Abdomen-Thigh Contact During Forward Reaching Tasks in Obese Individuals

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During seated forward reaching tasks in obese individuals, excessive abdominal tissue can come into contact with the anterior thigh. This soft tissue apposition acts as a mechanical restriction, altering functional biomechanics at the hip, and causing difficulty in certain daily activities such as bending down, or picking up objects from the floor. The purpose of the study was to investigate the contact forces and associated moments exerted by the abdomen on the thigh during seated forward-reaching tasks in adult obese individuals. Ten healthy subjects (age 58.1 ± 4.4) with elevated BMI (39.04 ± 5.02) participated in the study. Contact pressures between the abdomen and thigh were measured using a Tekscan Conformat pressure-mapping sensor during forward-reaching tasks. Kinematic and force plate data were obtained using an infrared motion capture system. The mean abdomen-thigh contact force was 10.17 ± 5.18% of body weight, ranging from 57.8 N to 200 N. Net extensor moment at the hip decreased by mean 16.5 ± 6.44% after accounting for the moment generated by abdomen-thigh tissue contact. In obese individuals, abdomen-thigh contact decreases the net moment at the hip joint during seated forward-reaching activities. This phenomenon should be taken into consideration for accurate biomechanical modeling in these individuals.

Keywords: biomechanics, kinetics, kinematics, motion analysis, obese

Obesity is increasing in prevalence, and has serious health consequences. Thirty-four percent of adults in the United States are overweight (BMI 25–30), and an additional 34% are obese (BMI >30). Obese individuals may have difficulty in certain daily living activities such as rising from a chair, climbing stairs, bending down, or picking up objects from the floor. Underlying these difficulties may be compromised joint ranges of motion, since adipose tissue around joints obstructs intersegmental rotations.

When obese subjects perform seated forward-reaching tasks, abdominal tissue comes into contact with the anterior thigh. This soft tissue apposition acts as a mechanical restriction, and may cause modification of the movement. Previously, strategies used during sit-to-stand movements in obese women have been addressed by modeling the abdominal tissue mass as a perfect homogenous hemisphere. The study predicted that trunk motion would be restricted and that there would be effects of obesity on kinetics of the hip and knee joints. On the other hand, the abdomen responds similarly to a bladder filled with water and has been modeled as a hydraulic system where the magnitude of abdominal pressure is related to the height of the hydrostatic column of the contents above the point of measurement. Consistent with this model, the application of external weights to the abdomen has been shown to increase intra-abdominal pressure (IAP) in animal models.

For obese individuals who attempt, or by virtue of their occupation are required, to get into forward leaning during sitting or squatting postures, where abdomen-thigh contact likely occurs, the consequence of increased abdominal pressure is uncertain. Obese individuals are biased toward significantly higher (5-7 mmHg) baseline IAP, as compared with nonobese subjects, with IAP being further affected by changes in position, that is, standing vs reclined. Elevated IAP has been associated with elevation of intracranial pressure (ICP), severe drops in cardiac output, lung atelectasis and a host of other medical conditions, including hernias. Substantial abdomen-thigh contact force, therefore, could have implications for systemic effects.

There has been limited research demonstrating the potential influence of increased body mass on kinematics and kinetics when performing functional activities. Besides changing the absolute load acting across lower extremity joints, obesity can cause changes in the movement strategy, with implications for the associated kinetics. Increased hip joint moments during standing work tasks have been reported in obese subjects and in
pregnant women and have been primarily attributed to postural changes rather than to the increased body mass. Sibella et al, on the other hand, reported lower hip moments during the sit-to-stand activity in obese subjects as compared with normal-weight subjects, a finding attributed to the limited trunk flexion. However, in activities where there is abdomen-thigh tissue contact, there is potential for these contact forces to change the kinetics, beyond what might otherwise happen due to the changing kinematics alone. Having valid biomechanical models for obese subjects is important as improved models that account for contact forces will result in better estimates of the muscle and joint forces present during a movement.

Previous biomechanical analysis, that has modeled the abdominal tissue mass as a perfect homogenous hemisphere, is not adequate for assessing contact pressure. Occasional attempts have been made to quantify the contact pressure between adjacent segments in situations where soft-tissue restricts motion. The effects of thigh-calf and heel-gluteus contact forces during squatting and kneeling in normal weight subjects have been documented. Those studies reported substantial thigh-calf contact force (>30% body weight per leg), which acted to considerably reduce the quadriceps forces during kneeling activities. However, to our knowledge, no study has quantified the contact force between the abdomen and the thigh segment.

