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Annals of Anesthesia and Pain Medicine

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A proposal of general model for estimation of skin to epidural space distance on the parturient population

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Received: Dec 28, 2019

Accepted: Jan 22, 2020

Published Online: Jan 24, 2020

Journal: Annals of Anesthesia and Pain Medicine

Publisher: MedDocs Publishers LLC

Online edition: http://meddocsonline.org/

Keywords: Epidural depth; Multilinear regression; Computational model; Data fusion

Abstract

Objective: The main goal of this manuscript is to propose new equations to estimate skin to epidural space distance based on parturient data. This information is very useful on epidural anesthesia procedure, which is considered the most challenging procedure to acquire practical skills. The incidence of failure in epidural block is around 23% to 30%. The estimation of skin to epidural space distance (SED) presents a crucial role in such a procedure.

Methods: Three works calculating this distance with different populations of parturients were used here to propose a general model. Data from six population groups were analyzed. In a first approach, the t-test is used to identify the populations that have no statistically differences. Then, the related population samples are combined based on patient data and population groups. An equation is proposed amplifying the input data in a second approach. On this, data from all the population groups of parturients are looked out as one big group.

Results: The proposed equation relates skin surface to epidural space distance with the Body Mass Index (BMI). Illustrations and computational experiments demonstrate propositions quality.

Conclusion: More universal equations for estimate distance from skin to epidural space in parturients are proposed and can be valuable for junior anesthesiologists in training.

Cite this article: de Melo RHC, Conci A, Popovici D, Carlos Galhardo Jr. A proposal of general model for estimation of skin to epidural space distance on the parturient population. Ann Anesth Pain Med 2019; 3(1): 1006.

Introduction

Epidural anesthesia is considered one of the blocks that demand a considerable effort to acquire competence [1]. The number of executions required to physicians master this technique is 77 +/- 9 procedures [2]. The incidence of failures according to a standard definition is around 23% to 30% [3,4]. Failure of the epidural block is considered when there are at least one or a combinational of the following: lack of adequate pain relief by 45 min from the start of epidural placement, puncture of dura matter, re-siting initial position, abortion of this anesthesia or patient dissatisfaction with analgesia at the follow-up visit [3].

The success of the epidural technique lies in the correct identification of epidural space. The Ultrasound (US) is an efficient tool to determine the position of the epidural space [5]. The use of such equipment is not a reality in the majority of cases of epidural punctures, mainly because of cost and availability, which limit its use in many medical centers. Tissues thickness estimation has an important role associated with the epidural procedure being related to the anesthetist ability. Additionally, this is a step necessary for the construction of a computational simulator to train anesthesiologists on the practice of the epidural block. The estimation of epidural depth, the distance from the skin surface to the epidural space (SED), showed in Figure 1, could be used to allow variability of cases for beginners on learning this technique. Identifying the epidural space is a tactile dependent procedure. Physicians need the information to correctly locate the area to apply the anesthetic. This anesthesia is a blind operation used in many real occasions of childbirth.

In epidural anesthesia, the patient can be either sitting or lying in the lateral position. The puncture strategy used can be midline or paramedian approach. These two ways of puncture are illustrated in Figure 2. Variations in position and puncture strategy can alter the distance from the skin surface to epidural space [6].

