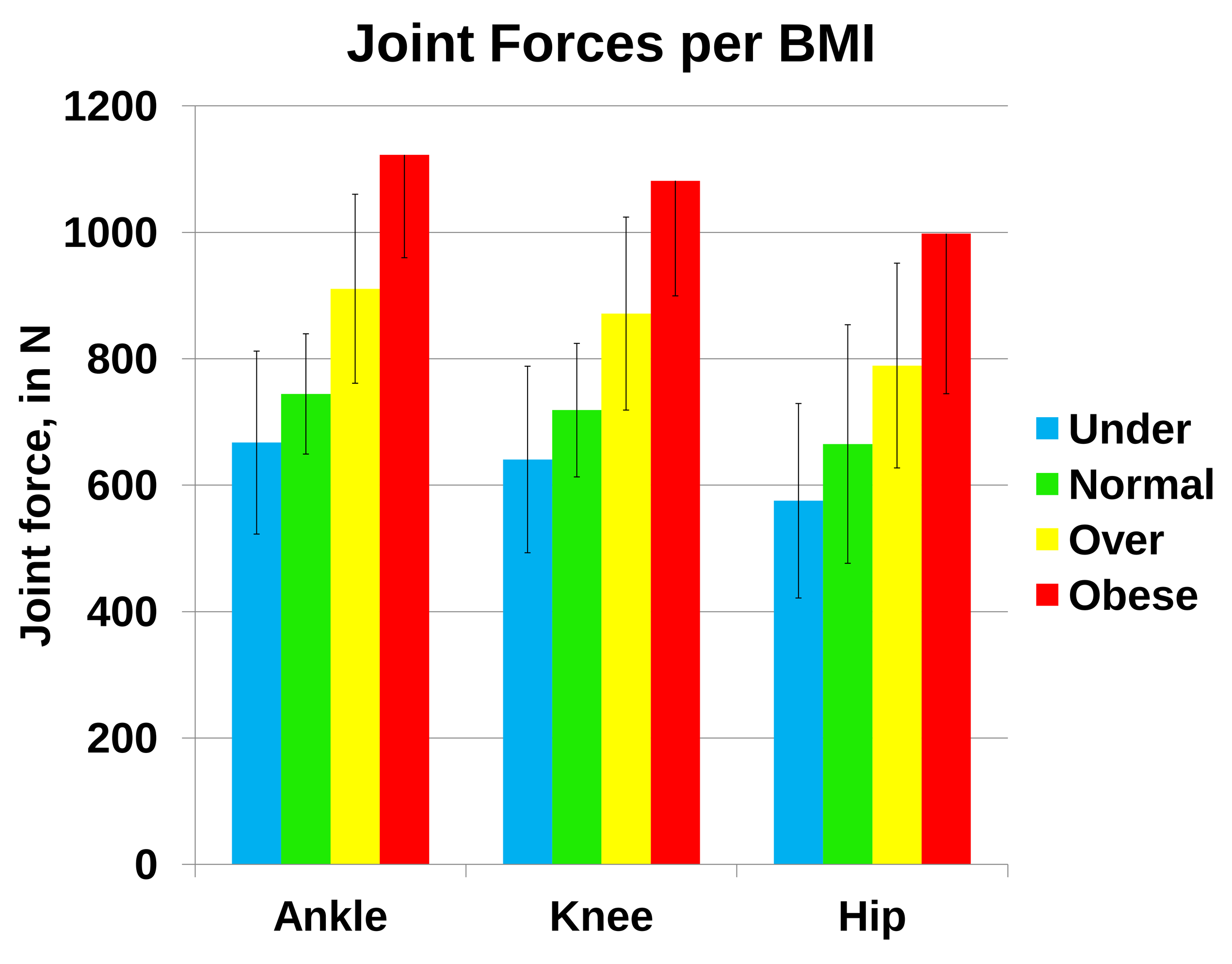
Obesity may initiate cartilage breakdown or may promote joint destruction, due to increased force on cartilage.[1] Obese and overweight people constantly report pain in the joints of their lower extremities, lower back, and shoulder. In addition, obesity has been proven to be one of the leading factors in causing osteoarthritis of the knee.[2] However, very few studies have concentrated on the effects of obesity in the biomechanics of the lower extremity joints.

