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Assessment of the pelvic and body interface pressure during different recumbent and semi-recumbent birthing positions

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ABSTRACT

Background: Childbirth, a multifaceted physiological event, undergoes dynamic changes influenced significantly by the chosen birthing position, impacting comfort and maternal and neonatal outcomes among other factors. This study aimed to investigate the bed-body interface pressure across five commonly adopted birthing positions, particularly focusing on their influence on pelvic expansion biomechanics during labour.

Methods: Twenty healthy participants, aged between 18 and 49 years, were evaluated. Interface pressure across multiple regions of interest, including the head, shoulder, pelvis, and full body, were meticulously assessed under different combinations of leg and back positioning.

Findings: Significant variations in interface pressure were observed based on chosen positions. Post hoc pairwise comparisons showed different pressure distributions for all regions of interest, with the combination of legs in stirrups and a flat back resulting in the lowest average pressure in the pelvic region. During the closed glottis pushing task, this combination exhibited lower peak pressure and peak pressure index in the pelvic region compared to other positions.

Interpretation: While upright positions are conventionally preferred, the study underscores the nuanced implications of recumbent and semi-recumbent positions. Although using stirrups with a flat back exerts less pressure, lying flat can impede blood flow and exacerbate pain, while stirrups might lead to discomfort and potential complications. Given these complexities, healthcare providers must consider multiple factors to determine optimal birthing positions. The interplay between birthing positions and obstetric outcomes awaits further exploration and refinement, marking an exciting frontier in maternal care.

1. Introduction

Childbirth is a universal human experience, yet how it is conducted varies considerably across cultures and healthcare systems. (Bohren et al., 2017; Greene, 2007; Gupta and Nikodem, 2000; Withers et al., 2018; Zakerihamidi et al., 2015) The World Health Organisation (WHO) encourages women in labour to ambulate and adopt upright positions, as these have been linked to favourable childbirth outcomes. (Zileni et al., 2021) Despite this, most women in developed and developing countries give birth in recumbent or semi-recumbent positions, often for the convenience and comfort of healthcare providers. (Desseauve et al., 2019; Satone and Tayade, 2023; Sharma et al., 2019) This practice is supported by the limited scientific evidence on the biomechanical properties of the pelvis in relation to maternal birthing positions, leading to a lack of confidence among birthing healthcare providers and the establishment of medical protocols favouring supine positions. (Borges et al., 2021; Desseauve et al., 2019; Gupta and Nikodem, 2000) This issue is particularly pertinent in low-income countries, where maternal and neonatal mortality rates are unacceptably high, with biomechanical complications being one of the main causes. (Borges et al., 2021) In India, for example, 92% of women are not offered an alternative birthing position choice other than supine/lithotomy, and 100% reported at least one indicator of mistreatment, such as slapping or being restrained. (Sharma et al., 2019) Similarly, in Africa and France, 91.4% (Zileni et al., 2021) and 90% (Desseauve et al., 2019) of women respectively deliver in the supine position, while in the USA, 68% of women deliver

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on their back, 23% in semi-sitting, 3% in side-lying, leaving only 6% adopting other positions. (Satone and Tayade, 2023) These figures underscore the urgent global need for comprehensive research to improve our understanding of childbirth biomechanics and the effect of birthing positions.

The expansion of the birth canal during labour depends largely on the pelvis bony architecture, and different maternal positions can significantly affect the ability of the sacral and coccygeal bones to move and rotate. (Borges et al., 2021; Reitter et al., 2014; Stansfield et al., 2021) Historically, pelvimetry was conducted to predict cephalopelvic disproportion, which occurs when there is a geometric mismatch between the pelvis and the presenting part of the foetus. However, this assessment is no longer used due to its ineffectiveness, potential liability, unnecessary discomfort, and unchanged outcomes. (Blackadar and Viera, 2004; Hemmerich et al., 2019) This can be attributed to the use of recumbent and semi-recumbent positions during the assessment that restrict the expansion of the pelvic outlet due to the pressure applied on the sacral region. (Michel et al., 2002; Siccardi et al., 2019) Current evidence suggests that only a small expansion of the birth canal is needed to safely manage obstructed labour. (Frémondière et al., 2023) Upright positions, known as flexible sacrum positions, allow the movement of the coccyx, thereby expanding the pelvic outlet. In contrast, non-flexible sacrum positions such as supine, lithotomy, semi-recumbent, and dorsal positions restrict the movement of both the sacrum and coccyx due to the presence of the bed or other hard surfaces that interface with them. (Hemmerich et al., 2019; Stansfield et al., 2021) Despite this, direct evidence regarding the extent of pressure applied to the pelvic region by the birthing surface during different non-flexible sacrum positions remains unexplored. This gap in research underscores the importance of understanding the physical constraints imposed by the birthing bed/surface, which could be a pivotal factor in optimising maternal and neonatal outcomes, particularly in regions where biomechanical complications are a prevalent concern. (Hemmerich et al., 2019) Such insights could empower healthcare providers to make more informed decisions and enhancing the childbirth experience for women globally. (Maung et al., 2022)

The aim of this study is to provide the first direct evidence of bed-body interface pressure across five globally predominant non-flexible sacrum positions. It is hypothesised that different recumbent and semi-recumbent birthing positions result in varying levels of pressure, thus influencing the biomechanics of pelvic expansion during labour. This hypothesis forms the foundational premise of our study, guiding the exploration of the intricate interplay between maternal positions, pressure distribution, and pelvic biomechanical dynamics.