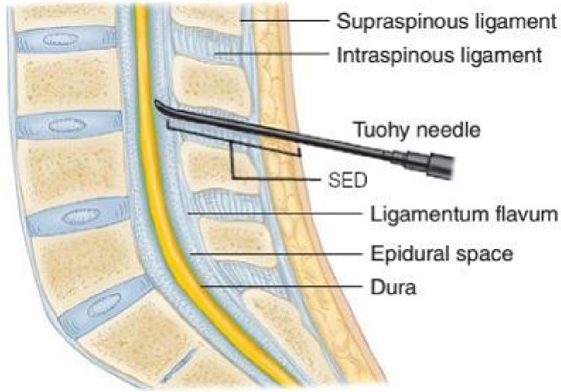

Figure 1: Criteria of exclusion

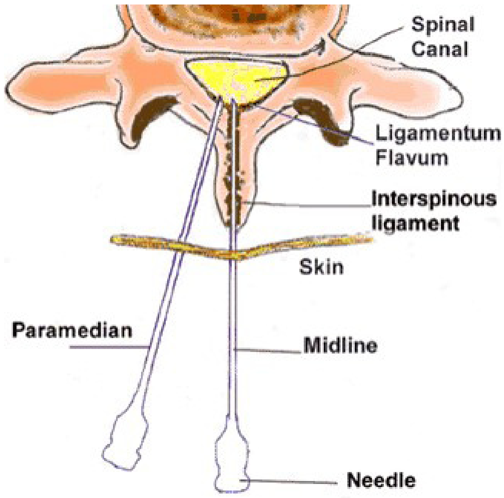

Figure 2: Midline and paramedian approaches of needle placement [8].

Related works

In this work body mass index (BMI) is defined to the standard equation of *mass* in kilograms divided by the square of the *height* in meters (kg/m^2). The *age* (*A*) refers to years, *mass* (*M*) to kilograms (kg), *height* (*H*) to meters (m) and the *skin to epidural space distance* (*SED*) to centimeters (cm).

Using 2009 parturient data from Michigan-USA, it was shown that the *SED* varies positively with *BMI* and negatively with *age* resulting in equation (1) where *Y* represents the estimated *SED* [6].

$$Y = 3 + 0.11\,BMI - 0.01\,A \qquad (1)$$

For equation (1) and all others here presented, the constants are not dimensionless. The unit of each constant makes all components of the equation result in centimeter, the same dimension of the *SED*.

The authors also conclude that the age influence on the *SED* is minimal (0.2 cm variation holding *BMI* with *age* increasing *age* from 20 to 42). Equation (1) could be simplified removing the *age* factor. Regarding the procedures, authors assumed that almost all the times the parturient were in the sitting position. The approach of needle insertion was not mentioned [6].

A UK study considers a population of 1210 parturient (1140 in UK sites and 70 Chinese data from Singapore) showing that both ethnicity and *BMI* influenced the *SED* [9]. These groups were defined and analyzed separately as: White (British, Irish and any other white background); Asian or Asian British (Indian, Pakistani, Bangladeshi or any other Asian background); Black or Black British (African, Caribbean or other black groups); and Chinese or Other ethnic group (Chinese, Japanese, Malaysian, Filipino etc). Instead of an equation for each one of the four groups, the authors present a plot and a table with sampled data for each group. The variation of *SED* of each group for different *BMI* is reproduced in table 1. This table also includes the mean and standard deviation (STD) of each group. All procedures considered were done with the patients in the sitting position using the midline approach of needle placement [9].

Data from 300 Indian patients were used to construct three equations, one for each group defined as: Parturients; Males; and Non-pregnant females. All of these groups used the same population size (n=100). The equation for the parturient group associates variations of *SED* with *mass*, *height* and *BMI*, as reproduced in (2). All data were obtained regarding midline insertion of the needle and with patient in lateral recumbent position [10].

$$Y = 4.75 + 0.21\,BMI + 4.70\,H - 0.05\,M \qquad (2)$$

More recent works proposed the determination of *SED* using only *BMI* as input with population sizes of n=120 and n=317 respectively [11,12]. In both cases the patients analyzed include men and women.

Table 1: Criteria of exclusion

BMI (kg/m^2)	Estimated *SED* (cm)			
	White	*Asian/British Asian*	*Black/British Black*	*Chinese*
20	4.7	4.5	5.0	4.4
25	5.3	5.1	5.7	4.7
30	6.0	5.7	6.5	5.1
35	6.6	6.2	7.2	5.4
40	7.2	6.8	8.0	5.7
Mean (STD)	5.5 (1.1)	5.0 (1.0)	6.0 (1.1)	4.8 (0.9)

This table illustrates how the *skin to epidural space distance* (*SED*) varies with the *body mass index* (*BMI*) for the four parturient groups described by Sharma et al [9]. Values of mean and standard deviation (STD) are also showed for comparisons.

Methods

The present study proposes more universal equations to determine *SED* of parturient, taking into account data from the previous local studies. The *SED* is an essential information to allow the creation of virtual patients on a simulator of epidural anesthesia for training purposes. The approaches of data fusion used for construction of the more general equations are presented in this section. As input we use three approaches commented on previous section [6,9,10] to determinethe *SED* on parturients.

