Case report

3-dimensional buttocks response to sitting: A case report

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KEYWORDS
MRI; Sitting; Anatomy; Muscle; Tissue deformation; Pressure ulcer

Abstract    Aim of the study: The aim of this study was to describe an individual’s 3-dimensional buttocks response to sitting. Within that exploration, we specifically considered tissue (i.e., fat and muscle) deformations, including tissue displacements that have not been identified by research published to date. Materials and methods: The buttocks anatomy of an able-bodied female during sitting was collected in a FONAR Upright MRI. T1-weighted Fast Spin Echo scans were collected with the individual seated on a custom wheelchair cushion with a cutout beneath the pelvis (“unloaded”), and seated on a 300 foam cushion (“loaded”). 2D slices of the MRI were analyzed, and bone and muscle were segmented to permit 3D rendering and analyses. Results: MRIs indicated a marked decrease in muscle thickness under the ischial tuberosity during loaded sitting. This change in thickness resulted from a combination of muscle displacement and distortion. The gluteus and hamstrings overlapped beneath the pelvis in an unloaded condition, enveloping the ischial tuberosity. But the overlap was removed under load. The hamstrings moved anteriorly, while the gluteus moved posterior-laterally. Under load, neither muscle was directly beneath the apex of the ischial tuberosity. Furthermore, there was a change in muscle shape, particularly posterior to the peak of the ischial tuberosity.

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Introduction

Sitting for extended periods has the potential to compromise tissue health for individuals with mobility impairments. Reduced mobility and impaired sensation, two factors common in individuals who use wheelchairs for mobility, combine to make tissue breakdown and pressure ulcer development a major economically and psychologically costly complication of wheelchair use [1]. Development of a pressure ulcer adversely impacts multiple aspects of the affected individual’s quality of life, including autonomy, socialization and financial status [2,3]. Pressure ulcers are also a significant burden on health care systems with treatment costs estimated to be in excess of $1.3 billion annually [4].

External pressure is the defining cause of pressure ulcers [5,6]. External pressure deforms the internal soft tissue and initiates a sequence of events resulting in pathophysiological responses [7]. While the precise mechanisms by which loading and the pathophysiological responses lead to pressure ulcers have not been established, tissue deformation appears to be the underlying factor that needs to be considered in assessing pressure ulcer risk and prevention [8–10].

Studies of buttock tissue deformation have used observation of tissue thickness directly underneath the ischial tuberosity (1-dimensional) based on MRI [11–13], or finite element (FE) modeling [14–18]. 1D measurement under the ischial tuberosity had limited sensitivity to different sitting surfaces, but differences were seen across large postural changes. Still, the measurements provided little insight into the nature of the buttocks response. FE models have used a number of different approaches to estimate this response. One group has used Open-MRI to measure upright sitting [14,15,19,20]. Their FE models were built based on the anatomy of an individual and “reverse engineered” to ensure that the unloaded and loaded anatomical geometry within a coronal plane were preserved. Although described as 3-dimensional, these models are limited to a 4 mm coronal slice. Another study, utilizing a simulated sitting posture scanned in a standard MRI, built a 3-D FE model of the buttocks [18].

All FE models require some critical assumptions that impact their validity. To reduce the complexity of the models, most models assume linear isotropic properties for human tissues, and use simplified boundary conditions between tissue layers [18,19,21,22]. Finally, coronal models assume that tissue deformations occur in the inferior, superior, medial or lateral directions. Taken together, these assumptions result in models reporting anywhere from 5 to 85% compressive strain underneath the ischial tuberosity, and an incomplete picture of what happens to the buttocks tissue during loading.

If the implications of their assumptions were addressed, FE models could be highly valuable, as they allow us to estimate how an individual’s tissue might respond to different support surfaces. For the results of these models to be improved, it is necessary to accurately understand tissue deformation and apply that knowledge to optimizing the assumptions used in FE model development.

Therefore, this study seeks to describe an able-bodied individual’s 3-dimensional buttocks response to loaded sitting, as compared with unloaded sitting. Within that exploration, we will specifically consider tissue deformations, including tissue distortions (or change in shape) as well as tissue displacements (movement of tissue or structures) that might not have been identified by research published to date.