2. Methods

2.1. Design

A within-subjects, repeated measures design was used to analyse changes in interface pressure parameters in five birthing positions. The study was planned 'with' and 'by' members of the public, not just 'to,' 'about,' or 'for' them, as per INVOLVE guidance. (NIHR Public Involvement, 2024) The study integrated a Patient and Public Involvement and Engagement (PPIE) group, comprising four women with recent childbirth experience and a clinical midwife, in its design process. Collaborating with our advisory board, this group shaped the study's methodological framework and the selection of birthing positions for assessment, prioritising positions most commonly adopted globally and considering the logistical feasibility of data collection timing. This collaborative approach ensured that the research was pertinent and aligned with the perspectives of the target demographic. As per INVOLVE guidance, one member of the PPIE group actively participated as a participant (INVOLVE, 2012; NIHR Public Involvement, 2024) to provide critical feedback about the setup and assessment procedure. The researcher who conducted the data collection was not aware of which participant was also a member of the PPIE group, to ensure objectivity.

2.2. Participants

Following established guidelines for pilot studies, which recommend a sample size of 12–20 participants, (Julious, 2005; Lancaster and Dodd, 2004) the research team determined that a sample size of $n = 20$ participants would be sufficient for this pilot study and its exploratory analysis. Eligible participants were females of reproductive age $\geq$ 18 - $\leq$ 49 years old, (World Health Organization, 2023a; World Health Organization, 2023b) who were not pregnant and free from any injury, pain, illness, or medical condition that would limit their ability to lie on their back or left side. Participants were recruited via poster advertisements and social media posts and had to actively opt into the study by contacting the researchers using the provided contact information. Interested individuals received a participant information sheet through a standardised email.

2.3. Data collection

The XSENSOR pressure mapping system (XSENSOR Technology Corporation, Canada) was used to capture interface pressure readings during the five lying positions. The system consisted of a full bed-size flexible pressure mapping pad (61 cm × 183 cm sensing area, 12.7 mm resolution, 6912 sensing points, 5-50 mmHg and 10-200 mmHg pressure ranges, and accuracy rate of ±10% of the calibrated values) that connected to a laptop equipped with XSENSOR PRO v6.0 software (XSENSOR Technology Corporation, Canada), enabling real-time recording. The sampling rate was one frame per second. (Webb and Chohan, 2023) Calibration of the system adhered to the manufacturer's instructions, ensuring data reliability and consistency, crucial for repeatable outcomes and minimal variability.

All measurements were conducted in the University's Clinical Skills Lab – Midwifery Suite, an exact replica of a birthing suite. The AVE 2 birthing bed (Linet, Czech Republic) was used for this study. The pressure mapping pad was affixed to the bed with adhesive tape to ensure that it remained in the same position for the duration of each assessment period. The pad was consistently placed in the same position for every participant. To standardise measurements, participants were instructed to position their pelvis within the delineated area specifically designed for pelvic pressure recording (Fig. 1-vi).

Each participant attended a single 75-min data collection session. Upon arrival, participants received a protocol reminder and the chance to clarify any queries before providing electronic consent. To optimise data accuracy, all participants were required to wear either leggings with a loose top or shorts with a t-shirt, and removed jewellery and hair accessories before recording age, height, and weight.

To minimise the effect of order bias or sequence-related influences, positions were randomised using the online Research Randomizer Tool. (Randomizer, 2023) The researcher informed the participant about the sequence of the positions to be adopted. The description of the five investigated positions is presented in Table 1. Prior to data recording, participants were instructed on the technique of closed-glottis pushing, which involves taking a deep breath, holding it, and exerting a strong downward push towards the perineum for 8 s. (Barasinski et al., 2023; ClinicalTrials.gov, 2023) Participants maintained each position for 10 min (Fig. 1). The selection of a 10-min period is based on recommendations from previous studies, which indicate that discomfort and pain may arise after 10 min. This makes it a suitable duration to balance effective data collection and participant well-being. (Lee et al., 2016) At the end of the 10 min in each position, participants were asked to perform closed-glottis pushing for a duration of 8 s to reflect the bearing down activity of labour. (Lemos et al., 2017) There was a minimum of 1-min interval between each position, and participants were offered breaks where required.