A. Generation of equations from data

For each one of the four groups of table I, the least-squares method was used to find the line that most closely approximates the five pairs of points *x=BMI* and *y=Estimated SED*. The result equations for each group that minimizes the sum of squared distances from every point is described in equations (3) for the White group, (4) for the Asian/British Asian, (5) for the Black/British Black and (6) for the Chinese group.

$$Y = 2.18 + 0.13\, BMI \qquad (3)$$

$$Y = 2.24 + 0.11\, BMI \qquad (4)$$

$$Y = 1.98 + 0.15\, BMI \qquad (5)$$

$$Y = 3.08 + 0.07\, BMI \qquad (6)$$

B. Estimating population dat

As the raw data from each population of the three analyzed works are not publicly available, two hundred data were randomly generated to simulate the patients. The minimum and maximum assumed values for each parameter were *mass* in kilograms (50- 70), *height* in meters (1.4 to 1.9), and *age* in years (18-40). *Mass* and *height* values were estimated to allow individuals with underweight, average weight, overweight and obesity based on Pregnancy Weight Gain Calculator [12]. The minimum age value takes into consideration the majority age of most countries. The maximum value was chosen based on the higher risk of pregnancies over this age. The fourth input variable, *BMI*, was calculated using the standard equation of *mass* in kilograms divided by the square of the *height* in meters. The linear equations of the works [6,10] and the equations (3) to (6) calculated from data of were used to estimate the *SED* value for each population. Considering that each equation correctly represents the populations, the *SED* estimation result corresponds to the individual's data from the populations of the six equations studied. Table II illustrates the mean and standard deviation (STD) of the randomly generated data for each of the parameters. Figure 3 illustrates the mean and STD for the estimated *SED* of the population results for each equation representing the groups.

Table 2: Random generated population data

Patient characteristics	*Mean*	*Standard deviation*
Age (years)	28.70	6.58
Height (m)	1.65	0.15
Mass (kg)	68.97	11.80
BMI (kg/m^2)	25.84	6.55

This table describes the mean and standard deviation of the four characteristics of the patients that were randomly generated to create the population data.

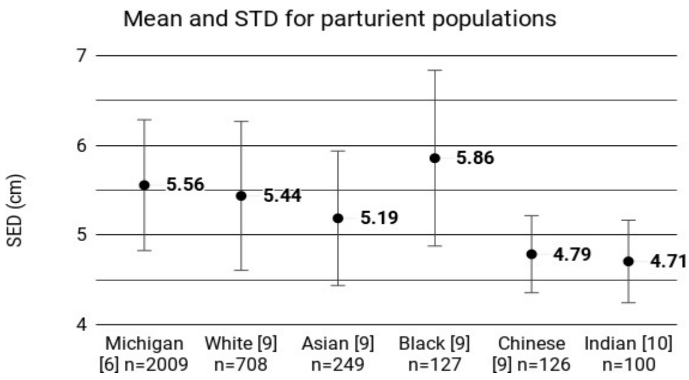

Figure 3: Mean and standard deviation of estimated SED for the parturient population.

C. Analyzing the populations

T-test [14] was performed to seek statistic similarities between the population groups, equal variances and hypothesized no mean difference was assumed for the comparisons between each pair of groups. The input values of the group in this test were the *SED* values. There is no difference in mean *SED* values between the Indian individuals generated by (2) and the Chinese individuals generated by the Chinese equation of equation (6) ($p>0.05$). So, in one of the here presented approaches, these two samples of populations were analyzed as an Indian-Chinese group. An important point to notice is that [9] indicates that Indians were represented by the Asian group but the two hundred individual samples generated for the Asian group [9] and Indian group present differences in mean *SED* values in the t-test. Figure 3 graphically illustrates the similarities between Indian (blue diamond) and Chinese (black X cross) group and the difference of Indian to Asian (orange circle) group.

