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# Comparative analysis of spinal flexion angles during smartphone use in toilet: a randomized cross-over with three-period study

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*Purpose*: The purpose of this study was to quantify the impact of smartphone use while sitting on the toilet on the spinal flexion angles and the time effect. *Methods*: Measurements of the spinal flexion angles in the sagittal plane were made by thirty participants while they sat on the toilet for 10 min, using a smartphone in either one, both, or neither hand. The individual's forehead, cervical, thoracic and lumbar spinal areas were each fitted with five different inertial motion sensors. SPSS 26.0 software was used to statistically evaluate all of the data. *Results*: People who used smartphones with both hands had considerably larger ($P < 0.05$) cervical and spinal flexion angles than those who did not. A statistically significant ($P < 0.001$) association was observed by regression analysis between time and spinal flexion angle ($r = 0.747$ for no smartphone, $r = 0.793$ for a smartphone used in one hand and $r = 0.855$ for a smartphone used in both hands). Consequently, when using the smartphone with both hands, the flexion angle of the spine entered a more stable state of angles. *Conclusions*: The results showed that the cervical region's flexion angles change when using a smartphone while sitting on the toilet. Even when not using a smartphone, the flexion angle of the spine when sitting on the toilet will progressively increase.

*Key words*: *toilet, smartphone, cervical spine, biomechanics, inertial measuring unit, sitting position*

## 1. Introduction

The pervasive use of smartphones has become an integral part of modern life [20], with people using them for communication, information and entertainment. Concerns have been expressed regarding the possible negative effects of this extensive usage on users' musculoskeletal health, specifically about the cervical spine [5], [7], [18]. Recent studies have reported a high prevalence of neck pain and other musculoskeletal disorders related to smartphone use, mainly due to the prolonged and awkward postures adopted while using these devices [3], [10], [17].

The "text neck" phenomenon, characterized by excessive neck flexion during smartphone use, has been identified as a significant contributor to the development of musculoskeletal disorders [6], [8], [15]. This position places increased mechanical load on the spine, leading to muscle fatigue, discomfort and, ultimately, chronic pain [3], [10]. In addition, smartphone users tend to maintain these positions for extended periods, exacerbating the strain on their musculoskeletal system in the case of sitting or standing posture. Given the increasing reliance on smartphones in daily life, the relationship between smartphone use and the activities of daily living including sitting on the toilet must be elucidated.

Moreover, 74.5% of the American respondents to a previous study reported using their smartphones while in the toilet [2]. It appeared that people are addicted to using their smartphones even when they go to the toilet

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[1]. In contrast to the typical sitting position, the toilet sitting posture tends to have a narrower angle between the spine and femur, which could facilitate bowel evacuation [14]. Studies that assess the relationship on spinal flexion angles between the different segments or the time effect on smartphone use while sitting on the toilet are scarce.

However, measured angles of previous studies did not fully demonstrate the flexion angle of the head and neck since only one detector was attached to the forehead [5], [6], [12]. There are possible changes in the flexion angles of the thoracic and lumbar vertebrae, which may also affect the cervical spine. To improve evaluation method, our study attached five inertial measurement unit (IMUs) to accurately measure the spinal flexion angle of each spinal region during movement.

Thus, this study was aimed to investigate how using a smartphone while sitting on a toilet affects the spine with time effects. Identifying ergonomic posture and educating users on smartphone usage can help prevent or alleviate health issues.

# 2. Materials and methods

## 2.1. Participants

Thirty healthy participants (15 women and 15 men) were included according to the following criteria [13]: 1) having used smartphone both while sitting and standing; 2) having used a touch-screen smartphone for at least a year. Participants were excluded if they suffered from one of the following diseases: 1) acute worsening of symptoms associated with spinal nerve compression due to trauma or other reasons; 2) tumors, infections in the spine and abnormalities in development; 3) past surgical procedures and neck trauma; 4) excessive osteoporosis; 5) cognitive deficiency; 6) pregnancy, nursing or planning to get pregnant while the study is underway. This trial design was a randomized cross-over with three-period study. The washout phase between each period was at least 5 minutes to minimize potential the carry-over effect. Considering that the subjects can know the stage they are in during the trial, the subjects and researchers are not blinded, only the analysts are blinded.