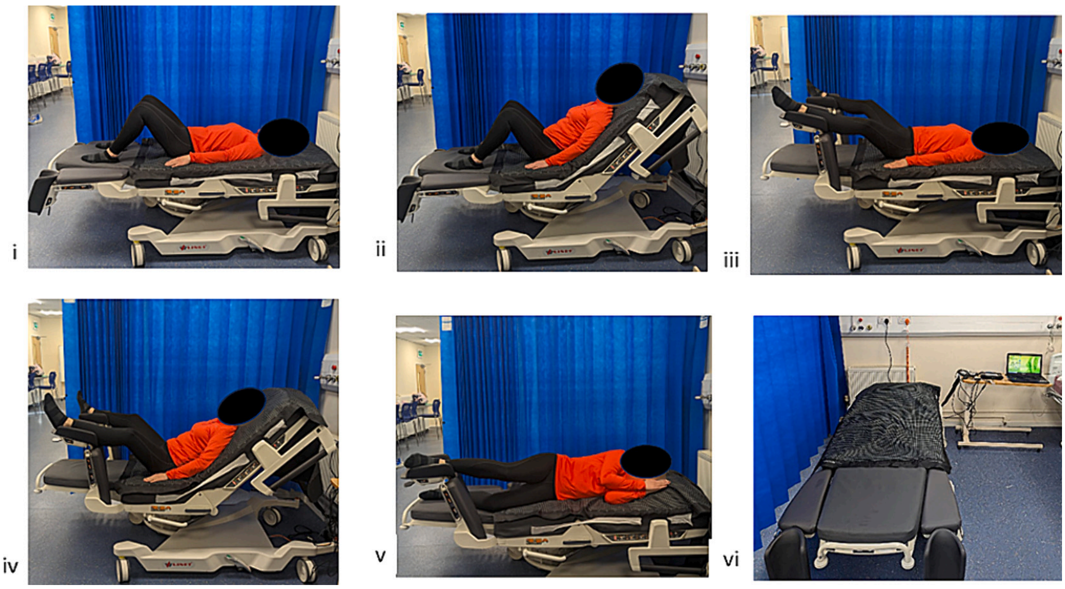

Fig. 1. Positions and study set up: i) Knees bent, flat back; ii) Knees bent, raised back; iii) Stirrups, flat back; iv) Stirrups, raised back; v) Left side lying; and vi) Study setup with pressure mapping pad placement on the AVE 2 birthing bed.

2.4. Data processing and analysis

The XSensor X3 Medical v6 Advanced Medical Mode was used for data processing. Considering the mattress type on the AVE 2 birthing bed, the initial 240 frames (4 min) were excluded to allow for the mattress to adapt to body pressure, a phenomenon known as the settling period. (Alresheedi et al., 2021) The subsequent 360 frames (6 min) were used for data processing and were merged using the average peak pressure. Furthermore, the initial 8 frames beyond the 600-frame mark (>10 min) were utilised to calculate the effects of closed glottis pushing tasks, by identifying the peak value.

Regions of interest (RoI) were manually identified due to anatomical variations and defined as described and illustrated in Fig. 2.

For each RoI, average, peak, and minimum pressure (mmHg), contact surface area (cm^2), and peak pressure index (PPI) (mmHg) were input into Microsoft Office Excel 365 (Microsoft Corp, USA) and then exported to SPSS v28 for windows (IBM Corp., USA) for analysis. For the closed glottis pushing task, peak pressure (mmHg) and PPI (mmHg) for each region of interest were reported. PPI is considered more reliable than peak pressure alone for assessing support surface performance as it evaluates pressure over a broader $10cm^2$ area, providing a comprehensive assessment beyond single sensor readings. (BES Rehab Ltd, 2013)

2.5. Statistical analysis

Descriptive statistics were used to describe the demographic characteristics of the study participants. As the left side lying position was not directly comparable with the other 4 positions, descriptive statistics were also used to describe this data. A repeated measures linear mixed model analysis was used to determining the effect of leg and back position on the reported variables. Where a significant main effect was identified, post-hoc pairwise comparisons were explored to determine exact differences. Statistical significance was set at $p < 0.05$. Mean (standard deviation (SD)), mean difference (MD), and confidence intervals (CI) were reported to provide a comprehensive understanding of the data and the differences observed.

2.6. Ethical considerations and data protection

The study received approval from the UCLan Ethics Committee (HEALTH 0377), and followed the Declaration of Helsinki principles. (World Medical Association, 2018) All collected information was strictly confidential, ensuring participant anonymity throughout the study. Data handling, analysis, and storage were in line with General Data Protection Regulation standards. During the consent process, participants were briefed on data protection measures and their rights concerning their data.

3. Results

3.1. Participant characteristics

Twenty healthy participants were included in the study; participants' characteristics are described in Table 2.

3.2. Comparison between supine conditions: Pressure related variables (Table 3)

3.2.1. Head RoI

For the head region, leg position did not significantly influence any of the pressure variables ($p > 0.134$). However, back position (inclination) had a statistically significant effect on average pressure ($p = 0.008$), peak pressure ($p < 0.001$), minimum pressure ($p = 0.003$), contact surface area ($p < 0.001$), and PPI ($p < 0.001$). Specifically, the flat back positions resulted in significantly higher average pressure (MD 1.0 mmHg, $p = 0.008$, CI 0.268–1.665), peak pressure (MD 8.6 mmHg, $p < 0.001$, CI 4.888–12.328), contact surface area (MD $32.5cm^2$, $p < 0.001$, CI 28.240–36.781) and PPI (MD 5.0 mmHg, $p < 0.001$, CI 2.622–7.417) compared to the raised back conditions. On the other hand, the flat back positions had a significantly lower minimum pressure (MD -0.265 mmHg, $p = 0.003$, CI -0.438 - -0.091) in comparison to the raised back positions.

3.2.2. Shoulders RoI

At the shoulders, leg position significantly influenced average pressure ($p = 0.002$) and contact surface area ($p = 0.046$). Use of stirrups increased both the average pressure (MD 0.8 mmHg, $p = 0.002$, CI 0.311–1.384) and contact surface area (MD $29.8cm^2$, $p = 0.046$, CI 0.575–59.103) compared to bent knees. Similarly, back position significantly affected average pressure ($p = 0.004$), peak pressure ($p = 0.006$), and contact surface area ($p < 0.001$). Flat back positions resulted

Table 1
Detailed description of the five positions assessed in the study.