The purpose of the current study was to measure the contact forces exerted by the abdomen on the thigh during forward-reaching tasks in obese adults, and to investigate factors that influence those forces. We hypothesize that abdomen-thigh contact force during functional reaching tasks will increase with waist circumference and body mass index (BMI).

Methods

Subjects

A convenience sample of 10 obese individuals (5 males, 5 females), aged 40 to 70 years (58.1 ± 4.4; mean ± SD), with body mass index (BMI; calculated as mass [kg]/height² [m²]) of more than 30, volunteered for the study. Individuals with any musculoskeletal or neurological ailments or with previous joint replacement surgeries were excluded. The study was approved by the local institutional review board.

Materials

Initially, the subject’s body mass, height and waist circumference were measured. Waist circumference was measured at the level of the right iliac crest, with a Gulick II plus (Gulick II measuring tape; Country Technology Inc., Gays Mills, WI) tape measure. Triads of infrared-emitting diodes (IREDs) were placed on the pelvis and trunk, and bilaterally on the thighs, legs, and feet. Markers were affixed to the lateral aspect of the foot, to the shaft of the tibia, and to the lateral aspect of the thigh. Femoral epicondyle motion was tracked by two markers mounted on a custom femoral tracking device. Pelvic markers were affixed on the sacrum using a 5 cm extension. A similar extension was placed on the lower cervical vertebrae to track the trunk segment.

A link-based model was generated for tracking each segment. Anatomical landmarks were digitized using a digitizing wand (Northern Digital, Inc.), relative to segment local coordinate systems, with the subject standing in a neutral position, to create an anatomical model. Segment principal axes were defined based on a single experienced clinician (BS) palpating and digitizing the following bony landmarks: Pelvis: anterior and posterior superior iliac spines; Trunk or Head Arm Trunk (HAT): C-7 and L-1 vertebrae and acromion process; Thigh: lateral and medial condyles; Shank: lateral and medial condyles and malleoli; Foot: posterior heel, metatarsal head, and second toe. The functional method was used to estimate the hip joint center. The reliability of digitizing the anterior superior iliac spine (ASIS) was verified on six obese and seven nonobese adult subjects by redigitizing the ASIS landmarks at the end of the digitizing process. The respective ICC for the X, Y, Z locations for obese/nonobese subjects was .93/.99; .92/.86; and .99/.99.

Kinematic data were collected using an Optotrak motion analysis system (Model 3020, Northern Digital Inc., Waterloo, Ontario, Canada) operating at 60 Hz. Kinematic data were filtered at 6Hz, using a zero phase lag fourth-order Butterworth low-pass filter. Kinetic data were obtained using a Kistler force plate (Kistler Instruments, Inc., Amherst, NY). The force plate data were sampled at 300 Hz, and were filtered at 6 Hz, thus providing ground reaction forces. Visual 3D software (C-Motion Inc. Kingston, Ontario) was used to perform link-segment calculations.

Contact pressure between the abdomen and thigh was measured using a Tekscan Conformat pressure-mapping sensor (Model #5330, Tekscan, South Boston, MA). The Conformat sensor had a sensing area of 47.1 by 47.1 cm, with 1024 sensing elements (sensels) distributed over 32 rows and 32 columns. The sensor’s thickness was 1.78 mm, its spatial resolution was 0.5 (0.461) sensels per cm², and its sensitivity range was 0–33.3 kPa. A second Conformat was placed on the chair, under the subject, to record the seat pressure. The seat mat was calibrated by having the subject sit on it for 30 s. For calibrating the thigh mat, a water bladder was used to simulate the abdominal tissue, with weights of 10 and 20 kg used to perform a power-law calibration. Mat calibrations and data acquisition were achieved with Tekscan software (Conformat Research 7.01 C). Spatial alignment between the pressure mat and the laboratory coordinates was accomplished by digitizing a point on the mat while it was positioned on the subject.

Forward Reaching Tasks

Subjects were positioned on a custom, normal height (45 cm), seat that did not support the right thigh (Figure 1a).
The Tekscan mat was snugly secured between thighs and the abdomen with the help of bungee cords anchored to the back of the seat. Subjects were asked to reach forward as if performing two forward-reaching functional activities: shoe tying, and object pickup tasks. Subjects started from an erectly seated position and then leaned over as if attempting to reach their right foot with both hands, simulated shoe tying; or as if reaching for an object placed on the floor 8 cm lateral to the right foot, simulated pickup. In all cases subjects were asked to make a maximal effort, even if they were not able to reach their shoe or the floor. Once subjects were in a maximally flexed posture, they were asked to hold the position for 5 s while pressure was recorded by the thigh mat. Each task was repeated three times. Peak force was calculated for both the shoe tying and pickup tasks.