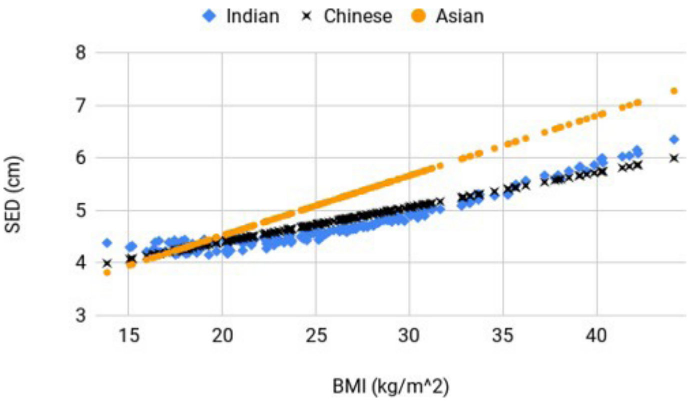

Figure 4: Scatter plot of BMI x SED comparing populations of Indian, Chinese and Asian groups.

The only other pair of groups that present no difference in mean *SED* in t-test (p>0.05) were the Michigan individuals generated by (1) and the White individuals generated by White equation (3). Authors of Michigan work commented that they do not collect data of race or ethnicity [6]. The 2018 census in [15] indicates that the Michigan population corresponds to a majority of white people (79%), Black and African American corresponds to 14% and Asian to 3.2%. The census date has a little more than a decade after the study data from Michigan [6]. An assumption was made here that these statistics did not change considerably over this time. With this assumption, the census data reinforces the statistically proved correspondence of these groups. We then consider Michigan estimated data together with the White group estimated using equation (3). The name of this new group is Michigan- White.

D. Approaches to construct the models

The combined inputs (*mass*, *height*, *age* and *BMI*) were considered as the independent variables in a multilinear regression model and the *SED* was considered as the dependent variable.

On the first approach two new groups of populations were formed, as commented on the previous section. The Indian-Chinese and Michigan-White groups use each one a population size of n=400.

For the second approach, all the six groups were combined, forming a population size of n=1200. All data were used to create a general equation. This approach is useful when the equation for a specific group does not exist or when measures approximated could be considered.

All statistical analyses regarding t-test and multilinear regression were made using XLMiner Analysis ToolPark [16], an add-on of Google Sheet.

Results

The linear regression equations of the two proposed approaches are presented in this section.

A. Different equations for groups of populations

The results of the Michigan-White linear regression were statistically significant for a relationship from *BMI*, *age* and *SED* (p<0.01). *Mass* and *height* did not represent a significant (p~1>0.01). Although statistically significant, the impact of age on the estimated *SED* is 0.11cm in the whole domain of age, which could be considered as irrelevant in *SED* estimation (minimum= 3.93, maximum=7.74 for this group), so, only *BMI* was used in the final equation. For the Indian-Chinese equation the only input variable that represents statistical significance in relation to *SED* was *BMI* (p<0.01). The new equation for this group was slightly different for the one of the Chinese group of equation (6) calculated from data of [9]. The regression equation (7) represent the Michigan-White group and equation (8) represent the new group ofIndian-Chinese.

$$Y = 2.44 + 0.12\,BMI \qquad (7)$$

$$Y = 3.03 + 0.07\,BMI \qquad (8)$$

The scatter plot of figure 4 shows that the results of the estimated *SED* for the new Michigan-White equation (orange circle) were always between the results of the two input equations. For *BMI* <32 the *SED* values from Michigan [6] are greater than the one from White group [9], after that limit the behavior is the opposite for almost all the remaining data.

Figure 5 shows that the results of the estimated *SED* for the Indian-Chinese equation (orange circle) have a small difference on the slope from the Chinese group of equation(6) (black X mark). The new equation has *SED* values lower than the Indian parturient group [10] for *BMI*<17 and *BMI*>35.

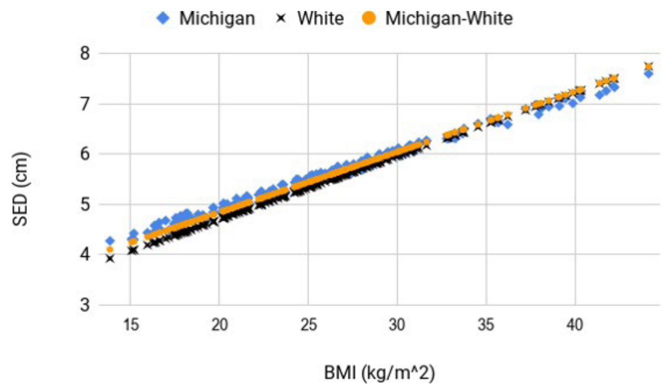

Figure 5: Scatter plot of *BMI x SED* comparing the inputs and output for the Michigan-White group.