N	Position	Description
i.	Lying flat on the back with knees bent and feet flat on the bed (Fig. 1-i)	The back of the bed was adjusted to 180° (flat). Participants were instructed to lie flat on their back with their knees bent and their feet placed flat on the bed (shoulder width apart). No specific instructions were given regarding the hip-knee angles, due to inter-participant differences in femoral/tibia length ratios and other anatomical variations. The only condition was to have the feet completely flat on the mattress. Participants were free to choose how far apart they placed their knees to maintain a comfortable position within the limits of the pressure mat. Participants were asked to rest their arms by the side of their body with the palms facing down on the bed (slightly away from the pelvis).
ii.	Lying on the back with knees bent and feet flat on the bed, with the head of the bed raised by 45° degrees (Fig. 1-ii)	Participants were instructed to lie on their back with their knees bent and their feet placed flat on the bed (shoulder width apart). Then the back of the bed was raised to 45°, after which participants had to confirm that they were in a comfortable position. No specific instructions were given regarding the hip-knee angles, due to inter-participant differences in femoral/tibia length ratios and other anatomical variations. The only condition was to have the feet completely flat on the mattress. Participants were free to choose how far apart they placed their knees to maintain a comfortable position. Participants were asked to rest their arms by the side of their body with the palms facing down on the bed (slightly away from the pelvis)
iii.	Lying flat on the back with legs in stirrups (Fig. 1-iii)	The back of the bed was adjusted to 180° degrees (flat). Participants were instructed to place the lower part of their calves and ankles on the stirrups in a position that felt comfortable for them to maintain for 10 min. Stirrups were adjusted as per each participant's anatomical needs. Participants were asked to rest their arms by the side of their body with the palms facing down on the bed (slightly away from the pelvis).
iv.	Lying on the back with legs in stirrups, with the head of the bed raised by 45° degrees (Fig. 1-iv)	Participants were instructed to place the lower part of their calves and ankles on the stirrups in a position that felt comfortable for them to maintain for 10 min. Stirrups were adjusted as per each participant's anatomical needs. Then the back of the bed was raised to 45°, after which participants had to confirm that they were in a comfortable position. Participants were asked to rest their arms by the side of their body with the palms facing down on the bed (slightly away from the pelvis).
v.	Left side lying position (Fig. 1-v)	The back of the bed was adjusted to 180° (flat). A pillow was placed under the participant's head and neck so that the spine could maintain a straight and natural horizontal alignment. Then the participant was instructed to place the calf and ankle of the upper leg on a stirrup that was positioned to replicate the support that would ordinarily be provided by the healthcare professional. Participants were asked to place their hands in a comfortable position to the side of their head.

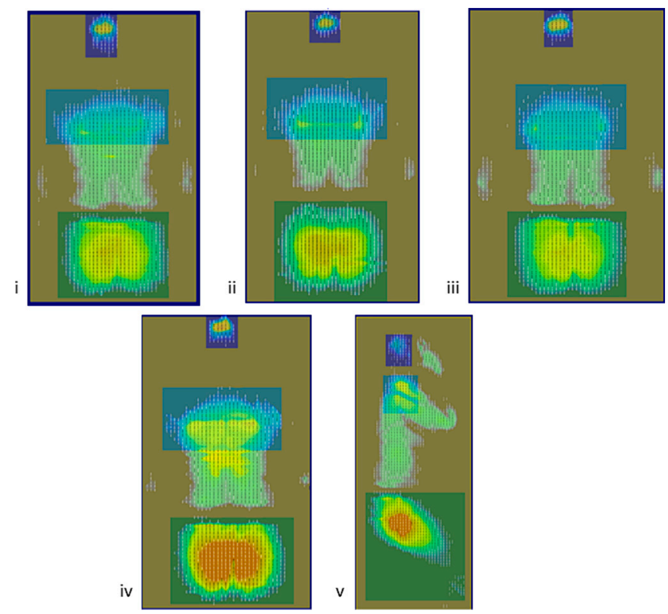

Fig. 2. Example of pressure maps of the five examined positions: i) Knees bent with a flat back; ii) Knees bent with a raised back; iii) Stirrups with a flat back; iv) Stirrups with a raised back; v) Left side lying.
Warmer colours indicate regions of concentrated pressure (Colour gradients: Blue to green: low pressure areas / minimum; Green to yellow: moderate pressure areas; yellow to red: high pressure areas (maximum). For the purpose of the study four RoIs, we selected and defined a) Head RoI: The minimal rectangular area containing all activated sensors in the head region; b) Shoulder RoI: An oblong area extending from the uppermost shoulder region (encompassing all activated sensors) to the horizontal line of the armpit; c) Pelvic RoI: In the supine position: The rectangular area from the belt line to the lower buttocks region. In the left side-lying position: The rectangular area from the belt line to the knee joint; d) Full Body: The entire activated area on the mat, including all activated sensors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Participant characteristics.

Demographics	Mean (SD)	Range
Age (years)	34.1 (8.1)	20–48
Height (m)	1.64 (0.06)	1.51–1.74
Weight (kg)	72.1 (11.6)	52–95
History of pregnancy (n)	Yes $n = 13$ No $n = 7$	
History of giving birth (n)	Yes $n = 11$ No $n = 9$	

in higher average pressure (MD 0.8 mmHg, $p = 0.004$, CI 0.261–1.333) and contact surface area (MD 85.9cm^2, $p < 0.001$, CI 56.624–115.152) but lower peak pressure (MD -2.6 mmHg, $p = 0.006$, CI -4.386 - -0.759) compared to raised back positions.

Post-hoc pairwise comparisons, focusing on variables where both leg and back position had a pronounced effect, revealed that the combination of bent knees and a raised back resulted in a significantly lower average shoulder pressure compared to stirrups with flat back (MD

Table 3
Mean (SD) values for average pressure (mmHg), peak pressure (mmHg), minimum pressure (mmHg), contact surface area (cm^2), and PPI (mmHg) were computed across all birthing positions.

