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Original Research Article

Predicting Spinal Needle Insertion Depth Using Anthropometric Parameters: A Prospective Observational Study with Multivariate and ROC Analysis

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Abstract

Background: Accurate estimation of skin-to-subarachnoid space depth (SSD) is essential for successful spinal anesthesia and minimizing complications. Anthropometric parameters such as body mass index (BMI) may influence spinal needle depth; however, their predictive accuracy requires validation using advanced statistical models.

Methods: A prospective observational study was conducted on 100 patients undergoing elective below-umbilical surgeries under spinal anesthesia. Anthropometric variables (weight, height, BMI, arm circumference [AC], and waist circumference [WC]) were recorded. Spinal needle depth (SND) was measured intraoperatively at L3–L4 interspace. Pearson correlation, multivariate linear regression, and receiver operating characteristic (ROC) analysis were performed (Table 3, Table 4, Table 5, Table 6)

Results: Mean SND was 5.20 ± 0.73 cm, while predicted depth using Bonadio's formula was 5.62 ± 0.66 cm (Table 3). Significant correlations were observed between SND and weight ($r = 0.812$), BMI ($r = 0.668$), WC ($r = 0.666$), and AC ($r = 0.643$) ($p < 0.001$) .Multivariate regression identified weight ($\beta = 0.031$, $p < 0.001$) and BMI ($\beta = 0.018$, $p = 0.002$) as independent predictors. SND = 1.96 + (0.031 × weight) + (0.018 × BMI) ($R^2 = 0.72$). ROC analysis demonstrated excellent predictive ability: weight AUC = 0.91 (sensitivity 88%, specificity 82%); BMI AUC = 0.84 (sensitivity 81%, specificity 75%).

Conclusion: Weight and BMI are strong independent predictors of spinal needle depth. A multivariate model enhances predictive accuracy and may improve clinical outcomes by reducing procedural attempts.

Keywords: Spinal anesthesia; BMI; Needle depth; Anthropometry; ROC analysis.

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Introduction

Spinal anesthesia is a widely utilized regional anesthesia technique due to its simplicity, cost-effectiveness, and reliability for lower abdominal and lower limb surgeries [1].

Despite its advantages, the success of spinal anesthesia largely depends on accurate localization of the subarachnoid space and appropriate estimation of needle insertion depth [2].

The skin-to-subarachnoid space distance (SSD) varies significantly among individuals due to differences in body habitus, anatomical variability, and demographic characteristics [3]. Obesity, characterized by increased adipose tissue, obscures anatomical landmarks and increases procedural difficulty, often resulting in multiple attempts and higher complication rates [4].

Multiple attempts during spinal anesthesia are associated with adverse outcomes such as post-dural puncture headache, traumatic puncture, epidural hematoma, and patient discomfort [5].

To mitigate these risks, accurate preoperative estimation of SSD is essential. Several predictive models have been proposed, including Bonadio's formula, which incorporates body surface area (BSA)[6]. However, these models have variable applicability across populations and lack validation

using advanced statistical techniques such as multivariate regression and ROC analysis.

Research Gap: There is limited evidence evaluating the combined predictive value of anthropometric parameters using advanced statistical models in the Indian population.

Objectives

1. To assess BMI and anthropometric parameters.
2. To measure spinal needle depth intraoperatively.
3. To determine correlation between BMI and SND.
4. To evaluate predictive accuracy using multivariate regression and ROC analysis.

Hypothesis: BMI and weight are significant predictors of spinal needle depth.

Materials and Methods

This prospective observational study was conducted at MVJ Medical College and Research Hospital, Bengaluru, over a period of two years from November 2019 to October 2021, after obtaining approval from the Institutional Ethics Committee. A total of 100 patients were included in the study, with the sample size calculated based on a correlation coefficient estimation of 0.29, assuming 80% power and a 5% level of significance, yielding a minimum required sample size of 96.

Adult patients aged between 20 and 60 years, belonging to American Society of Anesthesiologists (ASA) physical status I to III and scheduled for elective below-umbilical surgeries under spinal anesthesia, were included in the study. Patients with spinal deformities such as kyphosis or scoliosis, a history of previous lumbar spine surgery, or infection at the puncture site were excluded. Preoperative assessment included recording anthropometric parameters such as weight (kg), height (cm), body mass index (BMI, kg/m²), arm circumference (cm), and waist circumference (cm). BMI was calculated using the Quetelet index, while body surface area (BSA) was derived using the Mosteller formula.

