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Prospective study on ultrasonographic measurement of the spinal canal depth in very low birth weight infants

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ABSTRACT

Background Lumbar punctures (LP) in very low birth weight (VLBW) infants often have low success rates. Point-of-care ultrasound (POCUS)-based spinal canal depth (SCD) measurements may provide better outcomes.

Aim To provide POCUS-based SCD measurement values for VLBW infants using different calculation methods at the L4/5 and L3/4 levels.

Methods This prospective observational study involved 31 VLBW infants in the neonatal intensive care unit at Women's Wellness and Research Center, Doha, Qatar, from March 2022 to September 2023. The outcome measures included anterior (ASCD), mid (MSCD) and posterior spinal canal depth (PSCD) measurements. The study compared results from different calculation methods at the L4/5 and L3/4 levels.

Results A total of 63 ultrasound examinations were performed on 31 infants. The median gestational age was 25.0 weeks (IQR 24–27), with a birth weight of 817.9±170.2 g and a birth height of 31.6±2.8 cm. The MSCD at L4/5 was 7.1±0.5 mm and 6.9±0.5 mm at L3/4, with a mean difference (MD) of 0.20 (95% CI 0.15 to 0.24; p<0.001). The mean SC anteroposterior diameter at L4/5 was 3.8 mm versus 4.2 mm at L3/4 (MD −0.334, 95% CI −0.45 to 0.22; p<0.001). Weight-based and body surface area (BSA) calculations correlated best with MSCD at both levels. The MSCD in millimetres was determined by the equations 2×weight (kg)+6 (R^2=0.71) at L4/5 and (R^2=0.70) at L3/4 and 25×BSA (m^2)+5 (R^2=0.71) at L4/5 and (R^2=0.73) at L3/4 levels. Moreover, body weight and BSA showed a slightly stronger correlation with ASCD measurements compared with PSCD. All SCD measurements demonstrated a poor linear correlation with body length (cm) and body mass index (kg/m^2).

Conclusion This study offers reference data for POCUS-based SCD measurements in VLBW infants, demonstrating that body weight and BSA effectively predict SCD. These findings could enhance the accuracy of LPs in this population when ultrasound guidance is unavailable, supporting personalised care.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Lumbar punctures (LPs) in very low birth weight (VLBW) infants are often challenging, with low success rates. Best estimate values for spinal canal depth (SCD) measurements using different calculations in VLBW infants are lacking.

WHAT THIS STUDY ADDS

⇒ This study provides the first reference values for point-of-care ultrasound (POCUS)-based SCD measurements (anterior, mid and posterior) in VLBW infants and establishes a linear relationship between SCD and both body weight and body surface area. It also derives predictive formulas for SCD, which can be used to estimate SCD when POCUS guidance is unavailable.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The findings could improve LP success rates and reduce complications in VLBW infants, particularly in settings where POCUS is not feasible. The derived formulas and reference values may help promote personalised care. Future research should validate these findings and explore their integration into clinical practice.

INTRODUCTION

Very low birth weight (VLBW) infants are among the most vulnerable paediatric patients and often require precise clinical assessments, including sepsis evaluations that depend on accurate cerebrospinal fluid (CSF) sample data analysis. Several factors affect the success of lumbar puncture (LP) in these infants, including body weight, correct placement, respiratory support requirements and operator competence.[1] Moreover, VLBW infants may not follow the expected birth weight-gestational age (BW-GA) trajectories seen in term infants or older children due to the unique and suboptimal postnatal growth patterns.[2]

Successful LP rates in small preterm infants are low among neonatal trainees and practitioners, with approximately half of the cases being unsuccessful. These procedures are often complicated by issues such as traumatic taps, which can compromise the

Table 1 Baseline characteristics of very low birth weight infants

Patients (N=31)	Value
Birth weight (g), mean±SD	817.9±170.2
Birth length (cm), mean±SD	31.6±2.8
Multiples, n (%)	13 (19.4%)
Gestational age (weeks), median (IQR)	25.00 (24.00, 27.00)
Men, n (%)	18 (58.1%)
SGA, n (%)	5 (16.1%)
POCUS exams per patient, n (%)	
1	13 (41.9%)
2	10 (32.3%)
≥3	8 (25.8%)
Ethnicity, n (%)	
Middle eastern	14 (45.0%)
Asian	12 (38.7%)
African	4 (12.9%)
European	1 (3.2%)

IQR, interquartile range; POCUS, point-of-care ultrasound; SD, standard deviation; SGA, small for gestational age.

interpretation of CSF sample parameters.[3–7] Additionally, performing an LP becomes more complex in preterm infants due to their tiny target space and the likelihood of being on respiratory support, which can be compromised during positioning, leading to cardiorespiratory instability and may result in inadequate sampling.[8–10]