		Stirrups & Flat Back	Stirrups & Raised Back	Knees Bent & Flat Back	Knees Bent & Raised Back	Leg Position Main Effect	Back Position Main Effect
Head	Average	25.0 (2.7)	24.1 (2.0)	25.2 (3.2)	24.1 (1.8)	0.743	0.008*
	Peak	50.0 (17.1)	40.7 (5.6)	49.7 (19.0)	41.8 (4.9)	0.830	<0.001*
	Minimum	10.2 (0.2)	10.2 (0.2)	10.1 (0.1)	10.6 (0.7)	0.134	0.003*
	Contact area	92.0 (16.1)	60.6 (13.8)	92.0 (19.7)	58.4 (13.1)	0.602	<0.001*
	PPI	39.0 (10.3)	34.5 (4.2)	39.9 (7.4)	34.3 (3.0)	0.794	<0.001*
Shoulder	Average	21.5 (1.4)	20.8 (1.4)	20.8 (1.6)	19.9 (1.7)	0.002*	0.004*
	Peak	33.6 (2.7)	36.8 (8.4)	32.8 (2.5)	34.8 (4.8)	0.122	0.006*
	Minimum	10.1 (0.1)	10.0 (0.0)	10.0 (0.0)	10.1 (0.1)	0.780	0.629
	Contact area	490.7 (119.9)	408.9 (92.3)	464.9 (141.9)	375.0 (112.9)	0.046*	<0.001*
	PPI	30.6 (2.6)	30.2 (3.6)	29.9 (2.4)	29.4 (3.6)	0.152	0.388
Pelvis	Average	27.1 (1.3)	30.3 (1.2)	28.5 (1.2)	31.4 (1.8)	<0.001*	<0.001*
	Peak	49.5 (7.1)	65.9 (11.8)	51.2 (8.4)	69.9 (13.7)	0.093	<0.001*
	Minimum	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0.263	0.033*
	Contact area	821.3 (139.6)	959.0 (157.8)	806.3 (137.1)	883.6 (165.4)	0.017*	<0.001*
	PPI	43.7 (4.5)	57.9 (9.0)	46.3 (5.9)	60.9 (12.0)	0.025*	<0.001*
Full Body	Average	23.3 (1.0)	24.3 (1.0)	23.6 (0.9)	24.1 (1.3)	0.672	<0.001*
	Peak	55.3 (16.9)	65.9 (11.8)	55.6 (18.6)	69.9 (13.7)	0.429	<0.001*
	Minimum	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0.124	0.186
	Contact area	2196.3 (285.6)	2140.7 (304.1)	2274.7 (860.6)	1984.0 (313.9)	0.666	0.060
	PPI	43.5 (7.6)	58.0 (9.0)	46.4 (7.8)	60.9 (12.0)	0.041*	<0.001*
Closed Glottis Pushing	Head Peak	50.3 (18.7)	40.5 (6.4)	52.2 (30.3)	43.4 (8.5)	0.428	0.003*
	Shoulder Peak	32.8 (4.2)	35.8 (7.4)	32.5 (2.2)	35.4 (4.3)	0.727	0.003*
	Pelvis Peak	51.0 (10.5)	68.8 18.7)	53.8 (10.3)	73.6 (13.7)	0.121	<0.001*
	Full Body Peak	56.6 (18.8)	68.5 (19.3)	59.8 (29.3)	73.6 (13.7)	0.266	<0.001*
	Head PPI	34.0 (6.1)	31.5 (4.8)	39.8 (16.7)	35.3 (6.9)	0.007*	0.045*
	Shoulder PPI	32.9 (2.9)	29.7 (3.7)	30.9 (5.7)	32.2 (5,7)	0.805	0.335
	Pelvis PPI	49.5 (10.1)	52.0 (12.2)	50.6 (10.1)	51.6 (8.6)	0.835	0.317
	Full Body PPI	48.7 (10.7)	51.7 (12.6)	52.6 (14.1)	52.1 (8.1)	0.352	0.577

Linear mixed models were employed to determine the main effects for leg positions (Stirrups / Knees Bent) and back positions (Flat / Raised). A significance level of $p < 0.05$ was utilised, with * indicating statistical significance.

-1.645, $p < 0.001$, CI -2.409 - -0.880), stirrups with raised back (MD -0.972, $p = 0.014$, CI -1.736 - -0.207) and knees bent with flat back (MD -0.921, $p = 0.019$, CI -1.685 - -0.157). For contact surface area, flat back with stirrups caused a statistically significant increase compared to the raised back with stirrups (MD 81.6cm^2, $p < 0.001$, CI 40.120–123.591) and raised back with bent knees (MD 115.7cm^2, p < 0.001, CI 73.992–157.462). Flat back with bent knees caused a statistically significant increase in contact surface area compared to the raised back with stirrups (MD 56.5cm^2, $p = 0.009$, CI 14.313–97.784) and raised back with bent knees (MD 89.9cm^2, $p < 0.001$, CI 48.185–131.655).

3.2.3. Pelvic RoI

In the pelvic region, leg position significantly affected average pressure ($p < 0.001$), contact surface area ($p = 0.017$) and PPI ($p = 0.025$). With legs in stirrups, both average pressure (MD -1.3 mmHg, $p < 0.001$, CI -1.816 - -0.720) and PPI (MD -2.8 mmHg, p = 0.025, CI -5.177 - -0.367) were significantly lower compared to bent-knee position. However, contact surface area (MD 45.2cm^2, p = 0.017, CI 8.206–82.115) was significantly larger with legs in stirrups than with knees bent.

