Beware of the toilet: The risk for a deep tissue injury during toilet sitting

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A R T I C L E   I N F O

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Pressure injury
Toilet seat
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Transcutaneous oxygen tension

A B S T R A C T

A pressure injury (PrI) compromises quality of life and can be life-threatening. The fundamental cause of PrIs is sustained deformations in weight-bearing soft tissues, e.g., during prolonged sitting on inadequate surfaces such as a toilet seat. In nursing homes and geriatric facilities, patients need assistance using the restroom, and patients being left on the toilet for tens-of-minutes is a real-world scenario, unfortunately. Nevertheless, there are no published studies regarding sustained tissue loads during toilet sitting and their effects on tissue physiology. Here, the biomechanical and microcirculatory responses of the buttock tissues to toilet sitting were investigated using finite element modeling and cutaneous hemodynamic measurements, to explore the potential etiology of PrIs occurring on the toilet. We found that prolonged sitting on toilet seats involves a potential risk for PrI development, the extent of which is affected by the seat design. Additionally, we found that specialized toilet seat cushions are able to reduce this risk, by lowering instantaneous tissue exposures to internal stresses (by up to 88%) and maintaining reduced seat interface pressures. Furthermore, hemodynamic variables were altered during the toilet sitting; in particular, tcPO2 was decreased by 49% ± 7% (44 ± 2[mmHg]) to 22 ± 4[mmHg]) during sitting. The current study confirms that investing in expensive PrI prevention (PIP) products is likely to be ineffective for an immobilized patient who is left to sit on a bare toilet seat for long times. This argument highlights the need for a holistic-care approach, employing PIP devices that span across the entire environment where bodyweight forces apply to tissues.

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1. Introduction

A pressure injury (PrI) (also termed Pressure Ulcer), and particularly a deep tissue injury (DTI), compromises the quality of life and can be life-threatening [1]. The fundamental cause of PrIs is sustained deformations in weight-bearing soft tissues, especially during sitting [2,3]. The etiology of PrIs has been shown to be multifactorial, with 4 main mechanisms [4]: ischemia [5], cell deformation [6–9], reperfusion injury [10] and impairment of lymphatic vessels [11,12]. Sitting-acquired PrIs usually onset near the interfaces between the ischial-tuberosity (IT) bones and surrounding soft tissues [13,14]. It is a common complication in spinal cord injury (SCI) wheelchair-bound patients, where PrIs develop during wheelchair use [15–17]. Additionally, sitting-acquired PrIs might also be caused by prolonged sitting on other rigid surfaces such as plastic chairs, washroom stools or toilet seats. Products such as pressure-redistribution-cushions (PRCs) are commercially available to relieve mechanical loads within tissues at vulnerable body sites [16], including whilst sitting on toilet seats, yet the importance of continuing protection on these alternate sitting surfaces is often overlooked.

Treatment of PrIs is costly, which makes PrI prevention (PIP) a primary financial goal of health institutes. In the UK alone, the annual expenditure for treating PrIs is estimated between £1.4–2.1 billion, and the cost of treating a single PrI may reach £14,108 [18]. It is estimated that the prevalence of PrIs in SCI patients is 25%–33% of the US and European SCI populations [19,20]. However, a study regarding hospital incident reporting systems found that 86% of injuries go unreported, particularly, 26% of PrI cases go unreported (stage-I, stage-II, or un-staged) [21]. Additionally, there appears to...
be under-reporting for less severe PrIs [22,23]. Hence, it is reasonable to assume that the incidence of PrIs in general, and of sitting-acquired DTIs in particular, is underreported.

It is rather intuitive that sitting on a rigid and narrow surface such as standard plastic or wooden toilet seats for a prolonged period inflicts a risk for PrI development. In nursing homes and geriatric facilities, patients need assistance using the toilet or taking a shower. These daily routines can take up to 30-min for each event, and the prolonged sitting, combined with the factors of moisture, heat and skin fragility (particularly in elderly patients), result in an increased PrI risk [16,24,25]. Finite element (FE) computational modeling can be used to analyze internal soft tissue loads due to bodyweight and external forces that are applied during sitting, and eventually, assess the (relative) risk of developing PrIs for different sitting conditions [26]. Several studies employed the FE method to investigate the biomechanical aspects of sitting-acquired PrIs, and the use of PRCs [2,27–35]. However, no such study has been reported in the literature regarding tissue loads during toilet sitting.