Participants were required to provide informed consent before entering this study in the First People's Hospital of Shunde from May 17, 2021 to July 11, 2021. The study was approved by the Ethics Committee of the First People's Hospital of Shunde (Approval no. 20210603). All procedures were performed out in accordance with the Declaration of Helsinki and its subsequent amendments, or equivalent ethical norms, as well as the First People's Hospital of Shunde's ethical standards. To attain a statistical power of 0.80, the sample size had to meet the minimum number of samples. Every individual used their smartphones while sitting on the toilet. Before the experiment began, the researcher gave each participant an overview of the basic method.

## 2.2. Data collection

For every individual, the sagittal plane angle of spinal flexion was measured when the individual used a smartphone with both hands, only one hand, or not at all. Data were gathered using a standard toilet (DONGPENG, China) in a separate bathroom (Fig. 1a). Throughout the trial, no one was permitted to use the bathroom to prevent bias. All participants were permitted to remain in a sitting position without leaning back against the toilet lid to avoid any confounding effects if the angle or shape of the toilet lid is altered. Participants utilized their smartphones in accordance with their typical routines and completed the three 10-minute tasks listed below: 1) not using a smartphone while sitting on the toilet; 2) sitting on the toilet with both hands holding the smartphone and not switching to holding the smartphone with one hand; 3) using a smartphone with one hand but being unable to transition to using both hands while sitting on the toilet (Fig. 1d). Participants were randomly assigned to each task. The subjects were kept in their customary sitting position on the toilet for 10 min without being subjected to any additional restrictions, nor were they allowed to rise up or raise their heads. There were no restrictions on the experiment's browsing speed or content [13].

The Participants' spinal flexion angles were collected using a wireless inertial measuring unit (IMU, Posture Monitoring System, Klarity Medical & Equipment (GZ) Co., Ltd., China). Each participant had five IMUs affixed to the middle of their foreheads: the first sacral spinous process (S1), the third thoracic spinous process (T3), the sixth cervical spinous process (C6), and the first lumbar spinous process (L1) (Fig. 1e). Five distinct spinal areas were identified: lumbar (Lx): L1 to S1, upper thoracic (UTx): C6 to T3, lower thoracic (LTx): T3 to L1, cervical (Cx): forehead to C6, and spinal (Sx): forehead to S1.

Data were continuously recorded. The sagittal plane flexion angle of the spine and angular changes in the