### Data Analysis

Tekscan software was used to calculate the center of pressure and the resultant force on the right side due to abdomen-thigh contact. The Tekscan pressure distributions showed clear demarcation between the right and left sides (Figure 1b). Peak force was calculated for both the shoe tying and pickup tasks. Forces were normalized to body weight (BW). Trunk or HAT flexion angles were determined from link-segment analysis.

### Biomechanical Model

A two-dimensional free body diagram was used to explore the effect of abdomen-thigh contact force on hip joint biomechanics. A free body diagram (Figure 2) of the lower limb was generated using a section cut through the hip joint. The length...
of the femur, as obtained from the subject’s digitized skeletal model, was represented as a bridge of length \( L \) supported by the hip and knee joints, with the force from abdomen contact acting as an external force on the thigh. Antero-posterior component of ground reaction force was only 7.6% of the vertical GRF force. The medio-lateral component was also minimal at 3.5% of the total vertical force. The vector sum of vertical and antero-posterior GRF \( (F_{gf}) \) was used for calculations.

The resultant internal moment at the hip: \( \sum M_H = 0 \)

\[
M_H = (F_{gf} - [W_s + W_f]) \times L - W_t \times d - F_{at} \times a \quad (1)
\]

Seat force and location and magnitude of the abdomen-thigh contact force, was used to validate the values of contact force for five subjects. The difference between the hip moments estimated ranged from 2 to 18 N·m, with a mean percentage difference mean 7.8 ± 3.82%.

Statistical Analysis

Student’s \( t \) tests were used to assess differences between the peak contact force for shoe tie and pickup tasks. Pearson’s linear correlations were used to quantify trends between body-mass-related subject properties and the abdomen-thigh contact characteristics. Multiple linear regression analyses were conducted to determine relationships between anthropometric properties of the subjects (waist circumference, height, weight, and BMI) and experimental outcomes (maximal abdomen-thigh contact force, trunk angle, and extensor moment at the hip). Intra-class correlation (ICC) was used for calculating reliability between the three trials for each activity. The alpha level was set at 0.05, and SPSS (Version 19) was used for statistical analysis.

Results

The contact forces exerted by the abdomen on the thigh during forward-reaching tasks were mean 10.71 ± 5.03% of body weight (BW). The mean abdomen-thigh contact force for the shoe tying activity (112.8 ± 49.5) differed inappreciably from that for the pick-up task (116.47 ± 47.77), \( P = .87 \). The three replicate trials for each activity showed good reliability, with ICC’s of 0.78 and 0.71 for the shoe tying and pickup tasks respectively. The single highest value from all trials was selected for each subject for further analysis. For all subjects, abdomen-thigh contact forces were maximal when the trunk was maximally flexed. The range of the contact force was 57.8 N to 200 N. Individual subject characteristics and other results are presented (Table 1).

In addition, hip flexion was not different (98.7 ± 13.3 vs 98.8 ± 12.0°, \( P = .99 \)) for shoe tying and pickup tasks respectively. Hip abduction was 13.8 ± 9.6 for shoe tying and 11.4 ± 8.8 degree for pickup task, and not significantly different \( P = .1 \). The hip abduction angle showed a positive correlation with BMI, \( r^2 \) value 0.56.

A strong positive relation \( (r^2 = .77, P = .004) \) was seen between BMI and waist circumference, but subjects with larger waists or greater BMIs did not necessarily exert greater force on the thigh. The \( r^2 \) values for peak abdomen-thigh force vs BMI and vs waist circumference were 0.04 and 0.07 respectively. However, waist circumference showed a positive relationship with trunk flexion angle (Figure 3).