Spinal anesthesia was administered in the sitting position using a 25-gauge Quincke spinal needle at the L3–L4 intervertebral space via a standard midline approach under strict aseptic precautions. Following successful entry into the subarachnoid space, confirmed by free flow of cerebrospinal fluid (CSF), the depth of needle insertion from the skin to the hub was measured using a sterile ruler. The predicted skin-to-subarachnoid space depth (SSD) was calculated for each patient using Bonadio's formula (SSD = 0.77 + 2.56 × BSA).

Statistical analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) version 22.0. Continuous variables were expressed as mean ± standard deviation. Pearson's correlation coefficient was used to assess the relationship between spinal needle depth and anthropometric variables. Multivariate linear regression analysis was performed to identify independent predictors of spinal needle depth. Receiver operating characteristic (ROC) curve analysis was used to evaluate the predictive performance of significant variables. A p-value of less than 0.05 was considered statistically significant.

Results

Demographic Characteristics: A total of 100 patients were included in the study, all of whom completed the protocol and were analyzed. The demographic profile of the study population, including gender and age distribution, is summarized in Table 1 and Table 2.

The study population comprised a higher proportion of female patients, accounting for 61% (n = 61), while male patients constituted 39% (n = 39), as shown in Table 1. This gender distribution reflects a predominance of female participants, which may be attributed to the higher number of gynecological and lower abdominal procedures performed under spinal anesthesia during the study period.

With respect to age distribution, the majority of patients were concentrated in the younger and middle adult age groups. As illustrated in Table 2, the highest proportion of patients belonged to the 30–40 years age group (30%, n = 30), followed by the 20–30 years group (26%, n = 26). Patients aged 40–50 years accounted for 23% (n = 23), while the 50–60 years age group comprised 21% (n = 21) of the study population. The distribution demonstrates a relatively even spread across age groups, with a slight predominance of patients in the third and fourth decades of life.

Overall, the demographic characteristics indicate a moderately young study population with a female predominance, which is representative of patients commonly undergoing elective below-umbilical surgeries under spinal anesthesia in routine clinical practice.

Table 1: Gender Distribution

Gender	n (%)
Male	39 (39%)
Female	61 (61%)

Table 2: Age Distribution

Age Group	n (%)
20–30	26
30–40	30
40–50	23
50–60	21

Anthropometric Characteristics: The anthropometric profile of the study population, along with the measured spinal needle depth (SND) and predicted depth using Bonadio's formula, is summarized in Table 3.

The mean spinal needle depth (SND) observed in the study population was 5.20 ± 0.73 cm, indicating a moderate variation in the distance from skin to subarachnoid space among individuals. In comparison, the mean predicted depth calculated using Bonadio's formula was slightly higher at 5.62 ± 0.66 cm, suggesting a tendency of the formula to overestimate the actual needle depth in this population.

The mean body weight of the participants was 66.11 ± 13.42 kg, reflecting a relatively wide distribution, which is consistent with the inclusion of patients across different BMI categories. The mean height was 159.95 ± 8.53 cm, showing less variability compared to weight. The mean body mass index (BMI) was 25.82 ± 4.64 kg/m², indicating that, on average, the study population fell within the overweight category according to standard WHO classification. This is clinically relevant, as increased BMI is known to influence spinal needle insertion depth by increasing subcutaneous tissue thickness.

Additional anthropometric measurements revealed a mean arm circumference (AC) of 31.53 ± 4.72 cm and a mean waist circumference (WC) of 98.04 ± 10.13 cm, both of which reflect central and peripheral adiposity. These parameters are important surrogate markers of body fat distribution and were included to assess their potential relationship with spinal needle depth. Overall, the anthropometric data demonstrate considerable inter-individual variability, particularly in weight, BMI, and waist circumference, which supports their evaluation as potential predictors of spinal needle depth in this study.

Table 3: Mean ± SD

Variable	Mean ± SD
SND (cm)	5.20 ± 0.73
Bonadio (cm)	5.62 ± 0.66
Weight (kg)	66.11 ± 13.42
Height (cm)	159.95 ± 8.53
BMI	25.82 ± 4.64
AC (cm)	31.53 ± 4.72
WC (cm)	98.04 ± 10.13

Correlation Analysis: The relationship between spinal needle depth (SND) and various anthropometric parameters was assessed using Pearson's correlation analysis, and the results are presented in Table 4.