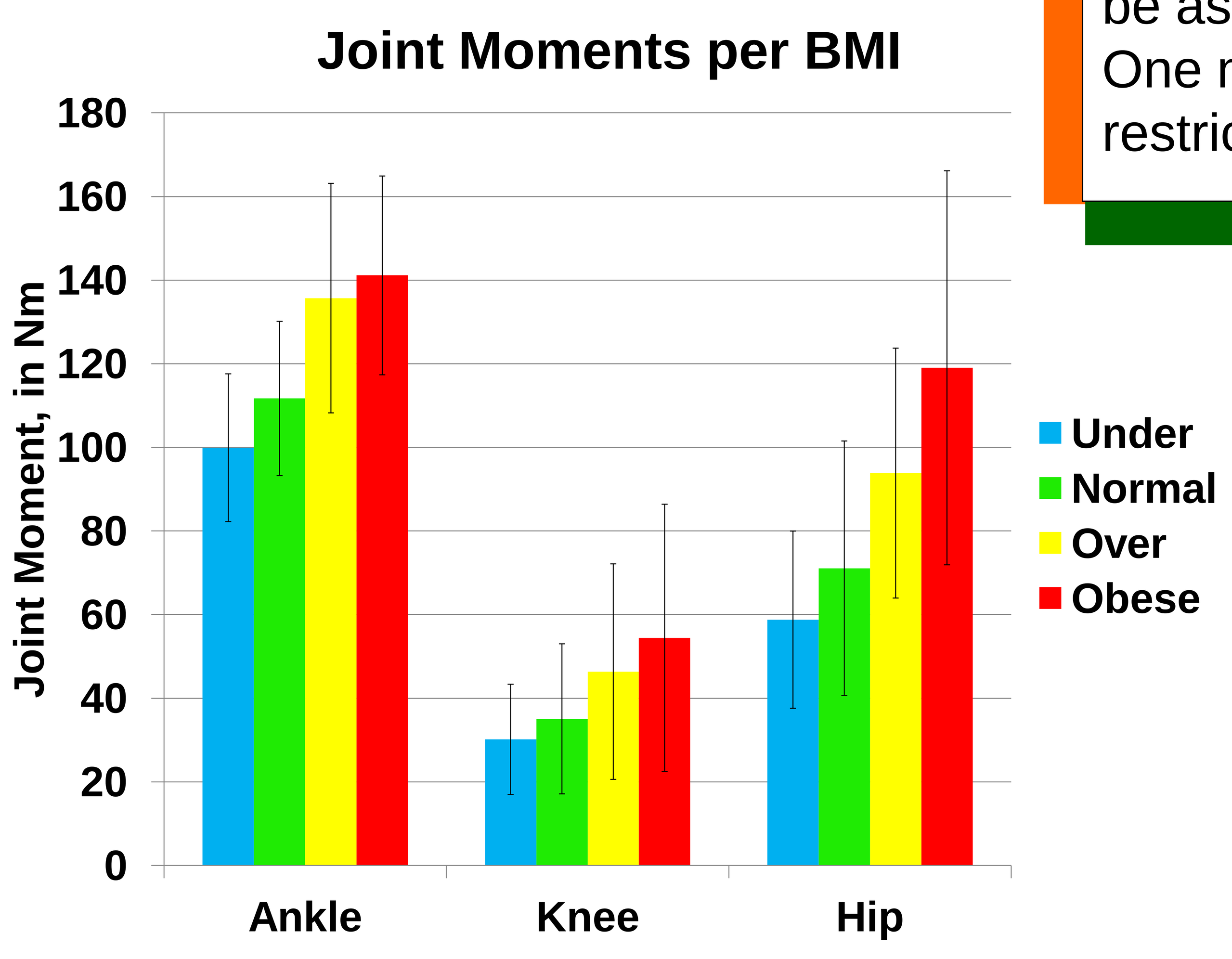
Obesity has been shown to increase the risk of mechanical failures of surgical procedures for musculoskeletal conditions. An accelerated rate of failure for joint arthoplasties is the most common[3,4] reported, and recently obesity was associated with a 12X increase in mechanical failure of internal fixation.[5] But the term "obesity" covers a wide spectrum of BMI's, so knowledge of the specific effect of selected ranges of BMI on joint mechanics can be a valuable resource for the Orthopaedic surgeon in the process of patient selection for given procedures.