A weak association \( (r^2 = .24) \) was seen for trunk flexion angle vs BMI, but no relationship was seen between trunk flexion angle and abdomen-thigh force \( (r^2 = .06) \). A very weak \( (r^2 = .09) \) relationship was seen between trunk flexion vs net extensor moment at the hip. The strength of this relationship improved considerably when trunk rotation was added to the model \( (r^2 = .68, P = .016) \).
Abdomen-Thigh Contact in Obese Individuals

Table 1  Subject demographic and anthropomorphic characteristics, along with the peak abdomen-thigh contact force and the corresponding trunk flexion angle (*missing values)

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
<th>Age (years)</th>
<th>BMI (kg/m²)</th>
<th>Peak Force (N)</th>
<th>Trunk (°)</th>
<th>Waist (cm)</th>
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<tr>
<td>1</td>
<td>1.65</td>
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<td>53</td>
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<td>135.0</td>
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<tr>
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<td>97</td>
<td>54</td>
<td>34.6</td>
<td>59.3</td>
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<tr>
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<tr>
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<td>SD</td>
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<td>4.4</td>
<td>5.0</td>
<td>48.5</td>
<td>12.2</td>
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</tbody>
</table>

Figure 3 — The significant \( P = .016 \) and strong relationship between waist circumference and (maximum) trunk flexion showed that higher waist circumference limited the amount of trunk flexion.

The range of moments generated by abdomen-thigh contact force was 6.6–36.6 N·m. The extensor moment at the hip joint ranged from 88 to 140 N·m, and decreased by mean 16.5 ± 6.44% after accounting for thigh-abdomen contact force. One subject had faulty force plate data, precluding kinetic calculation in that instance. A moderate positive relationship was seen between the net extensor moment at the hip joint and the peak abdomen-thigh contact force (Figure 4).

The multiple regression model using the peak abdomen-thigh force as the dependent variable with three predictors (trunk flexion, waist circumference, and BMI) produced \( r^2 = .516, P = .361 \). Adding the trunk rotation in the transverse plane failed to improve the prediction. Multiple regression (Eq. 2) was used to predict the magnitude of the abdomen-thigh force \( (F_a) \).

\[
F_a = -91.1 + 11.2 (\text{Waist circumference}) - 13.7 (\text{BMI}) + 3.9 (\text{Trunk flexion}) \tag{2}
\]

\[ P = .361 \]

Predicted value by the regression equation showed a strong relationship \( r^2 = .68 \) with the value measured by the Tekscan thigh mat.
The purpose of this study was to quantify abdomen-thigh contact force during forward-reaching tasks in obese individuals. The abdomen was found to exert a considerable force on the thigh, on average 10.71% of body weight, causing a decrease in the net extensor moment at the hip joint. However, intuitive associations were not substantiated between subject anthropometric properties and the abdomen-thigh contact force.

BMI showed a negative relationship with trunk forward flexion motion during forward reaching tasks, supporting previous studies that had reported obesity to be a factor in reducing forward flexion motion.\(^3\),\(^14\),\(^15\) Larsson and Mattsson\(^2\) reported that obese individuals experience difficulties in performing forward-reaching tasks, such as picking up coins from the floor and putting on socks. Even in less challenging activities such as sit-to-stand, obesity has been shown to affect trunk motion.\(^4\) In the current study, a negative association between waist circumference and trunk forward flexion was documented (Figure 3), substantiating the potentially restrictive effect of soft tissue contact.

A moderate positive relationship was seen between the net extensor moment at the hip joint and the peak abdomen-thigh contact force; this seems counterintuitive, as it was expected that the hip moment would tend to decrease as the contact force increased. These results could be affected by observed differences in task performance, as subjects reached for their shoe or for the object on the floor using unrestrained, self-selected strategies: for example, it was observed that subjects reached the shoes with their arm around the lateral side of their knee, which was reflected in different trunk motions. Contrary to previous studies of symmetrical activities where there was a direct relationship between forward trunk lean and hip moment, in the current study the strength of the relationship was markedly improved by including trunk rotation. This shows that other motions of the trunk come into play for these reaching tasks, complicating the prediction of contact forces.

The center of pressure of abdomen-thigh contact was affected by waist circumference. When the data were stratified based on gender, high correlation values emerged (0.93 for males, 0.91 for females), with males having a much steeper slope. While the limited number of subjects somewhat restricts interpretation, the trends suggest that females who have greater waist circumferences, tend to experience abdomen-thigh contact closer to the hip joint as compared with males (Figure 5). This finding could be attributed to the different distributions of adipose tissue in the abdomen and thigh, which have led to characterizing obesity of males as having an apple (android) shape and that of females a pear (gynoid) shape. BMI could also be a potential factor; trends were still seen when males and females with similar BMI were compared. The relationship between waist circumference and center of pressure of contact force based on gender is an interesting finding with potential for future research. To our knowledge, there has been only one study that specifically modeled the abdominal tissue of females.\(^4\) In that work,