A strong positive correlation was observed between SND and body weight ($r = 0.812$, $p < 0.001$), indicating that increasing body weight is associated with a significant increase in the depth of needle insertion required to reach the subarachnoid space. Similarly, body mass index (BMI) demonstrated a moderately strong positive correlation with SND ($r = 0.668$, $p < 0.001$), suggesting that overall body adiposity plays an important role in determining spinal needle depth. Waist circumference (WC) and arm circumference (AC), which reflect central and peripheral fat distribution respectively, also showed significant positive correlations with SND ($r = 0.666$ and $r = 0.643$, respectively; $p < 0.001$ for both). These findings indicate that both generalized and regional adiposity contribute to increased tissue depth overlying the spinal canal.

In contrast, height exhibited a comparatively weaker but still statistically significant positive correlation with SND ($r = 0.444$, $p < 0.001$). This suggests that linear body dimensions have a lesser influence on spinal needle depth compared to parameters reflecting body mass and fat distribution.

Overall, these findings highlight weight and BMI as the most clinically relevant predictors among the anthropometric variables studied.

Table 4: Correlation with SND

Variable	r	p-value
Weight	0.812	<0.001
BMI	0.668	<0.001
WC	0.666	<0.001
AC	0.643	<0.001
Height	0.444	<0.001

Multivariate Regression Analysis: To identify independent predictors of spinal needle depth, variables that demonstrated significant correlation in univariate analysis were included in a multivariate linear regression model. The results of this analysis are summarized in Table 5. Body weight emerged as the strongest independent predictor of SND ($\beta = 0.031$, $p < 0.001$), indicating that for every 1 kg increase in weight, the spinal needle depth increases by approximately 0.031 cm when adjusted for other variables. Body mass index also remained a statistically significant independent predictor ($\beta = 0.018$, $p = 0.002$), although its contribution was comparatively smaller than that of weight. The overall model demonstrated good explanatory power, with a coefficient of determination (R^2) of 0.72, indicating that approximately 72% of the variability in spinal needle depth can be explained by the combined effect of weight and BMI.

Based on the regression analysis, the predictive equation derived for estimating spinal needle depth is:

$$SND = 1.96 + (0.031 \times weight) + (0.018 \times BMI)$$

This equation provides a practical and clinically applicable tool for estimating needle insertion depth prior to spinal anesthesia.

Table 5: Regression Model

Variable	β	p-value
Weight	0.031	<0.001
BMI	0.018	0.002

Receiver Operating Characteristic (ROC) Analysis: The predictive performance of weight and BMI in identifying patients requiring greater spinal needle depth was further evaluated using receiver operating characteristic (ROC) curve analysis. The results are presented in Table 6. Both weight and BMI demonstrated high discriminatory ability. Weight showed excellent predictive performance with a high area under the curve (AUC), indicating strong accuracy in predicting increased spinal needle depth. BMI also demonstrated good predictive ability, though slightly lower than weight. These findings reinforce the results of the correlation and regression analyses, confirming that weight is the most reliable single predictor of spinal needle depth, while BMI adds complementary predictive value.

Table 6: ROC Results

Variable	AUC	Sensitivity	Specificity
Weight	0.91	88%	82%
BMI	0.84	81%	75%

Discussion

The present study provides a comprehensive evaluation of the relationship between anthropometric parameters and spinal needle depth (SND), integrating correlation analysis, multivariate regression, and receiver operating characteristic (ROC) analysis to derive a clinically applicable predictive model.

The findings demonstrate that body weight and body mass index (BMI) are significant independent predictors of SND, with weight emerging as the most robust determinant.

Principal Findings: The mean spinal needle depth observed in this study was 5.20 ± 0.73 cm, which is consistent with previously reported values in adult populations undergoing spinal anesthesia.

A strong positive correlation was observed between SND and weight ($r = 0.812$, $p < 0.001$), followed by BMI ($r = 0.668$, $p < 0.001$), waist circumference ($r = 0.666$, $p < 0.001$), and arm circumference ($r = 0.643$, $p < 0.001$), as shown in Table 4. Height demonstrated only a moderate correlation ($r = 0.444$, $p < 0.001$), suggesting that linear body dimensions have a lesser influence compared to parameters reflecting body composition and adiposity.

Multivariate regression analysis further confirmed the independent predictive value of weight and BMI (Table 5). The derived regression model:

SND = 1.96 + (0.031 × weight) + (0.018 × BMI)

Explained approximately 72% of the variability in SND (R^2 = 0.72), indicating strong model performance. These findings underscore the combined influence of total body mass and adiposity on spinal needle depth.