Peripheral microcirculatory variables could reflect local and systemic changes, and even predict the development of ischemic stress conditions [36–39]. Laser Doppler Flowmetry (LDF) and transcutaneous oxygen tension (tc-PO2) are well-established, reliable, noninvasive measures of the cutaneous flux and tissue oxygenation status, respectively, which can be utilized under external mechanical loads [40]. However, to-date, no study concerned the LDF and tc-PO2 of the buttocks tissues during toilet sitting, and how they may change over time.

In the present work, the immediate biomechanical and microcirculatory responses of the buttocks tissues to toilet sitting were investigated in the context of the risk of sitting-acquired PrIs, especially DTIs. Using FE simulations and cutaneous hemodynamics variables (recorded in healthy subjects), we explored the potential etiology of PrIs occurring on the toilet.

2. Methods

2.1. Finite element model

### 2.1.1. Geometry

To examine the effects of sitting on a bare toilet seat versus sitting on a toilet seat cushioned with foam, a set of six FE model variants of the buttock were developed (Table 1). Each variant was developed based on a coronal cross-section of the left buttock and included the IT-bone, gluteus-maximus skeletal muscle, colon smooth muscle, fat tissue, skin, and either a foam cushion (FC), or a bare toilet seat (Fig. 1). The model variants hence differed in the seating configuration and the stiffness property of the FC (Table 1).

A single coronal magnetic-resonance-imaging (MRI) slice was acquired from a male subject with SCI (age 21-years, 90 kg, SCI-level:T6) (Fig. 1a), which is representative of muscle-atrophy. The subject was scanned in our previous published work, details regarding the scan protocol are available in previous publications [2,27,28].

We used the ScanIP® module of Simpleware® [41] to segment the tissue components from the MRI slice and define a 4 mm uniform thickness to the structure. In two of the model variants (#1,#4), the buttock was seated on bare toilet seats: a horizontal, flat type, termed type-A (Fig. 1b), and an inclined type, termed type-B (Fig. 1d). Model variants #2,#3,#5 and #6 were tested with FCs placed above the seats (Fig. 1c and e). Shapes and dimensions of the seats represent real shapes and sizes of products that are currently in the market. Seat type-A is thicker (25 mm) and wider (90 mm) than seat type-B (thickness:10–20 mm, width:60 mm).

### 2.1.2. Mechanical properties

Constitutive laws and mechanical properties of all tissues were adopted from the literature (Table 2). Specifically, the IT-bone was assumed as linear-elastic isotropic material [13]. The muscle, fat and skin tissues were assumed to be nearly-incompressible, non-linear isotropic materials with their large deformation behavior described using an uncoupled Neo-Hookean material model [46] with a strain energy density (SED) function \( W = \frac{C_{\text{elas}}}{2} (\lambda_1^2 + \lambda_2^2 + \lambda_3^2 - 3) + \frac{1}{2} K \ln(F)^2 \)

where \( C_{\text{elas}} \) is the instantaneous shear modulus (Table 2), \( \lambda_i (i = 1, 2, 3) \) are the principal stretch ratios, \( K \) is the bulk modulus and \( F = \text{det}(F) \) where \( F \) is the deformation gradient tensor.

The FCs were assumed to be isotropic linear-elastic materials with properties based on experimentally reported data from cushion material tests [47,48]. Plastic toilet seats are usually made from Polypropylene and therefore were assumed here to behave isotropically and linear-elastically (Table 2).

### 2.1.3. Boundary and material transition conditions

Boundary conditions were chosen to simulate the vertical descent of the weight-bearing ITs when sitting on a bare versus cushioned toilet seat in a thin slice model. The front and back planes of the buttock, the toilet seat and the cushion (if present) were fixed in the perpendicular direction to avoid out-of-plane translations. The inferior surface of the toilet seat and the cushion (if included) were fixed for all translations and rotations. Frictional sliding was defined between the skin and the seat or between the skin and the cushion, with the coefficient of friction set as 0.4 in all the simulations. Tied interfaces were defined between all tissue components.

| Table 1
<table>
<thead>
<tr>
<th>The model variants.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model variant</td>
</tr>
<tr>
<td>#1</td>
</tr>
<tr>
<td>#2</td>
</tr>
<tr>
<td>#3</td>
</tr>
<tr>
<td>#4</td>
</tr>
<tr>
<td>#5</td>
</tr>
<tr>
<td>#6</td>
</tr>
</tbody>
</table>
To simulate the effect of the upper body weight on tissue deformations and loads in the buttocks during sitting, downward displacements in the range of 18–31 mm were prescribed on the superior surfaces of the IT. The total weight force was determined in preliminary analysis by comparing the vertical displacement of the IT against a flat rigid surface to the empirical descent of the IT, from the non-weight-bearing and weight-bearing MRI scans. We then applied vertical displacements in the current models, against the seats and/or cushions, until the desired reaction force was achieved, equivalent to the weight of the scanned subject.