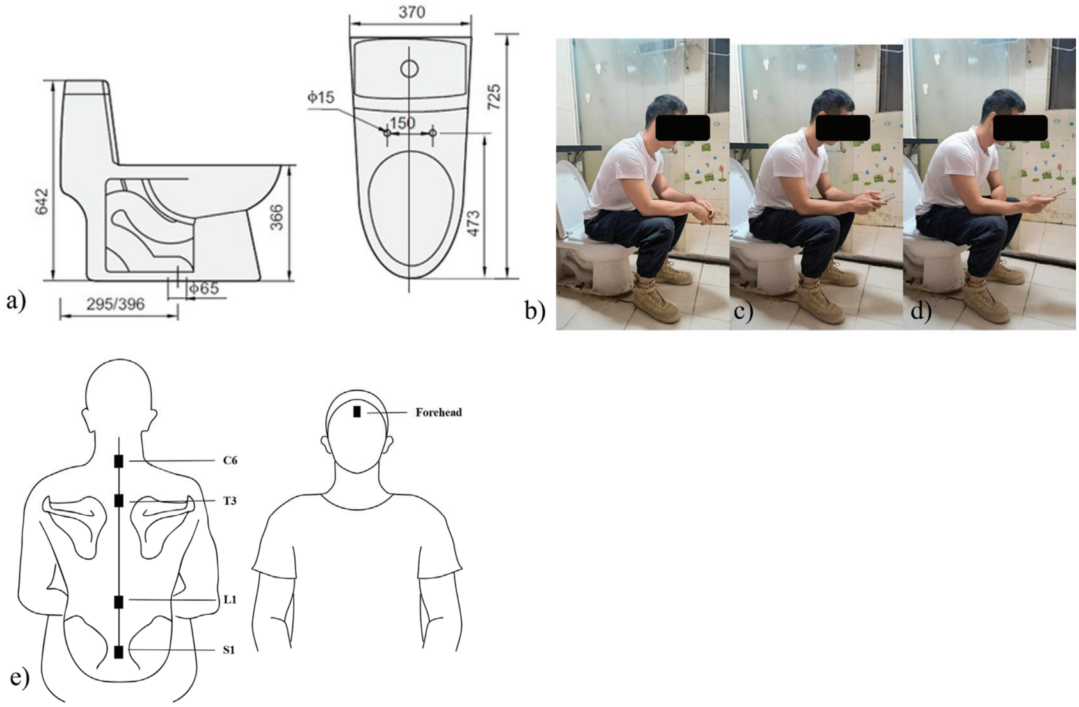


Fig. 1. Design drawing of toilet and proposed sitting position: (a) design drawing of toilet, (b) sitting on the toilet without smartphone, (c) with both hands smartphone, (d) one hand smartphone using (right), (e) position of the five inertial motion units (IMU) on the spine and the forehead

cervical, upper thoracic, lower thoracic and lumbar regions were recorded at a sampling rate of 100 Hz using an IMU. The participants flexed and extended the spine three times and then maintained a comfortable position while looking straightforward for 10 s. The participant looked forward for 10 s while maintaining a comfortable posture after flexing and extending their spine three times. This gave the participant's spinal flexion angle while they were standing as a baseline reference. When sitting on the toilet and bending their spine, their spinal flexion angles would increase. On the other hand, when extending their spine while sitting on the toilet, their spinal flexion angles would decrease. There were breaks of at least 5 min between each task. By deducing the reference posture's mean angle from the spinal flexion angle data obtained from the three sitting tasks, this information was obtained.

## 2.3. Statistical analysis

Information was acquired by creating probability distributions of the spinal flexion angle samples that were collected by sensors while the task was being performed. Samples of 10-min spinal flexion were taken for each sitting task on the toilet, and the samples were rearranged according to the angle. The values of the 10th, 50th and 90th percentile angles were calculated. Differences between the three tasks were examined for each variable using Tukey's post-hoc analysis and repeated measures ANOVA if the values were normality. The skewed data were analyzed by Kruskal–Wallis test. To examine the association between the flexion value data for spine regions and time points, Pearson correlation and linear regression were computed for scatter plots of flexion values for each task during a 10-min period. A two-sided significance level of $\alpha = 0.05$ was used. The data were analyzed using SPSS 26.0 (IBM SPSS Statistics Version 26; International Business Machines Corp., New York, USA) with a significance level of $p < 0.05$.

# 3. Results

The participants mean age ± SD was 25.7 ± 1.5 years. BMI was 21.4 ± 1.4 kg/m$^2$ (Table 1). Whether holding a smartphone with both hands, just one or without using a smartphone, the angle of spinal flexion when sitting on a toilet was measured and it showed that the angle of spinal flexion of 10th and 50th levels with both hands and one hand is larger than that without using a smartphone (Table 2). While there was no significant difference between the three tasks at the

90th percentile level, there were significant differences at both the 10th and 50th levels (Fig. 2a). Similar to the spinal flexion angle, at the 10th and 50th percentiles, significant differences were found across the three tasks. Conversely, the 90th percentile level could not be identified as significant in this analysis (Fig. 2b). Furthermore, during the three tasks, no discernible variations were found in the lumbar, lower thoracic, or upper thoracic areas (Table 2).