Back position also significantly influenced average pressure ($p < 0.001$), peak pressure (p < 0.001), minimum pressure ($p = 0.033$), contact surface area (p < 0.001) and PPI (p < 0.001). In the flat back condition, values for average pressure (MD 3.1 mmHg, p < 0.001, CI -3.641 - -2.544), peak pressure (MD 17.6 mmHg, p < 0.001, CI -20.869 - -14.247), minimum pressure (MD 0.02 mmHg, p = 0.033, CI -0.028 - -0.001), contact surface area (MD 107.5cm^2, p < 0.001, CI -144.454 - -70.545) and PPI (MD 14.5 mmHg, p < 0.001, CI -16.850 - -12.040) were all significantly lower compared to the raised back positions.

Post-hoc pairwise comparisons, focusing on variables where both leg and back positions had significant effects, demonstrated significant differences between all positions ($p < 0.006$). Specifically, the combination of legs in stirrups with a flat back exhibited the lowest average pressure (27.1 ± 1.3 mmHg). This was followed by bent knees with a flat back (28.5 ± 1.2 mmHg), then legs in stirrups with a raised back (30.3 ± 1.2 mmHg). The position combining bent knees with a raised back (31.4 ± 1.8 mmHg) had the highest average pressure. For contact surface area, flat back conditions resulted in a significant reduction compared to raised back positions ($p < 0.019$). The combination of a raised back with legs in stirrups also led to a significant increase in contact surface area compared to bent knees ($p = 0.005$). Similarly, for PPI, flat back conditions showed a significant reduction compared to raised back conditions ($p < 0.001$).

3.2.4. Full body

For full-body pressure considerations, leg position significantly affected PPI ($p = 0.041$), with PPI being notably lower (MD -2.9 mmHg, p = 0.041, CI -5.681 - -0.124) with legs in stirrups compared to when knees were bent. Back position significantly influenced average pressure ($p < 0.001$), peak pressure ($p < 0.001$), and PPI (p < 0.001). In flat back conditions, both average pressure (MD 0.7 mmHg, <0.001, CI -1.007 - -0354) and PPI (MD 14.5 mmHg. p < 0.001, CI -17.301 - -11.744) were lower, while peak pressure was reduced compared to raised back positions (MD 12.5 mmHg, $p < 0.001$, CI -17.698 - -7.224).

3.2.5. Closed glottis pushing task

For the closed glottis pushing task, leg position significantly affected head PPI ($p = 0.007$), with stirrups reducing it compared to bent knees (MD -4.8 mmHg, p = 0.007, CI -8.206 - -1.380). Back position also significantly impacted peak pressure at the head ($p = 0.003$), shoulders (p = 0.003), pelvis (p < 0.001), and full body (p < 0.001), and head PPI ($p = 0.045$). Flat back conditions decreased peak pressures at the shoulders (MD -2.9 mmHg, p = 0.003 CI -4.817 - -1.039), pelvis (MD -18.8 mmHg, p < 0.001, CI -23.613 - -13.949), and full body (-MD 12.8

mmHg, p < 0.001, CI -20.205 - -5.442), but increased head peak pressures (MD 9.3 mmHg, p = 0.003, CI 3.217–15.397) and PPI (MD 3.5 mmHg, p = 0.045, CI 0.075–6.901) versus raised back.

Post-hoc pairwise comparisons for the PPI at the head—where both leg and back position had significant effects—showed that PPI values were lower in both stirrup positions compared to situations with bent knees and a flat back ($p < 0.022$).

3.2.6. Side lying position

In the side-lying position (referenced in Table 4), during both static lying and closed glottis pushing phases, the pelvis-knee region exhibited the highest peak pressure (ranging from 57.1 to 60.0 mmHg) and PPI (between 51.2 and 51.5 mmHg). Although higher values were noted in the full body analysis, the exact location of these values remains unspecified. Conversely, the head consistently showed the lowest peak pressure (29.3 mmHg) and PPI (24.7 mmHg) during both task phases.

4. Discussion

Childbirth is a complex physiological process that involves dynamic changes in a woman's body, including variations in birthing positions. (Desseauve et al., 2017a; Desseauve et al., 2017b) The choice of birthing position has long been a significant topic in obstetrics aimed at optimising maternal comfort and childbirth outcomes. (Borges et al., 2021; Desseauve et al., 2017a; Desseauve et al., 2017b; Satone and Tayade, 2023) To our knowledge, this study represents the first quantitative assessment of pressure variations associated with different recumbent and semi-recumbent birthing positions, advancing our understanding of childbirth biomechanics. Our results demonstrate that the positional alignment of a woman's legs and back significantly influences pressure dynamics across various RoIs.

While numerous health organisations and healthcare providers recommend upright or flexible sacrum positions for various reasons, including the expansion of the pelvic outlet, and women are encouraged to adopt positions that maximise their comfort (Borges et al., 2021; Desseauve et al., 2019; Gupta et al., 2017; Gupta and Nikodem, 2000); there are circumstances where medical conditions or personal preferences necessitate recumbent or semi-recumbent positions, such as for epidural administration. (Gupta et al., 2017; Kibuka and Thornton, 2017; Kjeldsen et al., 2022; Mselle and Eustace, 2020; Satone and Tayade, 2023; Zileni et al., 2021) In these instances, our study provides valuable insights into the effect of birthing positions on pressure distribution and related comfort.