This study is focused on the comparison between obese and non-obese male subjects of ages 18 to 35 years old with measures of joint forces, moments, and range of motion during ambulation.

METHODS: Forty male subjects, ages eighteen to thirty five years old, were recruited. The procedure and methods for the experiment were reviewed and approved by the IRB. Subjects with prior limb injuries were excluded from the study First, the subjects' weight and anthropometric measurements were collected to calculate the BMI for use in the biomechanical model. Then 39 reflective markers were placed on the subject's body according to the Plug-in Gait model used.

The design of the experiment included four levels of BMI and two levels of gait speed (normal and fast). BMI levels were: Underweight (10 subjects), Overweight (10 subjects), Normal (10 subjects) and Obese (10 subjects). For each speed level a total of six good trials were collected per subject. A total of 480 trials were analyzed in this study. Dependent variables studied were: Temporal Characteristics – cadence, walking speed, stride length, stride time, stride width, step time, step length; sagittal, frontal, and rotational forces at the hip, knee, and ankle during gait; moments and angles at hip, knee, and ankle during gait.





RESULTS: The obese subjects walked with significantly slower gait by taking shorter steps and strides, while having significantly higher step widths and longer gait cycle times than the normal subjects. The obese subjects spent significantly less time in single support and more time in double support than normals. BMI significantly affected the forces and moments at the ankle, knee and hip. At normal walking speeds, heel strike and toe off forces were increased by 96% and 128%, respectively, for obese subjects. Ankle, knee and hip forces and moments in the 3 principle planes are shown in the figures for normal gait speed. At fast walking speeds the difference was even greater for heel strike, 97%, for hip force and moment, 159% and 124%, respectively, and for peak knee moment, 106%. Because of their circumductive gait pattern, the horizontal plane moment at the ankle was excessive in several of the obese subjects.

The hip joint in the coronal plane displayed the highest forces and moments for the obese subjects. These results are indicative of a gait compensation related to increasing body weight in the medial-lateral movements and alignments of the lower extremity joints.

DISCUSSION: These results confirm the idea that obesity leads to ambulation instability and thus obese subjects tend to adapt their gait pattern to reflect a slower and more tentative walking. The higher rotation angles at the ankle joint during both heel strike and toe off and the increased side loading and horizontal plane moments suggest a realignment of the limb to better support the body weight for the obese subjects. The gait adaptation in the obese group shows most in the coronal plane for the knee joint which has less force and only a mild increase in moment for the obese while the hip joint has much higher peak forces and moments. Since the ground reaction forces are higher for the obese subjects in the coronal plane than the non-obese counterparts, these forces have to gradually spread through the lower limb joints and the compartments in between. It seems that the knee avoids taking on more forces and moments in order to avoid overloading of the cartilage. However, the hip and ankle joints end up compensating for the extra forces and moments in order to better balance the body. The kinetic and kinematic results of this study suggest that obese subjects walk with greater joint loads with a waddling, and sometimes circumductive gait and that walking slower and maintaining more time in double limb support can reduce these loads and give some stability to the subject.

These results are indicative of a gait compensation related to increasing body weight in the medial-lateral compartment of the lower extremity joints. If candidates for musculoskeletal procedures are in the higher levels of BMI, the surgeons can expect the loading on their reconstructions or fixations to be as abnormal as for the asymptomatic persons measured in this study. One might need to consider special gait training, supplementary supports, restricted activities, etc. to protect the surgical procedures.

SIGNIFICANCE: Statistically significant effects of the BMI on the forces and moments at the ankle, knee and hip in the all planes were found. An increase in the body weight not only increases the load on the joints, but alters their distributions, directions and types.