Utilising ultrasound (US) for measuring spinal canal depth (SCD) presents a promising solution to these problems, offering quick and safer assessments in newborns. Additionally, point-of-care US (POCUS) is increasingly implemented across several fields in paediatrics to guide bedside assessment and procedures including LP. Evidence increasingly supports the benefits of US guidance, particularly in paediatric and neonatal patients with challenging cases, in addition to improving success rates, reducing complications, and minimising procedural time by providing real-time visualisation, enhancing precision, and promoting patient safety during procedures.[11–17]

Systematic reviews that included studies on paediatric populationspaediatric have shown that US-assisted LPs not only reduce the risk of failed procedures but also significantly decrease traumatic taps, the number of insertion attempts, needle redirections, and patient pain scores.[18 19] Similarly, studies in infants and paediatrics have shown a significant improvement in success rates with US-guided LPs.[19 20] However, several barriers to US-guided procedures exist in the neonatal intensive care units (NICU), including limited access to US machines around the clock, particularly in emergent situations, a lack of specialised training, and time and cost implications.[21 22] In such situations, physicians often revert to traditional LP procedures, resulting in higher failure or traumatic LP rates.

The study aimed to estimate SCD through POCUS-based measurements in a cohort of VLBW infants. The study seeks to address a gap in research by using different calculation methods at the L4/5 and L3/4 intervertebral levels and provide more accurate estimates of SCD for this population.

METHODOLOGY

Study design, setting and population

This was a prospective observational study. A total of 31 VLBW infants were recruited into the study after admission to the NICU of Women's Wellness and Research Centre, Doha, Qatar, from August 2022 to March 2023. All admitted preterm infants to the NICU were screened for eligibility to participate in the study. Clinically stable, preterm infants, as well as infants on ventilators with BW less than 1500 g, were included in the study. Infants with apparent spinal or known lumbosacral abnormalities, such as sacral pits/ dimples and spina bifida, were excluded.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

Registration and ethics

This study received approval from the Medical Research Center (MRC), of Hamad Medical Corporation (HMC), Doha, Qatar; protocol number MRC-01-22-058. Written informed consents were obtained from parents, granting permission for their infants' participation before their enrolment in the study. This study endeavoured to maintain a standard of high quality and integrity throughout its execution. The study was conducted in full conformance with principles of the 'Declaration of Helsinki', Good Clinical Practice (GCP) and within the laws and regulations of the Ministry of Public Health in Qatar. This study was not sponsored or funded by any institute, and the researchers have no conflict of interest to declare.

Study protocol

The study team collected standard clinical demographic information, including GA, BW, ethnicity, birth height, ethnicity, gender, current weight, and length, from anonymised medical records using a data collection Excel sheet.

POCUS measurements were conducted using a GE LOGIQ E9 Ultrasound Machine equipped with a high-frequency hockey stick linear probe (L8-18i) once the babies were clinically stable. Only neonatologists, trained in POCUS and approved by the study research team and supervising radiologist, performed the examinations. During examinations, infants were placed in the lateral recumbent position

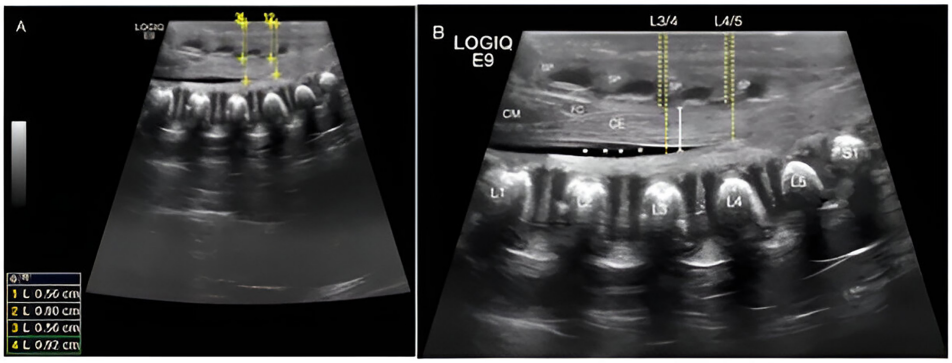

Figure 1 Schematic and ultrasound representation of spinal canal depth measurements. (A) Point-of-care ultrasound (POCUS) image demonstrating the actual measurements of posterior spinal canal depth (PSCD) and anterior spinal canal depth (ASCD) at the L4/L5 (Lines 1 and 2, respectively) and L3/L4 (Lines 3 and 4, respectively) vertebral levels. The mid-spinal canal depth (MSCD) was determined as the average of PSCD and ASCD (ASCD + PSCD)/2. (B) Schematic diagram illustrating the anatomical relationships of the PSCD (short dotted yellow line) and ASCD (long dotted yellow line) at both L3/L4 and L4/L5 levels. The solid white line represents the anteroposterior diameter of the spinal canal (SC). Key anatomical structures are labeled, including the spinal canal and cerebrospinal fluid (CSF) (indicated by asterisks), conus medullaris (CM), cauda equina (CE), filar cyst (FC), and spinous process (SP).