Table 1. Mean and standard deviation of participant information

| | N | Age [years] | Height [cm] | Weight [kg] | BMI [kg/m$^2$] |
|---|---|---|---|---|---|
| Male | 15 | 25.7(1.5) | 175.3(5.5) | 67.8(4.5) | 22.0(0.9) |
| Female | 15 | 25.6(1.5) | 160.9(4.2) | 53.9(5.4) | 20.4(2.6) |
| Total | 30 | 25.7(1.5) | 168.1(8.7) | 60.9(8.5) | 21.4(1.4) |

Further analysis of the spinal flexion angles data exhibited a time-dependent relationship with a positive correlation of $r = 0.747$ ($P < 0.001$) without smartphone use when sitting on the toilet. A significant increase of 0.002 degrees every 100 ms was indicated by the regression line's slope ($P < 0.001$). Thus, in the task 1 scenario (Fig. 2c), the estimated average degree at time zero was 22.809, and in 10 min, it grew to 34.809, demonstrating the appropriateness of the chosen parameters. Task 2, which involved using a smartphone with both hands while sitting on the toilet (Fig. 2d), revealed a similar correlation ($r = 0.793$; $P < 0.001$) with task 3 ($r = 0.855$; $P < 0.001$), which involved using a smartphone with both hands (Fig. 2e). When subjects sat on the toilet using both hands or one hand to use a smartphone, the spinal flexion angle changed with time. Moreover, the angle increased rapidly and subsequently remained relatively stable during the 10-minute period. Notably, the spinal flexion angle demonstrated greater stability when participants were sitting on the toilet while holding their smartphones with both hands as compared with holding only with one hand. For the cervical region, the regression lines and scatter plots also revealed the time-related correlation in the three tasks (Fig. 2f–h). Ten minutes of time were positively correlated with the cervical region's flexion angles in tasks 1 ($r = 0.104$; $P < 0.001$) and 3 ($r = 0.281$; $P < 0.001$) are both positively corelated with time in ten-minute duration (Fig. 2f and h). However, negatively correlations were observed when seated on the toilet with both-hands smartphone using ($r = 0.299$; $P < 0.001$) (Fig. 2g).