2.1.4. Numerical method and outcome measures

The model variants were meshed using the ScanIP module of Simpleware® [41], with finer meshes used in specific regions of interest associated with DTI, i.e. within the entire skin layer and at the muscle and fat tissue regions interfacing the IT (Fig. 1a). Each model included 1000–30,000 elements (Table 2). Greater mesh densities yielded negligible differences in all outcome measures in terms of numerical convergence or accuracy, in all model configurations (less than 2%).

FE simulations were set up using PreView of FEBio (Ver.1.18.2), analyzed using Pardiso linear solver of FEBio (Ver.2.2.6), and post-processed using PostView module of FEBio (Ver.1.9.1) [46]. Runtime of each model variant was under 2-min using a 64-bit Windows7-based workstation with an Intel Core i7-5820 K 3.30 GHz CPU, 32 GB of RAM.

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Fig. 1. Computational model of the buttock of an individual seated on different toilet seats: (a) MRI anatomy and segmentation. (b) Mesh of model configuration with a type-A seat, without a foam cushion (FC). (c) Mesh of model configuration with a type-A seat with FC. (d) Mesh of model configuration with a type-B toilet seat, without FC. (e) Mesh of model configuration with a type-B toilet seat, with FC.
frequency was 32 Hz, tc-PO2 and LDF accuracy was evaluated using the PeriFlux5000 system and PSW software (PeriFlux5000, PERIMED). The sampling rate was 10 kHz.


designated probe location was marked on the skin according to the designated probe location. The probe was attached accordingly while the patient was lying supine. The probe was placed naturally on the seat type-B (Fig. 1d).

Holes were drilled to accommodate the probes, which were mounted under the position of the right IT (Fig. 2b). The probe hole was located on the skin at the point of intersection between the fat, muscle (gluteus-maximus) and bone regions.

For all tissues, the above stress data were collected only from the elements below the imaginary horizontal line passing through the point of intersection between the fat, muscle (gluteus-maximus) and bone regions.

### 2.2. Peripheral microcirculatory hemodynamics measurements

In order to characterize hemodynamic changes, i.e. flow and oxygen supply in peripheral microcirculation following sitting on a bare toilet seat, we measured red blood cells (RBC) flux in the skin microcirculation, using LDF (1 mm-diameter flexible optic fiber, surrounded by 3 mm-diameter flat holder), and skin tissue oxygen tension using a tc-PO2 monitor (15 mm-diameter, 11.3 mm-height, rigid electrode placed in a 30 mm-diameter fixation ring). RBC flux and tc-PO2 values were recorded continuously using PERIMED™ system and PSW software (PeriFlux5000, PERIMED). The sampling frequency was 32 Hz, tc-PO2 and LDF accuracy was ±3 mmHg and ±5%, respectively.

#### 2.2.1. Experimental protocol

The following human studies were approved by the institutional ethics committee of Afeka Tel-Aviv Academic College of Engineering (approval number:23-06-2016-1-AFK). A sample of two healthy female subjects (ages 27 and 30, bodyweights 50 and 58 kg) and one healthy male subject (27 years-old, bodyweight 80 kg) participated in the experiments. Measurements were taken from the buttocks area, under the IT (Fig. 2a).

The toilet seat used in the experiments (Fig. 2b) resembles the seat type-B (Fig. 1d). Holes were drilled to fit the probes, which were mounted under the position of the right IT (Fig. 2b). The designated probe location was marked on the skin according to the probe hole while the participant was seated on the toilet seat. Probes were attached accordingly while the patient was lying prone, and the system was calibrated.

Baseline measurements were recorded for 5-min. Then, each subject sat on the toilet seat and data were recorded for 30-min (note: the arms were not supported on armrests and the feet were placed naturally on the floor, as in a realistic toilet-sitting posture). Finally, subjects stood up for 2-min of recovery before returning to a prone position for additional 15-min of recovery.