Table 2 Clinical profile of very low birth weight infants at the time of ultrasound exam

POCUS exams (N=63)	Value
Day of life at POCUS exam, mean±SD	27.7±17.7
Post-menstrual age (weeks), median (IQR)	29.6 (27.3, 31.1)
Males, n (%)	35 (55.5%)
Body weight at exam (g), mean±SD	949.3±247.8
Body length at exam (cm), median (IQR)	33.8 (32.0, 35.0)
Body surface area (m^2), mean±SD	0.09±0.02
Body mass index, mean±SD	8.3±1.4
US exam duration (min), mean±SD	8.7±2.4
Events*, n (%)	10 (15.9%)
Event duration (s), mean±SD	9.0±2.1
Intervention, n (%)	7 (11.1%)
Operator, n (%)	
1	18 (28.6%)
2	27 (42.9%)
3	8 (12.7%)
4	10 (15.9%)
Respiratory support, n (%)	
Room air	3 (4.8%)
NC/CPAP	18 (28.6%)
NIPPV	29 (46.0%)
Invasive ventilation	13 (20.6%)
Skin anomalies, n (%)	0.0%
Spinal haematomas, n (%)	0.0%

*Bradycardia, desaturation, tachycardia, apnoea.
CPAP, continuous positive airway pressure; NC, nasal cannula; NIPPV, nasal intermittent positive pressure ventilation; POCUS, point-of-care ultrasound.

with maximum but careful hip flexion. The probe was positioned between the posterior superior iliac crests along the vertebrae that correspond to the L4/L5 and then L3/L4 interspinous gaps determined by palpation and coated with ultrasonic gel.

Using frozen US images, the average of three measurements of 'anterior spinal canal depth' (ASCD) and 'posterior spinal canal depth' (PSCD) was taken in millimetres—that is, the distance between the skin and the anterior and posterior walls of the SC, respectively. The mid-spinal canal depth (MSCD) was determined as the average of PSCD and ASCD (ASCD+PSCD)/2. All the information gathered, including images and readings, was securely stored for future analysis. A professional radiologist thoroughly reviewed these images and examined the data to ensure the accuracy of the ultrasonographic measures.

To monitor adverse events related to the infants' positioning, metrics such as the number and duration of desaturations, bradycardias, apnoeas, vomiting and extubations were measured. Any potential risk was planned to be mitigated by stopping the procedure and retrying later or on another day once the baby became stable.

To minimise the consenting process and reduce the burden on families, repeated POCUS examinations were performed on the same infants at different body weights, with a minimum weight difference of 250 g. This approach ensured adequate data collection without impacting the validity or results of the study.

Outcomes

The primary outcome was the measurement of the distance in millimetres from the lumbar skin to both ASCD and PSCD by US in study subjects. The secondary outcome was the compilation of all the

Table 3 Spinal ultrasound measurement values at L4/5 and L3/4 levels

US exam level (N=63)	Measure (mm)	Mean±SD	Median (IQR)
L4/5	Posterior SCD	5.1±0.4	5.1 (4.8, 5.4)
	Anterior SCD	9.0±0.7	8.9 (8.5, 9.4)
	Mid SCD	7.1±0.5	7.0 (6.7, 7.4)
	SC AP diameter	3.8±0.6	3.9 (3.4, 4.3)
L3/4*	Posterior SCD	4.8±0.4	4.7 (4.5, 5.1)
	Anterior SCD	9.0±0.8	8.9 (8.5, 9.5)
	Mid SCD	6.9±0.5	6.9 (6.5, 7.2)
	SC AP diameter	4.2±0.7	4.1 (3.6, 4.8)

*Missing data: L3/4 spinal canal depth measurement (n=3).
AP, anteroposterior; IQR, interquartile range; SC, spinal canal; SCD, spinal canal depth; SD, standard deviation; US, ultrasound.

values into tables based on body weight (kg), body length (cm), body surface area (BSA, m^2) and body mass index (BMI, kg/m^2). BSA was calculated using the Haycock method (m^2=0.024265×weight $(kg)^{0.5378}$×height $(cm)^{0.3964}$).[23]