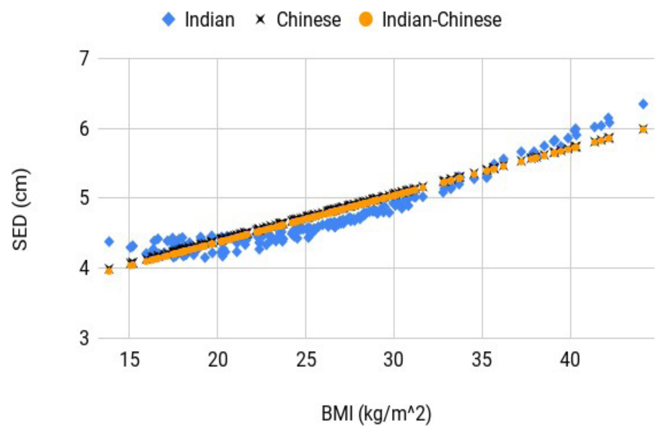

Figure 6: Scatter plot of *BMI x SED* comparing the inputs and output for the Indian-Chinese group.

B. One equation combining all the parturients data

For the second approach, we combine the samples of all the six populations without the information of ethnicity or origin. The influence of all four independent variables on *SED* was tested in a multiple linear regression model. Only *BMI* have shown statistical significance (p<0.01) for this model. The regression equation (9) represents the result of this.

$$Y = 2.52 + 0.11\,BMI \qquad (9)$$

The mean value of the *SED* for all the samples is 5.30 cm with an STD of 0.74 cm, the minimum *SED* value is 3.82 cm and the maximum is 8.60 cm.

Figure 6 shows the comparison of results of the estimated *SED* for all equations and the Generic equation with the combination of all data (orange circle). For small values of *BMI,* all the equations present very near *SED* values, as the *BMI* grows the majority of the results diverge.

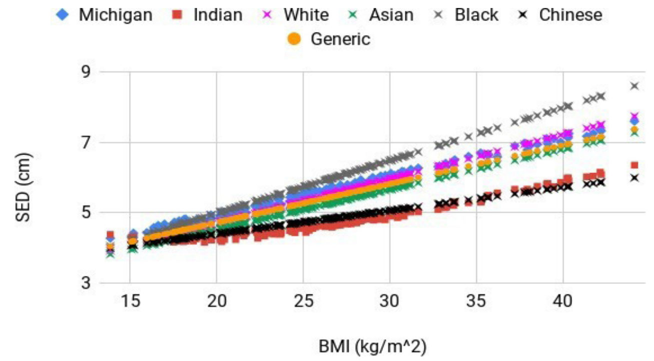

Figure 7: Scatter plot of BMI x SED comparing the inputs (all groups) and output (Generic equation).

The bigger values are the ones of the Black group of equation (5) and the smallest are the ones of the Chinese group of equation (6) or on Indian group of [10]. The Generic equation constructed with the samples of the parturient data of all the populations gives an average value of *SED*.

Discussion

It's important to highlight that the premise used for this study is that each analyzed equation correctly describes the population that it was based on. This was necessary, as we do not have access to the original population data of each of the works studied.

The curves illustrated on the results were all about *Body Mass Index* (*BMI*) versus Skin to Epidural space Distance (*SED*) because the *BMI* was the variable that has the greater relation with the *SED*. This was observed in many previous works and here too.

Concerning the approach of different equations for population groups, the results detailed on the last section support both visually and statistically that the population samples considered as input for each equation have similar characteristics. In this sense, the aggregation of data proposed represents an information gain for the groups. For both Michigan-White and Indian-Chinese equations, the estimated *SED* seems well suited. The similarities found between the Indian data and the Chinese one was unexpected as the Chinese group defined by the UK work includes theIndian population [9].