Table 2. Flexion angle without smartphone or with one-hand or both hand grip

| Flexion angles | Dependent variable | Not using | 95% CI | Both hands using | 95% CI | One hand using | 95% CI | *P*-value |
|---|---|---|---|---|---|---|---|---|
| Spinal Flexion Angle | 10th percentile | 13(2.4) | (8.1, 17.8) | 38.7(2.2) | (34.3, 43.2) | 39.1(2.1) | (34.7, 43.5) | <0.001 |
| | 50th percentile | 28.6(2.5) | (23.4, 33.8) | 46(2.3) | (41.4, 50.7) | 48.3(2.2) | (43.9, 52.7) | <0.001 |
| | 90th percentile | 47.8(4.8) | (37.9, 57.6) | 52(2.3) | (47.2, 56.8) | 54.1(2.1) | (49.8, 58.5) | >0.05 |
| Cervical Flexion Angle | 10th percentile | –24(2.2) | (–28.48, –19.42) | –5.2(2.2) | (–9.65, –0.66) | –6.2(1.7) | (–9.64, –2.70) | <0.001 |
| | 50th percentile | –12.1(2.1) | (–16.5, –7.65) | 0.5(2.2) | (–4.0, 5.1) | 0.6(1.7) | (–2.9, 4.1) | <0.001 |
| | 90th percentile | 1(2.8) | (–4.8, 6.8) | 8.4(2.2) | (3.8, 13.0) | 7.1(1.8) | (3.4, 10.7) | 0.06 |
| Upper Thoracic Flexion Angle | 10th percentile | –11.4(1.3) | (–14.0, –8.8) | –8.6(1.3) | (–11.3, –5.9) | –8.6(1.4) | (–11.4, –5.78) | >0.05 |
| | 50th percentile | –7.2(1.3) | (–9.9, –4.5) | –5.2(1.4) | (–7.95, –2.4) | –5.4(1.5) | (–8.4, –2.4) | >0.05 |
| | 90th percentile | –0.3(1.9) | (–4.1, 3.6) | –1.6(1.4) | (–4.5, 1.4) | –2(1.5) | (–5.1, 1.2) | >0.05 |
| Lower Thoracic Flexion Angle | 10th percentile | 12.1(2.3) | (7.5, 16.7) | 17.9(2.5) | (12.8, 23.0) | 17.1(2.4) | (12.2, 21.9) | >0.05 |
| | 50th percentile | 21.2(2.2) | (16.7, 25.7) | 22.8(2.4) | (18.0, 27.7) | 22.8(2.2) | (18.3, 27.3) | >0.05 |
| | 90th percentile | 26.1(2.0) | (21.9, 30.2) | 26(2.2) | (21.5, 30.5) | 26(2.2) | (21.6, 30.4) | >0.05 |
| Lumbar Flexion Angle | 10th percentile | 21.3(2.1) | (17.0, 25.6) | 22.9(2.7) | (17.3, 28.4) | 25.2(2.2) | (20.6, 29.8) | >0.05 |
| | 50th percentile | 28.8(2.3) | (24.1, 33.5) | 30.7(2.6) | (25.3, 36.0) | 31.1(2.3) | (26.4, 35.8) | >0.05 |
| | 90th percentile | 32.8(2.2) | (28.3, 37.3) | 33.2(2.5) | (28.2, 38.3) | 34(2.3) | (29.4, 38.6) | >0.05 |

Note: Values are presented as mean and standard deviation.

# 4. Discussion

When comparing smartphone use while sitting on the toilet with no smartphone use, this study discov-