Statistical consideration and data analysis

Descriptive analysis was used to create tables, graphs and trendlines analysis for the whole study population according to different measurements and methods. The SCD measurements obtained from each interspinous space for every patient and subsequently for the entire cohort were compared using mean and SD or median (IQR) when indicated. Three separate measurements were taken from each patient during each exam, and SCD values were averaged, creating a single data point for each patient. For data presentation, continuous data were reported as the mean ± standard deviation (SD), while categorical data were presented as numbers with corresponding percentages in parentheses. Statistical analysis was performed using SPSS statistical software (V.29; IBM Corporation, Armonk, New York). The student's t-test was used to compare continuous parametric variables, while the Mann-Whitney U test was used for continuous non-parametric variables. For categorical variables, the appropriate test, either the χ^2 test or Fisher's exact test, was employed. The distribution of data was assessed through the Shapiro-Wilk test. A p value of <0.05 was considered statistically significant.

For a correlation between baby weight in grams and SCD with the minimum correlation of 0.40, 90% statistical power, 5% level of the type I error (α) and 10% type II error rate (β), the sample size of 63 was calculated as adequate.

Intrarater and inter-rater reliabilities were assessed using the intraclass correlation coefficient (ICC) with a one-way random effects model for average measures reliability (ICC (1,3)). For intrarater reliability, each of the four raters performed repeated measurements on a subset of participants, and ICC (1,3) was used to estimate the reliability of the average measurements for each rater. For inter-rater reliability, each rater independently assessed a unique set of participants, with no overlap in the participants seen by different raters, and ICC (1,3) was used to estimate the reliability of the average measurements across the four raters, assuming no systematic differences between raters. ICC values were interpreted as follows: <0.50=poor, 0.50–0.75=moderate, 0.75–0.90=good and >0.90=excellent reliability.[24 25] The 95% CIs for the ICC values were also calculated.

RESULTS

A total of 31 preterm infants with a GA ranging from 23 to 33 weeks and weighing less than 1500 g were included in the study. Their median GA in weeks was 25.0 (IQR 24.0–27.0) weeks, and the mean BW was 817.9±170.2 g. Approximately 42% of patients underwent a single POCUS examination, while the remaining 58% had at least two separate exams performed at different body weights. The demographic characteristics are summarised in table 1.

Figure 1 depicts the actual measurements of PSCD and ASCD at L4/5 and L3/L4 vertebral levels of a 10-day-old female infant at 770 g (figure 1A). A schematic illustrates anatomic landmarks of the SC structures (figure 1B).

A total of 63 examinations were carried out on the 31 neonates. The age of the neonates at examination was 27.7±17.8 days, and the weight and height at examination were 949±278 g and 33.8 (32.0–35.0) cm, respectively. BSA (m^2) was 0.09±0.02 and BMI (kg/m^2) 8.3±1.4. The duration of the POCUS exam was 8.7+2.4 min, with events observed during exams,

Table 4 Comparison of spinal canal measurements between L4/5 and L3/4 levels

Measure (mm)	L4/5 Mean±SD	L3/4 Mean±SD	Mean difference	95th CI	P
Posterior SCD	5.1 (0.4)	4.81 (0.4)	0.32	0.29 to 0.39	<0.001
Anterior SCD	9.0 (0.7)	9.0 (0.8)	−0.01	−0.09 to 0.06	0.704
Mid SCD	7.1 (0.5)	6.9 (0.5)	0.20	0.15 to 0.24	<0.001
SC AP diameter	3.8 (0.6)	4.2 (0.7)	−0.33	−0.45 to 0.22	<0.001

AP, anteroposterior; IQR, interquartile range; SC, spinal canal; SCD, spinal canal depth; SD, standard deviation.

Table 5 Intrarater reliability of spinal canal diameter measurements across repeated assessments

Rater	SCD level	SCD parameter	ICC1,3	95% CI
1	L3–4	PSCD	0.71	0.29 to 0.90
2	L3–4	PSCD	0.60	0.20 to 0.81
3	L3–4	PSCD	0.84	0.47 to 0.97
4	L3–4	PSCD	0.70	0.04 to 0.93
1	L3–4	ASCD	0.96	0.91 to 0.98
2	L3–4	ASCD	0.89	0.79 to 0.94
3	L3–4	ASCD	0.97	0.89 to 0.99
4	L3–4	ASCD	0.87	0.58 to 0.96
1	L4–5	PSCD	0.63	0.21 to 0.94
2	L4–5	PSCD	0.79	0.60 to 0.89
3	L4–5	PSCD	0.88	0.57 to 0.98
4	L4–5	PSCD	0.74	0.29 to 0.93
1	L4–5	ASCD	0.94	0.86 to 0.97
2	L4–5	ASCD	0.85	0.71 to 0.92
3	L4–5	ASCD	0.97	0.90 to 0.99
4	L4–5	ASCD	0.75	0.26 to 0.93