#### 2.2.2. Outcome measures

The following variables were recorded [49]: (i) Flux of RBCs — the product of the relative moving RBCs and the relative velocity of these cells in the measured volume (Perfusion Units (PU)). (ii) Concentration of moving RBCs (CMBC). (iii) Oxygen released in the tissues through the capillaries (tc-PO2).

In order to compare tc-PO2 measurements between subjects, a “Z”-normalization (Z-score), was applied (Eq. (3)).

\[
 Z = \frac{s - \mu}{\sigma} \tag{3}
\]

where \( s \) is the non-normalized value, and \( \mu \) and \( \sigma \) are the mean and standard-deviation of its distribution, respectively.

Additionally, the frequency spectra (filtered with a 7-term moving-average filter) of the PU and CMBC measures for the sitting stage were analyzed, and compared to the baseline.

![Fig. 2. Tissue oxygenation measurements: (a) Location of the probes (indicated by circles), and (b) the toilet seat used in our experiments, with holes designated to fit the location of the probes.](image)

### Table 2

Mechanical properties of the model components and characteristics of the finite element mesh.

<table>
<thead>
<tr>
<th>Model component</th>
<th>Shear modulus [kPa]</th>
<th>Bulk modulus [kPa]</th>
<th>Elastic modulus [kPa]</th>
<th>Poisson’s ratio</th>
<th>Number of mesh elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin(^a)</td>
<td>31.9</td>
<td>3179.37</td>
<td>–</td>
<td>0.495</td>
<td>8984</td>
</tr>
<tr>
<td>Fat(^b)</td>
<td>0.286</td>
<td>28.5</td>
<td>–</td>
<td>0.495</td>
<td>28,879</td>
</tr>
<tr>
<td>Muscle(^c)</td>
<td>7.1</td>
<td>707.6</td>
<td>–</td>
<td>0.495</td>
<td>10,268</td>
</tr>
<tr>
<td>Bone(^d)</td>
<td>–</td>
<td>–</td>
<td>7 × 10^6</td>
<td>0.3</td>
<td>2170</td>
</tr>
<tr>
<td>Foam cushions(^e)</td>
<td>–</td>
<td>–</td>
<td>7</td>
<td>0.3</td>
<td>1900</td>
</tr>
<tr>
<td>Toilet-seat(^d) Type A</td>
<td>–</td>
<td>–</td>
<td>1.75 × 10^6</td>
<td>0.45</td>
<td>1521</td>
</tr>
<tr>
<td>Type B</td>
<td>–</td>
<td>–</td>
<td>1.75 × 10^6</td>
<td>0.45</td>
<td>1018</td>
</tr>
</tbody>
</table>

\(^a\) Data were adopted from the literature \([2,42]\).

\(^b\) Data were adopted from the literature \([2,43,44]\).

\(^c\) Data were adopted from the literature \([47,48]\).

\(^d\) Data were adopted from the literature \([45]\).
frequency spectrum per each subject and outcome measure.

2.3. Human subject pressure mapping

Interface pressures were assessed for a 31-year-old female, 82 Kg; The subject was mapped (using the XSensor X3 DISPLAY system and PX100:36.36.02 pad) while sitting on bare surfaces and with the use of air-cell-based (ACB) cushions. The ACB cushions were used on a contoured toilet seat as well as a flat toilet seat and a shower commode seat. The cushions were preconditioned (de-stressed) and maps were recorded instantaneously after 3-min of loaded time. One pressure map was recorded for each sitting scenario.

3. Results

3.1. Finite element modeling

Comparison of the effective stresses in the soft tissue immediately upon sitting on bare seats of types A and B are shown in Fig. 3. Stress concentrations appeared in gluteal muscle tissues adjacent to the IT, and in the skin of the buttocks in contact with the seats, for the two seat types. Stress values in the tissues were considerably greater for the type-B seat compared to type-A. Peak effective, compressive, tensile, and shear stresses in all tissues were lower when the FCs were incorporated, with respect to sitting on the bare seats, (Fig. 4, Table 3).

3.2. Peripheral microcirculatory hemodynamics measurements

Throughout the experiments, subjects changed their body postures several times, during which the LDF and tc-PO2 variables were continuously measured. Alteration of a subject’s posture (e.g. lying to sitting) resulted in considerable changes in tissue deformation patterns in their buttocks, which consequently affected the peripheral microcirculatory hemodynamics, manifested in the RBC flux and tc-PO2 readings (Fig. 5, Table 4).

