ORIGINAL ARTICLE

Comparison of Axillary, Tympanic and Rectal Body Temperatures Using a Covariate-Adjusted Receiver Operating Characteristic Approach

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Abstract

Background: Accurate temperature measurement is crucial in pediatric population. Before diagnostic tests are implemented in practice, it is suggested that their accuracy or ability to discriminate to be studied. The accuracy of a diagnostic test can be summarized in a Receiver Operating Characteristic (ROC) curve. This study was carried out to compare the accuracy of tympanic and axillary methods with rectal measurement in children less than 6 years old.

Methods: A total of 220 pair of ears, axillaries, and rectal sites were used to determine the body temperature in patients aged between 3 months and 6 years, who referred to Emergency Department of Ali Asghar Hospital affiliated to Bushehr University of Medical Sciences. Rectal temperature (RT) was considered as gold standard. Fever was defined as RT $\geq 38^{o}$C. RT, axillary, right and left tympanic temperature were measured. Measure agreement was assessed by covariate-adjusted ROC regression.

Results: By comparing the area under the curves in Hanely method and the results from ROC regression analysis, we found out a significant agreement among the three measuring techniques and none of them was more accurate than the others.

Conclusions: None of these techniques (axillary, right and left tympanic) was more accurate than the others and it is better to use a technique that is more convenient, painless, and safer than rectal temperature. We also propose using a modified parametric distribution-free ROC estimator which is conceptually easy and is simple to implement with the existing softwares for comparing the accuracy of medical tests.

Keywords: Covariate-adjusted ROC curve; Accuracy; Tympanic; Axillaries; Rectal temperature; Pediatric; Fever

Introduction

A popular topic in medical research is development of biomarkers to classify subjects as diseased or disease-free by finding proper cutoff points. This analysis is done by receiver operating characteristics curve (ROC). A ROC curve is obtained by calculating the sensitivity and specificity of every observed data value and plotting sensitivity against 1-specificity. Sometimes, patient or marker specific factors (covariates) other than disease affect finding the cutoff point. To account for factors that might influence the test accuracy, various ROC regression methods have been proposed. The concept of covariate adjustment is well established in therapeutic and etiologic studies. However, it has received little attention in the growing area of medical research (development of markers for disease diagnosis, screening, or prognosis) where classification of accuracy, rather than association, is of primary interest.[1] In evaluating these markers, it is often necessary to account for covariates which are associated with the marker of interest. These covariates may include subject characteristics, test operator skill, test procedures, or aspects of specimen handling.

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It displays the tradeoff between false-positive and false negative error rates associated with classification rules based on the marker.[1]

The degree of body temperature is an important indicator of illness in children.[2] Measuring temperature in children can be difficult, especially when they are not cooperative or restless.[3] The ideal technique for measuring body temperature should be painless, reproducible, rapid, and accurately reflect the core temperature.[4] The rectal site has long been considered as the gold standard for temperature measurement in young children.[5] This technique is accurate and reproducible but unpleasant and sometimes dangerous.[4] On the other hand, rectal temperature can be time consuming, and uncomfortable.[5] Likewise, injuries such as rectal perforation and probable cross-contamination infection may occur.[6]

Temperature can be measured at various sites but the best site is still a matter of controversy.[7] The axilla is a safe and accessible site but concerns have been raised about its accuracy.[3] Tympanic temperature offers a fast and non-invasive recording, but early studies indicated many contradictory findings about its accuracy and reliability.[8-12]

Considerable research has focused on the development of new technologies to facilitate non-invasive diagnosis. While non-invasive diagnostic methods continue to improve, they are somehow imperfect.[13] So before new methods are implemented in practice, it is imperative to study the accuracy of the test.[14] This is accomplished using ROC regression analysis of test accuracy.

The focus of this paper was to compare the accuracy of three body temperature measuring techniques (Right Tympanic, Left Tympanic, Axillary), as covariate, in detecting febrile children and clarify if they are reliable and accurate when compared with rectal temperature in children.