A one-way random effects model for average measures reliability (ICC(1,3)), average of 3 repeats per rater. 95% CI provides an estimate of precision for each ICC value.
ASCD, anterior spinal canal depth; ICC, intraclass correlation coefficients; L, lumbar vertebral level; PSCD, posterior spinal canal depth; SCD, spinal canal depth.

including oxygen desaturation and bradycardia or apnoea in nine patients and tachycardia in one patient (15.9%); seven of these events required interventions. Events lasted 9.0±2.1 s; during these events, all examinations were interrupted, and there was one instance where one patient required manual stimulation. Most infants (79.4%) were on non-invasive respiratory support, 20.6% were on invasive mechanical ventilation, and only three patients were in room air. No skin abnormalities or spinal haematoma were noted on any of the neonates. No differences in measurements were noted between the four operators. The clinical profile of the study population is summarised in table 2.

The results for the spinal US measurements at the L4/5 and L3/4 levels are summarised in table 3. The PSCD at the L4/L5 and L3/L4 levels was 5.1±0.4 mm and 4.8±0.4 mm, respectively. The ASCD at the L4/L5 and L3/L4 levels was 9.0±0.7 mm and 9.0±0.8 mm, respectively. The MSCD at the L4/L5 and L3/L4 levels was 7.01±0.5 mm and 6.9±0.5 mm, respectively. The SC AP diameter at the L4/L5 and L3/L4 levels was 3.8±0.6 mm and 4.2±0.7 mm, respectively.

Table 4 compares SCD measurements at L4/L5 and L3/L4 levels. Both PSCD (5.1 vs 4.81 mm; mean difference 0.32, p<0.001) and MSCD (7.1 vs 6.9 mm; mean difference 0.2, p<0.001) were deeper at L4/L5 compared with L3/L4. In contrast, the SC anteroposterior diameters were wider at L3/4 compared with L4/5, with a mean difference of −0.33 (p<0.001).

Table 5 summarises the results of intrarater reliability for SCD measurements (ICC(1,3)). PSCD reliability ranged from 0.60 to 0.88, with rater 3 at L4-5 showing the highest ICC (0.88). ASCD reliability was higher, ranging from 0.75 to 0.97, with rater 3 achieving the highest ICC at both levels (0.97). ASCD measurements demonstrated greater consistency across raters compared with PSCD.

Table 6 summarises the results of inter-rater reliability for SCD measurements (ICC(1,3)), stratified by body weight and BSA. For 500–<1000 g infants, ASCD reliability was higher (ICC=0.81–0.91) than PSCD (ICC=0.79–0.80). For 1000–<1500 g infants, PSCD reliability at L3-4 was highest (ICC=0.92), while ASCD reliability ranged from 0.66 to 0.79. In the 0.06–0.1 m² BSA group, PSCD reliability at L4-5 was excellent (ICC=0.96), while ASCD reliability ranged from 0.87 to 0.94. In the 0.1–0.13 m² BSA group, PSCD reliability at L3-4 was highest (ICC=0.95), though some ICCs had wide CIs, indicating variability.

Table 7 summarises the equations for estimating ASCD, PSCD and MSCD at the L4/5 and L3/4 levels based on four different calculation methods. All these variables showed a different positive linear correlation with SCD. Of the four variables we investigated, body weight (kg) and BSA (m²) showed the strongest correlation with MSCD. Body weight had a correlation coefficient (R^2) of 0.71 at the L4/5 level and 0.70 at the L3/4 level, while BSA consistently correlated with MSCD at 0.71 at the L4/5 level and 0.73 at the L3/4

Table 6 Interrater reliability of ultrasound measurements of spinal canal diameter among four raters