Methods

Protocol

One healthy, female adult (32 years old, height 1.57 m, weight 49.9 kg) was scanned in a 0.6 T resistive FONAR Upright MRI (FONAR Corporation, Melville, NY) which permits a seated scanning posture (Fig. 1). Scans were collected in two conditions. The first scan was collected in a seated, unloaded condition using a custom wheelchair cushion (Fig. 2). This cushion shape is based on common anthropometry and uses a more rigid foam to ensure that the ischial tuberosities were fully unloaded. The second scan was collected on a 7.6 cm piece of flat HR45 foam. In both conditions,
the MRI coil was placed beneath the wheelchair cushion.

The scan was collected using a T1-weighted Fast Spin Echo protocol, with 110 contiguous sagittal slices of 3 mm thickness, and a 350 mm in-plane field of view. The echo time was minimized for the scanner at this field of view at 17 ms, with echo train length of 3 and a TR in the range 600–700 ms, optimized automatically by the scanner for minimizing scan time. The scan used 256 phase encodings and 1 NEX. The participant tried to relax her leg and buttocks muscles and remain stationary for the duration of the scan.

Analysis

Buttocks anatomy was identified by two experienced radiographers looking at the MRI scans in 3D on a Vitrea radiology workstation (Vital Images, Minnetonka, MN). Analysis was focused on changes in soft tissue relative to bony prominences, with a particular focus on the muscles arising from the ischial tuberosities (i.e., gluteus and hamstring muscle groups) as well as subcutaneous fat and fascia. Analysis was performed using Analyze 10.0 (AnalyzeDirect, Inc., Overland Park, Kansas) by the same radiographers. 2D slices were created in the coronal and sagittal planes and analyzed visually. Muscles and bones were segmented using a spline tool that lets the user manually identify boundaries by selecting a series of points which are then joined using splines. This process is repeated on a slice by slice basis and the 3D model constructed. 3D surfaces were extracted based on those segmentations, and rendered using ParaView 3.0 (Kitware, Inc. Clifton Park, NY). The apex of the ischial tuberosity was identified visually by comparison of consecutive slices.

Results

Coronal 2D images of the region showed significant deformation of the muscle layer as indicated by a marked decrease in thickness directly inferior to the ischial tuberosity (Figs. 3 and 4). Measured at the apex of the ischial tuberosity in the coronal view, gluteus muscle thickness appears to be reduced by almost 70% under load (from 22.5 mm to 7.2 mm). In addition, the muscle appears to displace laterally in the coronal view (Fig. 3A and B). In distinction, the fatty layer inferior to the muscle showed a much smaller decrease in thickness. Fat thickness is reduced approximately 25% at the apex of the ischial tuberosity, from 8.5 mm to 6.3 mm.

Figure 1  FONAR upright MRI.

Figure 2  Two sitting conditions were used in the scanner. (A) The custom wheelchair cushion unloads the tissue underneath the ischial tuberosities; (B) Subject seated on the custom cushion; (C) Subject seated on HR45 foam cushion.
Figure 3  Front coronal view of the loaded buttocks demonstrates gluteus distortion, with gluteus highlighted in red. Raw (A) and annotated (B) MRI slices taken at apex of the right ischial tuberosity (IT), and (C) approximately 3 cm posterior to the apex of the IT. The gap between the IT and the gluteus is due to the presence of the sacrotuberous ligament and obturator internus muscle inferior to the IT.

Additional coronal scans, taken 3 cm posterior to the apex of the ischial tuberosity, show a different presentation of tissue deformation (Fig. 3C). At this location, the overall thickness of the muscle directly under the ischial tuberosity did not change as much. However, distortion is indicated by a noted change in muscle shape, including the delineations of two different muscles under the ischial tuberosity: the gluteus and the obturator internus. Also shown in the more posterior coronal scan is...
a bifurcating blood vessel when the tissue is under load. The blood vessel does not appear in the unloaded condition. A review of adjacent coronal images found the blood vessel in unloaded tissue within a slice located 3.5 mm anterior to that shown in Fig. 3C. In other words, during loading, the blood vessel displaced 3.5 mm posteriorly.