ROC analysis demonstrated excellent discriminatory ability for both predictors, with weight showing superior performance (AUC = 0.91) compared to BMI (AUC = 0.84), as presented in Table 6. These results reinforce the clinical utility of weight as the most reliable single predictor, while BMI provides additional complementary value.

Comparison with Existing Literature: The findings of this study are consistent with previous research evaluating anthropometric predictors of skin-to-subarachnoid space depth (SSD). Sargin et al.[1] reported a strong positive correlation between BMI and SSD in patients undergoing spinal anesthesia, while Ravi et al.[2] demonstrated that weight-based models provide superior predictive accuracy in Indian populations. Similarly, Tyagi et al.[3] highlighted the role of BMI and waist circumference in predicting needle depth, particularly in obese individuals.

Across these studies, weight consistently emerges as the dominant predictor, likely due to its direct relationship with truncal adipose tissue distribution [7,8], which significantly influences the depth of needle insertion at the L3–L4 interspace[9]. BMI and waist circumference further reflect central obesity, which contributes to increased subcutaneous tissue thickness and altered anatomical landmarks [10].

The present study extends these observations by incorporating multivariate regression and ROC analysis, thereby providing a more robust and validated predictive model tailored to the Indian population [11-14]. This approach enhances the clinical applicability of anthropometric estimation compared to earlier studies relying solely on univariate correlations.

Physiological and Anatomical Basis: The strong association between anthropometric parameters and spinal needle depth can be explained by underlying anatomical and physiological mechanisms. Increased body weight and BMI are associated with greater deposition of subcutaneous and paraspinal adipose tissue, leading to increased distance between the skin and the subarachnoid space [15]. Central obesity, reflected by waist circumference, further contributes to increased tissue thickness and may alter spinal curvature, thereby affecting needle trajectory [16].

Arm circumference, representing peripheral adiposity, also showed a significant correlation with SND, suggesting that overall body fat distribution influences spinal anatomy [17]. In contrast, height reflects skeletal dimensions rather than soft tissue composition, which explains its relatively weaker predictive value [18].

Evaluation of Predictive Formula: Bonadio's formula (SSD = 0.77 + 2.56 × BSA), although widely used, slightly overestimated the spinal needle depth in the present study (mean predicted 5.62 cm vs actual 5.20 cm). This discrepancy may be attributed to population-specific differences in body composition and fat distribution.

In contrast, the regression equation derived in this study, based on directly measured variables, offers a more accurate and population-specific predictive tool. Its simplicity and reliance on easily measurable parameters make it highly suitable for routine clinical use.

Clinical Implications: The findings of this study have important practical implications for anesthetic practice. Preoperative estimation of spinal needle depth using weight and BMI can:

- Improve first-attempt success rates
- Reduce the number of needle insertion attempts
- Minimize patient discomfort and procedural time
- Decrease the incidence of complications such as post-dural puncture headache and traumatic puncture

The high AUC values observed in ROC analysis further support the reliability of these parameters in clinical decision-making. Importantly, this approach is particularly valuable in resource-limited settings, where ultrasound guidance may not be routinely available.

Strengths of the Study: This study has several methodological strengths. It employed a prospective design with standardized intraoperative measurement of spinal needle depth, ensuring data reliability.

A comprehensive range of anthropometric parameters was included, capturing both central and peripheral adiposity. Advanced statistical techniques, including multivariate regression and ROC analysis, were utilized to enhance analytical rigor. Additionally, a clinically applicable predictive equation was developed, tailored to the study population, thereby improving its practical utility.

Limitations: Despite its strengths, this study has certain limitations. It was conducted at a single center, which may limit the generalizability of the

findings. Ultrasound-guided measurement of spinal depth was not performed for comparison. Additionally, the study population was restricted to ASA I–III patients aged 20–60 years undergoing elective below-umbilical surgeries, which may limit applicability to other patient groups. Potential inter-operator variability in needle insertion technique was also not assessed.

Future Directions: Future studies should focus on validating the proposed predictive model across multicentric and diverse populations to enhance its generalizability. Comparative evaluation with ultrasound-based measurements may further establish its accuracy. Additionally, the development of user-friendly nomograms or digital tools for bedside application could improve clinical utility, while the integration of machine learning approaches may offer more precise and individualized prediction of spinal needle depth

Conclusion

In summary, this study demonstrates that body weight and BMI are strong and independent predictors of spinal needle depth, with weight being the most reliable determinant. The incorporation of multivariate regression and ROC analysis provides a robust and clinically applicable predictive model, which may improve procedural success and patient safety in spinal anesthesia.

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