	SCD level	SCD parameter	ICC1,3	95% CI
Body weight (g)				
500 – <1000	L4–5	PSCD	0.79	–0.1 to 0.98
500 – <1000	L4–5	ASCD	0.81	0.19 to 0.99
500 – <1000	L3–4	PSCD	0.80	–0.44 to 0.99
500 – <1000	L3–4	ASCD	0.91	0.20 to 1.00
1000 – <1500	L4–5	PSCD	0.73	0.17 to 0.966
1000 – <1500	L4–5	ASCD	0.66	–0.07 to 1.00
1000 – <1500	L3–4	PSCD	0.92	0.60 to 0.99
1000 – <1500	L3–4	ASCD	0.79	0.14 to 0.99
Body surface area (m^2)				
0.06–0.1	L4–5	PSCD	0.96	0.81 to 0.99
0.06–0.1	L4–5	ASCD	0.94	0.79 to 0.98
0.06–0.1	L3–4	PSCD	0.75	0.19 to 0.95
0.06–0.1	L3–4	ASCD	0.87	0.45 to 0.99
0.1–0.13	L4–5	PSCD	0.54	–18.2 to 9.8
0.1–0.13	L4–5	ASCD	0.79	–0.77 to 0.99
0.1–0.13	L3–4	PSCD	0.95	0.57 to 1.00
0.1–0.13	L3–4	ASCD	0.87	0.30 to 0.98

Inter-rater reliability was assessed using the ICC with a one-way random effects model for average measures reliability (ICC(1,3)). Four raters independently assessed two subgroups of babies (different weight and body surface area categories), with no overlap in the babies seen by each rater. The ICC estimates the reliability of the average ratings across the four raters, assuming no systematic differences between raters.
ASCD, anterior spinal canal depth; ICC, Intraclass correlation coefficients; L, lumbar vertebra level; PSCD, posterior spinal canal depth; SCD, spinal canal depth.

level. The derived equation for the MSCD (in mm) at the L4/L5 and L3/4 vertebral levels based on weight was 1.6×weight (kg)+5.5 (rounded off to 2×weight (kg)+6). The derived equation for the MSCD at the L4/L5 level based on BSA was 25×BSA (m^2)+4.7 (rounded off to 25xBSA (m^2)+5), which is the same as the L3/4 equation after rounding off (MSCD at L3/4 was 24.5xBSA (m^2)+4.6). BMI showed the least linear relationship with MSCD, with R^2 0.26 and 0.20 at L4/5 and L3/4 SCD levels, respectively, while body

Table 7 Spinal canal depth fit line equation and correlation coefficient values at the L4/5 and L3/4 levels using different methods

SC depth level		L4/5 (N=63)		L3/4 (N=60)	
SC depth level (mm)	Method (X)	Fit line equation (SCD=y)	R^2 linear	Fit line equation (SCD=y)	R^2 linear
Posterior SCD	Weight (kg)	X*1.0+4.2	0.41	X*1.1+3.8	0.41
	Length (cm)	X*0.1+3.7	0.15	X*0.1+3.0	0.18
	BMI (kg/m^2)	X*0.1+4.1	0.23	X*0.1+3.7	0.21
	BSA (m^2)	X*14.8+3.7	0.38	X*15.9+3.3	0.39
Anterior SCD	Weight (kg)	X*2.2+6.9	0.62	X*2.2+6.9	0.51
	Length (cm)	X*0.1+4.7	0.43	X*0.1+4.7	0.39
	BMI (kg/m^2)	X*0.2+7.3	0.18	X*0.2+7.6	0.16
	BSA (m^2)	X*35.7+5.6	0.66	X*35.4+5.7	0.56
Mid SCD	Weight (kg)	X*1.6+5.5	0.71	X*1.6+5.5	0.70
	Length (cm)	X*0.1+4.3	0.39	X*0.1+4.0	0.44
	BMI (kg/m^2)	X*0.2+5.6	0.26	X*0.2+5.7	0.20
	BSA (m^2)	X*25+4.7	0.71	X*24.5+4.6	0.73

BMI, body mass index; BSA, body surface area measured by Haycock method[23] ; R^2, correlation coefficient; SCD, spinal canal depth.

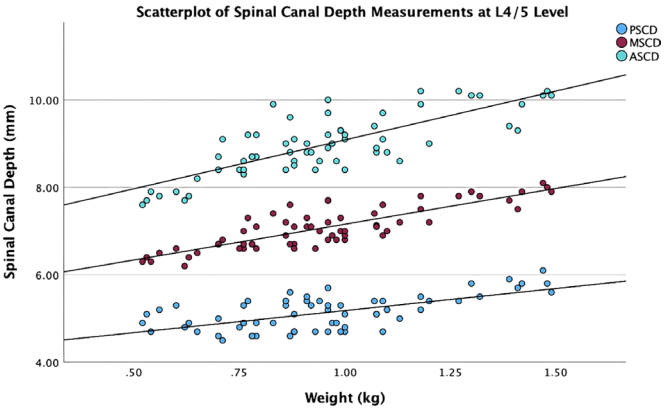

Figure 2 Scatterplot of spinal canal depth measurement values at L4/5 levels with body weight (kg). ASCD, anterior spinal canal depth; MSCD, mid spinal canal depth; PSCD, posterior spinal canal depth.