Sagittal scans of bony prominences depict antero-posterior distortion and displacement (Fig. 4). Muscle thickness under the ischial tuberosity is greatly reduced under load. In addition, the total area of muscle tissue visible in this space was reduced in the loaded condition. This sagittal view of the ischial tuberosity also shows pronounced deformation of the fatty tissue layer that was not apparent in the coronal view. Finally, the sagittal slice captured fascia and ligaments that appear to be projecting anteriorly off the ischium.

Segmenting the slices and extracting a 3D surface offered another perspective on deformation (Fig. 5). Fig. 5A shows muscles surrounding the lateral aspect of the ischium, ilium and the proximal femur from a medial viewpoint, and Fig. 5B shows the same structures from a lateral viewpoint. While the gluteus and hamstrings overlap beneath the pelvis in an unloaded condition, enveloping the ischial tuberosity, the overlap is removed under load. The hamstrings move anteriorly, while the gluteus moves posterior-laterally. Under load, neither muscle is directly beneath the apex of the ischial tuberosity. The lateral view (Fig. 5B) also illustrates the displacement and shape change of the muscles under load.

Discussion

The 2D images in the sagittal and coronal planes in combination with 3D renderings of weight-bearing bony prominences confirm the value of assessing tissue deformation in multiple planes. The 2D coronal and sagittal images show extensive displacement of the muscles surrounding the ischial tuberosity. One can infer that muscular deformation in response to loading is a combination of distortion and displacement. Specifically, there appears to be posterior and lateral displacement of the gluteus and anterior displacement of the hamstrings. In combination with displacement, sitting loads distort the gluteus resulting in a muscle that is thinner in places, and less flat than the unloaded muscle. Distortion inherently results in shearing of the muscle fibers, while displacement of the muscle will cause shearing where the muscle connects to other tissue.

The complex deformation of buttocks tissue seen in this case study may help explain the inconsistent results reported in FE models. Studies by Linder-Ganz et al. and Elsner et al. predict very high compressive strains (>50%) in the gluteus muscle directly beneath the ischial tuberosity under load [15,23]. In distinction, Makhsous et al. reported that their FE model predicted only 30% and 58% of the proximal and anterior displacements of the gluteus under load compared with their MRI [18]. Studying deformations in 3 dimensions will help improve these models by characterizing the complex distortions and displacements occurring in the anterior-posterior and medial-lateral directions.

There is a need to conduct future studies using this methodology to observe, rather than predict, the buttocks response to sitting in larger, more diverse populations. Furthermore, methods of non-rigid registration can be used to quantify the
3-dimensional buttocks response to sitting

complex deformations [24,25]. Such studies will allow for a proper investigation into two constructs that impact the buttocks—cushion interface: Deformation Resistance of individuals and the Shape Compliance of wheelchair cushions. Deformation Resistance can be defined as the intrinsic characteristic of an individual’s soft tissues to withstand extrinsic applied forces. Shape Compliance is defined as the ability of a cushion to support the buttocks with minimal buttocks deformation. Wheelchair seating involves finding a good match between the body and the supporting surface (cushion). Better understanding and measurement of these synergistic constructs is needed to improve clinical interventions and design better cushions.

As a case report, this study has a number of important limitations. First, this is a study of a single, able-bodied individual. While it certainly demonstrates that current FE models do not accurately represent all buttocks responses, the generalizability of the tissue response is not known. Mass of fat and muscle and muscle tone are variables that will differ across people that will influence deformation. Additionally, despite efforts to reproduce the sitting posture precisely during the two conditions, slight changes may have impacted the results. Finally, the choice to present information according to the Cartesian scanning planes makes interpretation a little challenging, as compared with the oblique views (which would allow a view of the long axis of the ischium). However, presentation in this manner is consistent with previous work and with the direction of loading. Future work would benefit from a 3D registration process that will allow analysis and visualization along any planes.

In conclusion, 3D imaging of the seated buttocks provides a unique opportunity to study the actual buttocks response to sitting.

Conflict of interest statement

The authors have no conflicts of interest to report.

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