Focusing on the sitting period, tc-PO2 values in all subjects showed a similar behavior over time (Fig. 6, Table 5): When subjects sat on the bare toilet seat, there was an immediate decrease in tc-PO2 values, which we refer to as ‘phase-1’ of the sitting period. After reaching a minimum, there was an increase in tc-PO2 values, which we term as ‘phase-2’. In the remaining sitting period, which we call ‘phase-3’, a moderate decline was observed in tc-PO2 values (compared to extent and rate of decrease in the aforementioned phase-1). Interestingly, the average duration for each phase was similar for all subjects (Fig. 6, Table 6).

The frequency spectrum of the PU and CMBC signals during the sitting period showed a similar trend: the frequency intensity of both signals was the highest in phase-1 of the sitting, and decreased along the remaining sitting time. The baseline frequency intensity was similar to phase-3 of the sitting (Fig. 7).

3.3. Human subject pressure mapping

The use of cushions dramatically reduced peak interface pressures in all cases (Fig. 8).

4. Discussion

It is common knowledge that prolonged sitting on rigid surfaces may cause PrIs development in the buttocks. The problems that arise from prolonged sitting on the toilet in at-risk individuals are well-known to clinicians and caregivers and can extend beyond tissue breakdown to internal prolapse. Although confirmatory for the clinicians, we found it important to quantify this effect with scientific data as a proof of concept in the literature, based on both FE modeling and hemodynamic studies in 3 healthy subjects (the rationale for testing a convenience sample of 3 subjects is that sitting on rigid surfaces is a known risk factor).

Peak stresses occurring in all tissues during toilet sitting were comparable to data reported for chair sitting [2,27,28,32,34,50]. Furthermore, our simulations indicate that: (i) The specific toilet seat design affects the internal loading state in the soft tissues of the weight-bearing buttocks considerably, whereas some seat designs are superior to others in causing less localized tissue deformations and stresses. (ii) Toilet seat cushions can be effective in mitigating internal tissue loads. However, the extent of tissue loads reduction for a certain individual (with specific anatomy and tissue properties) depends not only on the type of cushion being used, but also on the (complex) interactions between the toilet seat design and the cushion design (which includes geometry features and material stiffness properties). Consistently for all tissues, the cushions could act to (partially) correct an inferior design of the seat in terms of tissue protection. This was apparent in the more dramatic reduction of stresses offered by the addition of a cushion to type-B, which originally generated the more at-risk biomechanical conditions with respect to type-A (Figs. 3 and 4).

FE modeling inevitably involves underlying assumptions and computational accuracy issues. The limitations of the buttock model used here were discussed elsewhere in the context of wheelchair sitting [28,35]. The modeling is a snapshot of the initial response to load, which is a limitation as stress relaxation is expected at the deformed tissues, with individual characteristics that depend on age, tissue composition and health status. We used a pseudo-2D cross-section of the buttock rather than a full 3D-model; 3D-modeling would have ideally showed results that are potentially more accurate, also regarding translational motion of the buttock, however, at a price of additional numerical complexity and computing power.

The pressure mapping indeed demonstrated a pressure redistribution capacity of designated cushions on toilet seats and shower commodes, which protects the tissues near the ITs (Fig. 8). These data are consistent with the FE simulations that likewise, support the use of toilet seat cushions [28,35].

Alterations in microcirculatory variables during the
experimental stages (Fig. 5) are due to metabolic changes in capillaries, corresponding to the state of tissue deformations. These results are consistent with previous studies, which observed a trend of reduction in tissue oxygenation under external loads [40,51,52].

tc-PO2 value decreased in phase-1 of sitting, followed by an increase in phase-2 and a decline again in phase-3. This behavior was likely caused by capillary obstruction, which promotes local ischemia and hypoxia (phase-1) [53] followed by vasodilation, a local compensation mechanism which elevates oxygen levels (phase-2) [54]. Finally, the accumulation of excess lactate during hypoxia [55] may result in the gradually decreasing transcutaneous oxygen levels (phase-3). The 3-phases response to prolonged loading observed in the 3 healthy young subjects is rare in at-risk