Analyzing the data of all parturient groups as one makes the population more diverse. The level of explanation could be indicated through the adjusted r-square which represents how close the data are to the fitted regression model. The value of adjusted R-square for the Michigan-White is 98.82%, for the Indian-Chinese group is 94.22% and for the Generic group the value is 69.19%.

The model of the Generic equation is 25% less precise concerning population than the Indian-Chinese equation and 30% concerning the Michigan-White equation of the first approach. With a fit of almost 70%, the result of the Generic equation could be satisfactory on a range of applications which not have a demand for a huge precision estimation of the *SED* or even when a more precise equation does not exist for the group of the population been studied.

As limitations of this study, the authors point out the use of approximated data of the populations, estimated from the equations used as input. The approach is more general than local studies but considered only populations from the UK, Singapore, USA (Michigan) and India.

Conclusion

We described two approaches to determine *skin to epidural space distances* on parturients. The idea is to use this data as input to the creation of virtual patients on a simulator of epidural anesthesia as the one on development presented in Figure 8 [17]. The first approach uses population group information to give a more precise output. The Indian-Chinese equation brought a question on the formation of groups proposed by the UK work [9] and is open to debate in this matter. The second approach gives an average value that could be used in the lack of an equation for the group of population or when a rough estimate is acceptable. In both proposed approaches here the fused data using multicentric populations produced equations that can be more universal applied to the problem of estimating the skin to epidural distance.

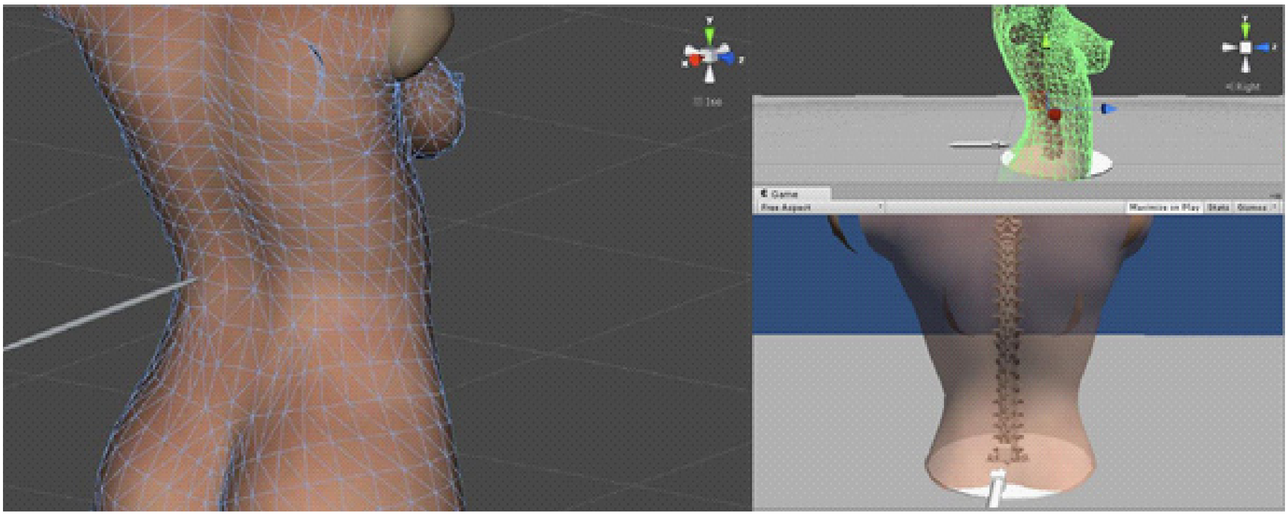

Figure 8: Some screen of the applicon on development for training epidural block [17] .

Future works

Future works include the determination of the thickness of each layer of tissue that exists in the distance between the skin and the epidural space to provide more detailed information to the simulator. Another possible study is to include more data to create different equations for the two possible positions of the parturient on the epidural block.

Acknowledgement

R.H.C.M. thanks CAPES Brazilian Foundation for the financial support. A.C. is partially supported by FAPERJ (CNE and CNPq Brazilian Agency projects MACC/INCT Pq. 305416/2018-9 and Univ. 402988/2016-7.

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