Our comprehensive analysis extends beyond the pelvic region, offering a holistic understanding of pressure dynamics during various positions. While the primary focus remains on the pelvis due to the movements of the sacrum, coccyx, and the sacroiliac joint (SIJ), (Borell and Fernstrom, 1957; Hemmerich et al., 2019) this broader perspective enables us to understand how pressure is distributed across several body areas when positions change. For the full body analysis, our results highlight the significant impact of leg position on PPI, with stirrups resulting in lower values compared to knees bent. Back position also exerts a notable influence, as flat back positions exhibit lower average pressure, peak pressure, and PPI compared to raised back positions. These findings suggest that leg and back positioning can have a profound effect on pressure redistribution across the entire body, potentially impacting overall maternal comfort and tissue integrity.

Similar trends were observed in the pelvic RoI, where legs on stirrups were associated with lower average pressure and PPI, and increased contact surface area compared to knees bent. Moreover, flat back positions exhibited decreased average pressure, peak pressure, minimum pressure, contact surface area, and PPI in contrast to raised back positions. Post-hoc analyses revealed that the combination of legs in stirrups and a flat back resulted in the lowest average pressure, while knees bent with a raised back led to the highest average pressure. These results emphasise the importance of considering leg and back positioning together to optimise pressure distribution, especially in the pelvic RoI. Likewise, for the closed glottis pushing task, the flat back position with legs on stirrups demonstrated the lowest pressure values in the pelvic RoI. These findings suggest that thoughtful selection of leg and back positioning may mitigate excessive pressure during the pushing phase, thus benefiting childbirth outcomes and maternal comfort. In addition, our findings indicate that during the side-lying position, peak pressure and PPI were highest in the pelvis-knee region, particularly during the closed glottis pushing task. This observation shows the importance of precise pelvic positioning, especially during side-lying births, where the location and magnitude of pressure distribution may be pivotal in specific scenarios.

However, it's important to note that lying flat is generally discouraged due to its potential to compress major blood vessels, which can impede uterine blood flow and foetal oxygenation, and may exacerbate pain during contractions, potentially being detrimental to both maternal and foetal health. (Krywko and King, 2023; Warland, 2017) Additionally, while stirrups provide advantageous access to the perineal area and birth canal, facilitating monitoring and interventions, their use is not without discomfort and possible complications, such as perineal tears and limited mobility. (Gupta et al., 2017; Satone and Tayade, 2023)

Given these considerations, healthcare providers should carefully evaluate multiple factors when determining the optimal birthing position for each individual case. Future research is urgently needed to determine the optimal back angle, considering individual anatomy and comfort, to avoid extremes of either flat or overly inclined positions. Additionally, further studies are necessary to determine when stirrups should be used for pressure relief and when it is beneficial to maintain higher pressure for specific scenarios, considering the significant impact of pressure parameters in the pelvic region. Moreover, the chosen birthing position profoundly affects perineal health and childbirth outcomes (Gupta et al., 2017), guiding clinical decisions to protect this vulnerable area. Echoing other studies that call for more research into birthing positions and their associated benefits and risks, (Gupta et al., 2017) we also advocate for further investigation into the mechanics of childbirth and their correlation with clinical outcomes.

Additionally, investigating maternal comfort preferences alongside pressure distribution during childbirth provides crucial insights. Pressure on the pelvic region affects the expansion capacity of the pelvic outlet, impacting labour progress, and the risk of complications. (Borell and Fernstrom, 1957; Frémondière et al., 2023; Michel et al., 2002; Reitter et al., 2014; Siccardi et al., 2019; Stansfield et al., 2021) Medical professionals should recognise that variations in leg and back positioning significantly influence the maternal experience during labour, enhancing satisfaction and well-being. Therefore, it is essential for

Table 4

Mean (SD) values for average pressure (mmHg), peak pressure (mmHg), minimum pressure (mmHg), contact surface area (cm^2) and PPI (mmHg) for left side lying.

	Head	Shoulder	Pelvis - Knee	Full Body	Closed Glottis Pushing	
Average	18.3 (4.5)	25.4 (1.7)	26.7 (1.6)	23.3 (0.9)	Head Peak	30.9 (6.5)
Peak	29.3 (6.2)	44.3 (10.5)	57.1 (13.2)	58.8 (13.7)	Shoulder Peak	46.9 (14.4)
Minimum	14.8 (20.8)	10.1 (0.1)	10.0 (0.0)	10.0 (0.0)	Pelvis - Knee Peak	60.0 (24.9)
Contact area	133.4 (28.8)	281.9 (81.9)	941.5 (187.3)	2236.9 (363.7)	Full Body Peak	64.1 (25.1)
					Head PPI	24.4 (4.0)
PPI	24.7 (3.9)	37.1 (5.0)	51.2 (7.9)	49.4 (10.1)	Shoulder PPI	37.8 (6.4)
					Pelvis PPI	51.5 (16.0)
					Full Body PPI	52.6 (15.7)

healthcare providers to offer various positional options and support informed choices prioritising safety and well-being for both mother and baby. (Gupta et al., 2017; Gupta and Nikodem, 2000; Kjeldsen et al., 2022; Mselle and Eustace, 2020)

When addressing the impact of pressure on the pelvis and SIJ, it's important to consider the surface material. Hard surfaces, such as metallic beds, beds with minimal cushioning, or even giving birth on the floor, can lead to substantially increased pressure levels. (Kim et al., 2015; Shi et al., 2021) This not only causes significant discomfort but can also hinder the necessary pelvic movements for vaginal birth. This consideration is particularly relevant in low- and middle-income countries, where birthing conditions might be less than ideal. In such settings, the use of metallic beds without adequate padding could amplify the pressure and heighten the injury risk to women. (Byrom, 2023; The News Minute, 2023)