![Extensor Moment at Hip vs Peak Contact Force](image)

\[y = 0.4203x + 49.27\]

\[R^2 = 0.42\]

**Figure 4** — There was a moderate relationship \((P = .06)\) between abdomen-thigh contact force and the net extensor moment at the hip. The extensor moment values were obtained after accounting for the moment generated by the abdomen-thigh contact force.
the additional tissue mass associated with obesity was modeled as a rigid hemisphere, under the assumption that 40% of the fat mass was located on the abdomen, with the remaining 60% being distributed in the thighs, assuming gynoid obesity. The basis for this specific distribution is questionable, and of course it is problematic to model compressible adipose tissue as a rigid hemisphere. While that model helped to explain the effects of obesity on the sit-to-stand movement, such a model probably would not reasonably mimic the forward-reaching activities considered in the current study.

It was hypothesized that obese subjects with higher BMIs would have higher abdomen-thigh contact forces. However, no significant relationship emerged between BMI and contact force. For example, Subject A, who had a BMI 47 kg/m², exerted only 56.7 N (4.32% BW) of force, the lowest among all subjects. Subject B, on the other hand, whose BMI was 32.6 kg/m², exerted 189.1 N (20% BW). The waist circumference of Subject A was 150 cm, compared with 102.5 cm for subject B, which implies that Subject A was not able to lean down enough (trunk flexion angle = 38.7 degrees) to exert more force. However, these various associations were inconsistent across subjects, as evidenced by the low correlation values for waist circumference and trunk flexion with contact force.

Although a weak relationship was found between BMI and contact force, adding waist circumference as a variable did improve the prediction of abdomen-thigh contact force. Therefore, BMI alone may not be the best way to characterize obesity, as it does not distinguish between the weight associated with muscle versus fat. It has been shown that a given BMI may not correspond to the same degree of body fatness across different populations. Measures of absolute and relative waist size, such as waist circumference and waist-hip-ratio, have been suggested as more relevant clinical measures of the extent of adiposity.16

Limitations of the study included the use of Tekscan sensors, which are designed to measure compressive forces, with shear forces potentially causing errors.11 However, during the reaching task, the thigh mat was subjected to an almost pure compression force, with minimal shear. Only the normal force component acting on the thigh was obtained and used in the sagittal plane free body diagram developed to examine the effect of abdomen-thigh contact force. The difficulty in tracking the underlying skeleton in obese individuals can lead to errors. In this study we attempted to minimize these errors by: using a custom femoral tracking device12 on the right knee for better tracking of the femoral epicondyles; using the functional method of estimating the hip joint center;18 and tracking the pelvis using a marker triad over the sacrum. Above-hip variables such as arm length and flexibility of the spine were not taken into consideration, which could have led to inaccurate estimation of the trunk lean angle. In addition, by using a standard height chair, different body sizes may have influenced the amount of trunk lean and effort to perform tasks in the subjects of different stature. The study...
had only ten subjects and while no data were presented on normal-weight subjects, pilot trials showed anecdotally that minimal contact force was registered between the abdomen and thigh in these individuals during the reaching activities. Finally, IAP and physiological changes were not measured as part of this project.

Range of motion reductions due to abdomen-thigh contact (Figure 3) could have implications during certain activities of daily living. In the workplace, various postures can increase work-related biomechanical stresses due to a smaller range of feasible body postures from which the obese individual can select than is the case for nonobese individuals. After accounting for the abdomen-thigh contact force the mean extensor moment at the hip was reduced by 16.5%, potentially reducing loading of low back extensor muscles during forward reaching tasks in obese subjects. However, this comes at the cost of increased abdominal pressure. The addition of external weights, up to 69 N, has been shown to significantly increase the intra-abdominal pressure in pigs, by approximately 60%. Although to our knowledge no such studies have been done in humans, the abdomen-thigh contact forces documented in the current study were relatively higher than this for some subjects, and therefore could have negative consequences for medical conditions associated with obesity and related comorbidities such as osteoarthritis, including obesity-related conditions, for example systemic hypertension.

To conclude, the current study documented the development of appreciable abdomen-thigh contact force in the obese population for forward-reaching movements. Similar contact forces would be expected to be present in seated reaching and squatting work postures and daily activities in obese individuals. These contact forces should be included in biomechanical models for accurate estimation of hip joint forces and moments during these activities. In addition, these contact forces likely cause an increase in intra-abdominal pressure, with secondary physiological effects; however, this remains to be supported with future research.

Acknowledgments

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References