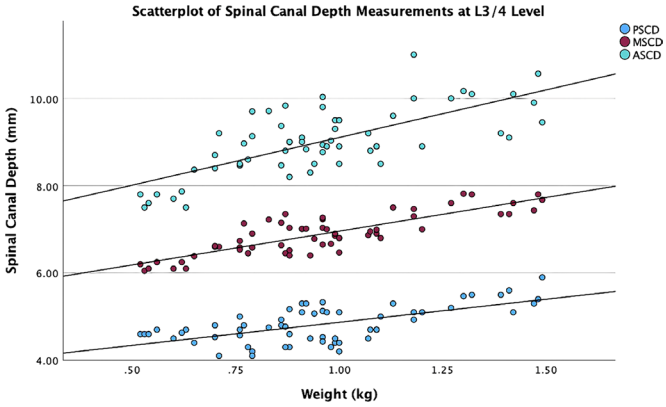

Figure 4 Scatterplot of spinal canal depth measurement values at L3/4 levels with body weight (kg). ASCD, anterior spinal canal depth; MSCD, mid spinal canal depth; PSCD, posterior spinal canal depth.

length has a moderate correlation with MSCD, with R^2 0.39 and 0.44 at the L4/5 and L3/4 SCD levels, respectively.

Figures 2–5 depict four scatterplots of the linear relationship between all SCD (PSCD, MSCD and ASCD) measurements at the L4/5 and L3/4 levels with body weight (kg) and BSA (m^2), respectively.

DISCUSSION

In this study, we reported POCUS-based SCD measurements using different methods to establish the best-fit equation for SCD assessment in neonatal patients. The study reports SCD measurements exclusively in VLBW neonates, which can be used in clinical practice to calculate SCD for successful LP for babies of similar disposition. Less than half of our study participants were Middle Eastern, with the remaining being primarily Asians. We did not exclude babies with more severe clinical status, such as babies on respiratory support, which reflects the typical condition of VLBW preemies and increases the generalisability of our study results to these populations. In the study, we included comparing calculations obtained from two different lumbar vertebral levels (L4/5 and L3/4), which added to the uniqueness of the study.

We also demonstrated a positive linear correlation between body weight, BSA, BMI, length and SCD measurement. Out of these variables, we found that weight and BSA correlate the most closely with MSCD, which aligns with other studies showing weight to be the most predictive of MSCD.[23 26] The MSCD (in mm) was found to be determined by the formula 2× weight (kg)+6 and 25× BSA (m^2)+5 at both the L3/L4 and L4/L5 levels.

Our results are similar to those of previous studies. A 2008 UK study that performed US-based SCD measurements of 105 neonates (with a median GA of 34 weeks and a wide BW range of 0.52–4.61 kg at the L3/L4 level and derived the formula: 2×weight (Kg)+7 for estimation of mid SCD in mm).[14] The broader range of study participants could account for our study's slight difference. A 2014 study on lumbar spine anatomy in newborns from Spain specified that the proper needle insertion depth in mm (ie, the MSCD depth) based on US measurements was 2.5×weight in kilograms+6.[10] The more significant difference between this formula and ours is expected as our study included

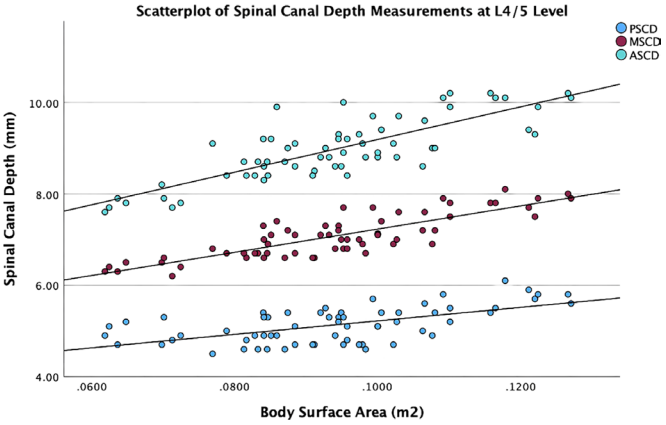

Figure 3 Scatterplot of spinal canal depth measurement values at L4/5 levels with body surface area (m^2). ASCD, anterior spinal canal depth; MSCD, mid spinal canal depth; PSCD, posterior spinal canal depth.