While our study contributes to understanding childbirth biomechanics, it is imperative to acknowledge potential limitations. Although, the sample size is deemed suitable for a pilot study, boasting a participant age range from 20 to 48 years - reflective of the general population of women of reproductive age - and including women both with and without a history of pregnancy and childbirth to enhance the relevance of our findings, the study's relatively modest scale may limit the generalisability of its conclusions to a broader and more varied demographic with diverse anatomical characteristics. A notable consideration is the known variability in the architecture of the body pelvis, sacral slope, length of the sacrum, lumbar lordosis, and other anatomical differences among women of different ethnic backgrounds. (Abdool et al., 2017; Handa et al., 2008; Lok et al., 2016; Zárate-Kalfópulos et al., 2012a) Despite these known disparities, ethnicity was not captured as a parameter in our research due to the limited sample size, which would not support meaningful conclusions or relational analyses. Although it's possible that women from various ethnic backgrounds may not exhibit significant differences in the positions that yield the least pelvic area pressure, existing research indicates that ethnic variations in pelvic anatomy can influence some variables, such as the efficacy of techniques like the McRoberts' manoeuvre with or without suprapubic pressure. (Lok et al., 2016) Moreover, nuances such as the sacral slope being approximately 3.6^{o} larger in Caucasian women compared to their Asian counterparts, (Lok et al., 2016; Zárate-Kalfópulos et al., 2012b) and the observation that East Asian women tend to have reduced pelvic organ mobility in the anterior and posterior vaginal compartments, (Abdool et al., 2017) emphasise the need for expanded research. Investigating a more extensive population across different ethnic groups will furnish more specific insights tailored to each group.

Additionally, the study's inclusion criteria - limiting participants to women of reproductive age without any injury, pain, illness, or medical condition that would hinder specific positions - may further constrain the generalisability to broader populations, including females with medical conditions that could affect their ability, or the way they engage, to assume certain positions. Also, despite potential variations in pelvic-bed interface pressure between pregnant and non-pregnant women, attributable to factors such as increased weight, the presence of the fetus, amniotic fluid, placenta, and pregnancy-related biomechanical and physiological changes (Conder et al., 2019), ethical considerations precluded the inclusion of pregnant women in the study. The study design incorporated the flat back lying position, as it is prevalent in several low- and middle-income countries. However, this position may precipitate aortocaval compression syndrome, a condition predominantly affecting pregnant women beyond the 20th week of gestation. When in the supine position, the enlarged uterus can obstruct central circulation by compressing the inferior vena cava and aorta, thereby restricting blood flow to the placenta. This obstruction can lead to significant morbidity and mortality risks for both the mother and foetus, (Krywko and King, 2023; Warland, 2017) necessitating the exclusion of pregnant women from the study. Finally, although the body and pelvic region are the most critical areas to monitor for pressure, we acknowledge that a more comprehensive mapping, including the legs on stirrups and other areas, would provide a more complete understanding of the pressure distribution. However, the AVE 2 birthing bed has three adjustable parts in each lower section, with gaps between them. During our extensive setup studies to ensure accurate and reliable data collection, these gaps and the shape of the stirrups caused the pressure mapping mat to crease, resulting in false pressure readings. For this reason, we opted for this specific setup, which did not include certain areas.

Despite its limitations, this study serves as a pivotal step, offering a foundation for future research to build upon and refine. By exploring the dynamics of pressure during childbirth, we provide valuable insights into the physical forces involved. Such knowledge is critical for healthcare professionals, potentially enhancing their ability to manage complications arising during delivery, including shoulder dystocia or breech presentations. More broadly, our findings carry significant public health ramifications. By paving the way for evidence-based adjustments in birthing protocols and positions, we can enhance outcomes for both mothers and infants. However, the universal applicability of these insights will depend on their adaptability across diverse settings. Factors like the availability, cost, and condition of birthing beds-especially in government hospitals in low- to middle-income countries-highlight the necessity for context-specific solutions. In situations where conditions are suboptimal and there's no medical need for a woman to lie down, promoting flexible sacrum (upright) positions becomes essential. In alignment with global initiatives aiming to diminish maternal and neonatal mortality rates, our study contributes to a deeper understanding of the mechanics of childbirth; a necessary step toward comprehending physiology and devising strategies to enhance global childbirth practices and overall well-being.

5. Conclusion

In conclusion, upright positions should be the preferred method for childbirth, as they exert zero or minimal pressure on critical areas of the body essential for the birthing process. In cases where a woman must assume a lying position, this study has demonstrated that both leg and back positioning during recumbent and semi-recumbent positions significantly influence interface pressure parameters at various RoIs. Our findings underscore the pivotal role of leg and back positioning in shaping pressure dynamics and their potential impact on labour progression. As birthing practices continue to evolve, and there is a resurgence of interest in alternative birthing positions, such evidence-based insights become increasingly invaluable. By providing guidance rooted in rigorous research on optimal positioning, healthcare professionals can better support expectant mothers, ensuring both safety and comfort throughout the birthing process. Looking ahead, the interplay between birthing positions and obstetric outcomes remains an exciting frontier, awaiting further exploration and refinement.

CRediT authorship contribution statement

Anastasia Topalidou: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Lauren Haworth:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. **Inderjeet Kaur:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Maimoona Ahmed:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Ambreen Chohan:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

None.

Data availability

All data supporting the results of this study are available via the UCLanData repository DOI:10.17030/uclan.data.00000418 Link: https://uclandata.uclan.ac.uk/418/

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