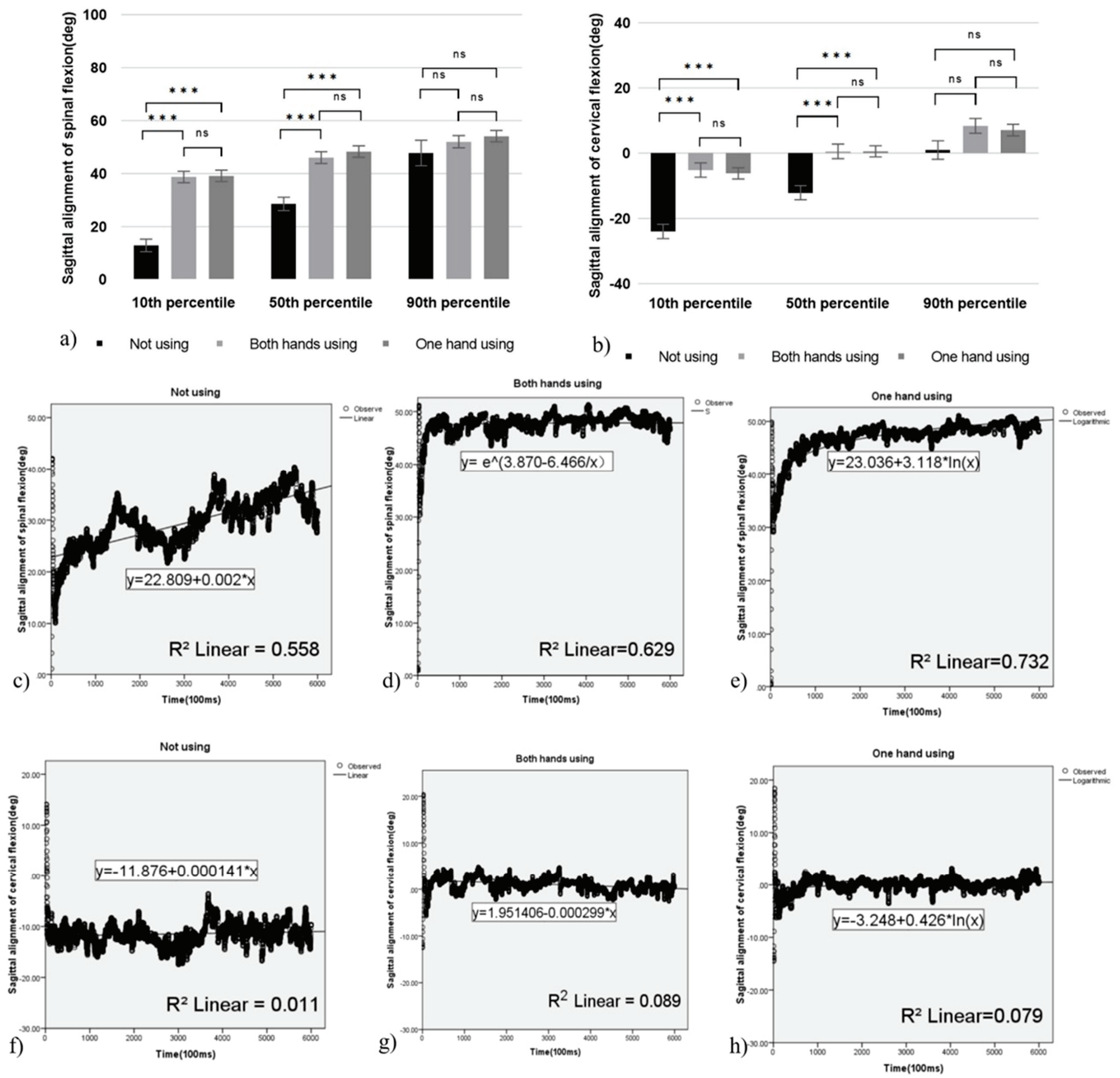


Fig. 2. Spinal and cervical flexion angle alterations when sitting on the toilet.
(a) Spinal and (b) cervical flexion angle alterations. Error bars indicate standard deviation.
Bars with "*" indicate significant differences ( $p < 0.05$) in the Tukey's test. Over the duration of the 6000 data collections (one collection every 100 msec), average spinal flexion angle values of all the subjects without using smartphone (c), with both-hand using (d) and with one-hand using (e). Average cervical flexion angles without using smartphone (f), with both-hand using (g) and with single-hand using (h) were also presented.
The regression analysis showed a significant correlation between the scatter plot and the regression line ( $p < 0.001$)

ered a significant difference in cervical and spinal flexion at the 10th and 50th percentiles. These results suggested that using a smartphone while sitting on the toilet may cause the spinal angle to increase, particularly in the neck region.

The existing literature on angle collection is largely based on neck or head region when associated with using a smartphone [4], [6]. There are possible changes in the flexion angle of the thoracic and lumbar vertebrae, which may also affect the cervical spine. To improve evaluation method, our study attached five IMUs to the forehead, C6, T3, L1 and S1 to accurately measure the spinal flexion angle of each spinal region during movement. However, sitting on the toilet tends to narrow the angle between the spine and femur compared with a typical sitting posture. Considering the specific posture on the toilet, five sensors were employed to more accurately separate the spine into four regions in comparison with previous studies [4], [11]. Thus, we calculated the angle of entire spine for better evaluation.

Using a smartphone for extended periods of time while maintaining poor posture aggravates upper crossover syndrome and spinal loading [6]. Abnormal posture, scapular raising, and head center of gravity are often shifted by prolonged forward head and neck positions.