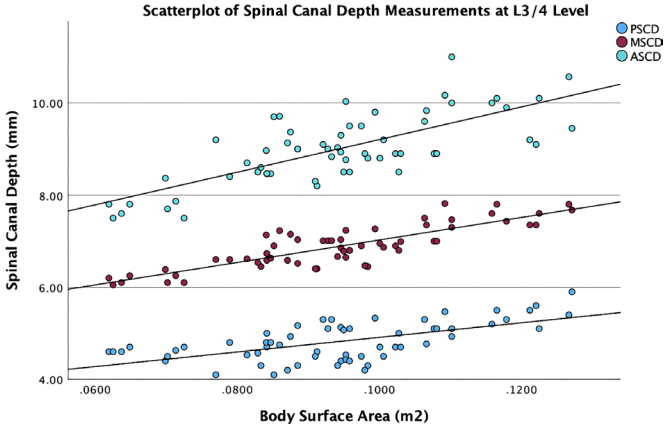

Figure 5 Scatterplot of spinal canal depth measurement values at L3/4 levels with body surface area (m^2). ASCD, anterior spinal canal depth; MSCD, mid spinal canal depth; PSCD, posterior spinal canal depth.

VLBW infants (mean BW of 817 g). In contrast, this study included mostly term infants (61% of the study population) with a more considerable median weight of 2.721 kg and IQR of 1.922–3.314 kg. Finally, a 2023 Indian study on 127 neonates with a mean GA of 34 weeks and mean weight of 1877 g at the time of examination reported the correlation between body weight and MSCD by the formula: MSCD in cm=0.2×weight (kg)+0.45; the closest yet to our raw formula of 1.6×weight+5.6 but still incomparable due to the differences in the mean GA and mean weight in their study and ours.[26]

Limited studies exist in the paediatric population to evaluate equations incorporating weight and height, such as BMI and BSA, related to SCD.[27] Bonadio *et al* used BSA to determine spinal needle depth in 158 children aged 1–18 years. Similar to our study, out of all other variables, BSA showed the highest correlation with SCD across various age groups in the study population. The derived formula is the depth of LP (cm)=0.77 cm+2.56×BSA m^2.[28 29] Height was also considered for spinal needle depth; Craig *et al* described 107 children aged 0–16 years. The derived formula is LP depth (cm)=height (cm)×0.03.[30] The study done by Celik *et al*, examining children 2 to 144 months, showed various formulas tailored to multiple patient groups using weight and heights in consideration.[29]

It is also noteworthy that the differences between the formulas obtained for SCD in studies may not only be due to the varying weight and GA of the included participants but also due to the naturally occurring genetic variations in the sizes of neonates globally.

We acknowledge that spinal needles are not graded with cm or mm markings, making precise depth estimation challenging. However, a practical approach could be marking the needle with a Steri-Strip at the estimated MSCD or approximately 2 mm beyond it (ASCD). This simple technique may help guide needle insertion and improve success rates when using the estimated SCD measurements.

In our study, two operators performed the majority of the POCUS examinations, with most exams demonstrating good intrarater reliability. Additionally, interrater reliability showed consistent agreement across the two categories of body weight and BSA.

Previous studies have shown that the diameter of the SC increases in the sitting position compared with the lateral recumbent position in newborn infants.[10 31] In a cohort of LBW infants, the SC width increased from 3.44 mm in the lateral recumbent position to 3.86 mm in the sitting position and further increased to 4.08 mm with hip flexion.[10] In our study, we exclusively used the lateral decubitus position, as most infants were on respiratory support, making the sitting position challenging. We also applied maximum leg flexion tolerated by infants receiving respiratory support, including invasive and non-invasive ventilation, to minimise stress and adverse events related to the examination. While the prone position is also comforting and may be better tolerated by preterm infants, it was not an option in this study. Future studies could evaluate SCD measurements using POCUS in different positions for VLBW infants.[32]

We believe these reference values could enhance LP success rates in VLBW infants when applied before the procedure, particularly in settings where POCUS-guided LP is not feasible. Although our study was sufficiently powered, a possible limitation of our study is the small sample size, as a larger sample size could perhaps allow for more reference values and, hence, more accurate predictions with these reference values. Additionally, our reference value should be applied cautiously to other populations as our results may not be generalisable because most of our population were Middle Easterns and Asians. Similar studies can be carried out in other populations to create reference values for these populations.

CONCLUSION

This study provides reference values for POCUS-based measurements of SCD in VLBW infants and establishes a linear relationship between SCD and both body weight and BSA. The derived formulas and SCD measurements have the potential to improve LP success rates and reduce the incidence of traumatic taps in this population, particularly when US-guided LP is not feasible. Future research could evaluate whether knowledge of these US-generated values improves LP success rates compared with traditional or POCUS-guided approaches. Additionally, further studies are needed to explore the optimal POCUS-derived needle entry angles for LPs in VLBW infants or to compare SCD in this population across different positions, such as sitting and prone.

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