Table 3

<table>
<thead>
<tr>
<th>Seating Condition</th>
<th>Effective Stress ($\sigma_e$) Improvement (in percentage) for the muscle, fat and skin tissues, when comparing different model variants.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat of type A compared to Seat of type B (non-cushioned)</td>
<td>Cushioned seat of type A Compared to bare type A seat</td>
</tr>
<tr>
<td></td>
<td>7 [kPa] cushion</td>
</tr>
<tr>
<td>Muscle</td>
<td>-22%</td>
</tr>
<tr>
<td>Fat</td>
<td>-73%</td>
</tr>
<tr>
<td>Skin</td>
<td>-43%</td>
</tr>
</tbody>
</table>

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individuals as demonstrated before [56]. Indeed, the prolonged suppression of tissue oxygenation and blood flow under body-weight load likely indicates a potential risk to the individual. We observed moderate changes in the PU signal across the experimental stages, which may reflect compensatory mechanisms in the microcirculation. Frequency analysis of LDF signals provides information regarding the distinctive rhythms which constitute skin perfusion, vasomotion of the capillaries, and oscillation in tone of the blood vessel walls [57]; the reduction in frequency intensity is the impact of this vasomotion on the capillaries.

5. Conclusions

Using computational modeling and hemodynamic measurements, we confirmed that prolonged sitting on toilet seats involves a potential risk for PrIs, and this potential risk is affected by the seat design — a narrower and inclined seat may result in increased exposures to stresses. Additionally, we showed that specialized cushions are able to reduce the risk. Most importantly, the present work illustrates that investing in expensive PIP beds or cushions is likely to be ineffective for an immobilized patient who is left to sit on the toilet for long times. This argument points to the need for a holistic care approach — including a range of PIP devices throughout the entire environment.

Table 4
Average tc-PO2 [mmHg] values in the experimental stages, for all three subjects.

<table>
<thead>
<tr>
<th>Average tc-PO2 [mmHg]</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prone Lying (Baseline)</td>
<td>41.2</td>
<td>47.5</td>
<td>42.2</td>
</tr>
<tr>
<td>Sitting</td>
<td>24.8</td>
<td>27.0</td>
<td>15.5</td>
</tr>
<tr>
<td>Standing</td>
<td>23.7</td>
<td>29.9</td>
<td>33.9</td>
</tr>
<tr>
<td>Prone Lying (Recovery)</td>
<td>22.3</td>
<td>28.3</td>
<td>29.1</td>
</tr>
</tbody>
</table>

Table 5
Average tc-PO2 [mmHg] values during the three sitting phases, for all three subjects.

<table>
<thead>
<tr>
<th>Average tc-PO2 [mmHg]</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase-1</td>
<td>15.8</td>
<td>14.5</td>
<td>5.6</td>
</tr>
<tr>
<td>Phase-2</td>
<td>23.0</td>
<td>25.0</td>
<td>11.2</td>
</tr>
<tr>
<td>Phase-3</td>
<td>25.3</td>
<td>29.7</td>
<td>19.6</td>
</tr>
</tbody>
</table>

Table 6
Time duration of each sitting phase, for all three subjects.

<table>
<thead>
<tr>
<th>Time Duration [minutes:seconds]</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase-1</td>
<td>00:27</td>
<td>02:12</td>
<td>04:12</td>
</tr>
<tr>
<td>Phase-2</td>
<td>03:49</td>
<td>10:39</td>
<td>07:36</td>
</tr>
<tr>
<td>Phase-3</td>
<td>25:44</td>
<td>17:09</td>
<td>18:12</td>
</tr>
</tbody>
</table>

1 The flux of RBCs (PU) is calculated using the equation Flux = flow/cross-sectional-area. While flow and cross-sectional-area both decrease, due to capillary obstruction, the change in the flux values is small [36,37].
Fig. 7. Intensity distributions of perfusion units (PU) and concentration of moving blood cells (CMBC) frequency spectra, obtained from subjects #1, #2 and #3. The frequency intensity of each signal decreases across the three sitting phases; however, the frequency intensity of the third phase is similar to the baseline signal. The peak values at the frequencies around 1 Hz (0.9–1.2 Hz) represent the heartbeat frequency of the subjects (which ranged between 54 and 72 beats per minute).

Fig. 8. Interface pressure mapping of sitting on different bare toilet seats versus sitting on the same seats when cushioned: (a) Air-cell-based (ACB) toilet seat cushion on a flat seat. (b) ACB toilet seat cushion on a contoured seat. (c) ACB shower commode cushion on a shower commode seat. The use of cushions dramatically reduced peak interface pressures in all cases.
where bodyweight forces apply, to minimize the occurrence of these wounds.

**Conflict of interests**

None.

**References**