Compared to Xie's studies on the spinal flexion angle while sitting on a chair [19], the overall flexion angle of spine is almost the same with our study. This means that using a phone while sitting on a chair and using a phone while sitting on a toilet has a similar load on the spine, exacerbating the problem of upper crossover syndrome. However, it is unknown how variations in spinal flexion angle relate to muscle loading on the spine when using a smartphone while sitting on the toilet. According to Vasavada et al. [16], the strain on the spinal extension muscles correlates with the spinal flexion angle. Using a smartphone puts more strain on the spinal extensor muscles than not using one, making it harder to keep the head stable while sitting on the toilet. However, more research is required to confirm which aspect of the muscle load is elevated in studies assessing electromyography (EMG) of the spinal muscles. The cervical spine showed greater flexion angle and a more stable flexion posture when sitting on the toilet with both hands or one hand smartphone using compared to no smartphone using in our study. Besides, Yoon et al. [20] demonstrated significant variations in the head flexion angle between one and both hands. However, our findings were inconsistent with their study that no significant difference was found between both hands and one-hand smartphone use in each spine region. This might be the result of the fact that, in order to maintain each person in their true natural condition, our study did not require participants to perform certain prescribed tasks, such as browsing the internet with a smartphone in one hand or messaging with a smartphone in both hands [6].

No discernible variation was observed in the thoracic degrees of flexion, suggesting that the thoracic spinal area could retain comparable degrees of flexion and a certain degree of stability in any given posture. Gulnihal Metin et al. [9] reported that the angle of flexion in lumbar region was approximately 3.2° when sitting and using a smartphone with single hand. However, in this study, the lumbar flexion angle was relatively larger, reaching a 50th percentile angle of 31° when sitting on the toilet. These findings suggested that using a smartphone with single hand while sitting on the toilet might exert a greater load on the lumbar spine than sitting on a chair. However, further studies are required to demonstrate the stress and discomfort on the lumbar region when using the smartphone with both hands on the toilet. Limitations are lack of confounding testing, small sample size and limited biomechanical evaluation.

To increase the value of this study, future research should incorporate more intricate tasks and realistic usage. Furthermore, additional research is needed to determine how the spinal flexion angle varies between squatting and normal toilets to cover all possible evacuation scenarios.

# 5. Conclusions

This study examined the amount of spinal flexion at various postures while using a smartphone while sitting on the toilet. As a result, the degree of spinal flexion, particularly to the cervical spine, may increase when using a smartphone while sitting on the toilet. Furthermore, even without using a smartphone, sitting on the toilet can eventually increase spinal flexion angles.

## Abbreviations

BMI – Body Mass Index;
IMU – Inertial Motion Unit;
C6 – sixth cervical spinous process;
T3 – third thoracic spinous process;
L1 – first lumbar spinous process;
S1 – first sacral spinous process;
Cx – Forehead to C6;
Utx – C6 to T3;
LTx – T3 to L1;
Lx – L1 to S1;
Sx – Forehead to S1.

## Competing of interests

The authors declare no competing interests.

## Author contributions

Ziyi Luo contributed to the preparation of the research program, interpretation of data for the work and drafting the article. Baojian Li, Ying Liu, Lu Liu and Yang Li contributed to execution of research and statistical analysis. Gang Liu contributed to the preparation of the research program. All authors reviewed and approved the final version of the manuscript.

# Declarations
# Ethics approval consent to participate

The study was approved by the Ethics Committee of The First People's Hospital of Shunde (Approval number: 20210603). All participants were accustomed to using a smartphone while sitting on the toilet, and written informed consent for data application for future clinical studies was obtained preoperatively. The researcher completed a basic procedure introduction to all participants before starting the experiment. All eligible participants were provided with an explanation of the objectives and procedures of the study and were asked to sign an informed consent form prior to commencing the study. We confirm that all methods were carried out in accordance with relevant guidelines and regulations.

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