Materials and Methods

In a cross-sectional study with convenience sampling, 220 children aged 3 months to six years, who referred to Emergency Department of Ali Asghar Hospital affiliated to Bushehr University of Medical Sciences (south of Iran, in the vicinity of Persian Gulf), were recruited. Axillaries, tympanic (right and left) and rectal sites were used to determine the body temperature. Rectal temperature (RT) was considered as gold standard. Fever was defined as RT $\geq 38^{o}$C. The three instruments used were tympanic thermometer (Gentle 510, Omron factory, Philippines), axillaries temperature (Flex temp CE0197, Omron, Philippines) and rectal digital temperature (Protemp CE 0473, Omron, Philippines). The more description of data, design and measurement consideration can be found in Jahanpour ***et al.'s study***.[15]

The area under the receiver-operating characteristic (ROC) curve was determined to demonstrate the discriminatory power of tympanic and axillary techniques in prediction of fever in children. ROC curve analysis was performed as follows: Sensitivity was plotted as a function of the false positive rate (1-specificity) for predicting the febrile child. An area under the curve of 1.0 represents a perfect test with 100 percent sensitivity and 100 percent specificity, whereas an area of 0.5 represents a random discrimination. Areas under the curve above 0.7 might indicate a reasonably good clinical test. Different ROC curves were compared using the method proposed by Hanley and McNeil.[16]

We also used ROC regression methodology to compare ROC curves for different measuring techniques. In ROC model, the ROC curve is a parametric function of covariates but distributions of the diagnostic test results are not specified (parametric distribution free approach). Statistical analyses were performed using the Stata version 8 and the SPSS software package (version 13, SPSS Inc. Chicago, Illinois, USA).

Results

According to the findings, the rectal temperature in these patients ranged from 34.7ºC to 39.1ºC, with a mean (SD) of 36.7ºC (0.92); the axillary temperature ranged from 34.4ºC to 39.5ºC with a mean (SD) of 36.6ºC (0.98). The right tympanic temperature ranged from 34.9ºC to 39ºC, with a mean (SD) of 36.4ºC (0.85) and the left tympanic temperature ranged from 34.8ºC to 39.3ºC with a mean (SD) of 36.4ºC (0.82). Our Gold standard for fever was a rectal temperature greater than 38^{0}C, with this criterion, 13% of the referred patients were febrile.

To illustrate the diagnostic accuracy of the three techniques, right tympanic, left tympanic and axillary for the prediction of fever in children, ROC curves were calculated and the area under the ROC curves representing the diagnostic threshold was determined. There were no significant differences in the AUC for right tympanic, left tympanic and axillary for predicting fever in children. The corresponding AUCs were 0.953 (95% C.I: 0.915-0.990), compared to 0.948 (95% C.I: 0.903-0.992), and 0.943 (95% C.I: 0.895-0.992) respectively with a *p* value=0.884 (Figure 1).

We modeled the ROC curve as a binomial curve for the three measuring techniques:

$ROC(t)=\Phi(g_1+g_2\Phi^{-1}(t))$, Φ=cumulative normal distribution, t=1-specificity (=false positive rate=FPR), and γ's as parameters.(1)

Estimated parameters are $\hat{g}_1 =$ 2.53 (SE=0.15) and $\hat{g}_2 =$ 1.05 (SE=0.12) for right tympanic, $\hat{g}_1 =$ 2.19 (SE=0.11) and $\hat{g}_2 =$ 0.84 (SE=0.10) for left tympanic and $\hat{g}_1 =$ 2.06 (SE=0.10) and $\hat{g}_2 =$ 0.80 (SE=0.09) for axillary. It seems that the slopes and intercepts are similar in the three techniques.

We used the regression framework to compare ROC curves for the three techniques. Each child contributed three observations to the analysis. Let X_1 be a corresponding indicator variable, equal to one for the right tympanic technique and zero for others and X_2 be a corresponding indicator variable equal to one for the left tympanic technique and zero for others. The following ROC regression model was fitted:

$$ROC(t)=\Phi(g_1+g_2\Phi^{-1}(t)+b_1X_1+b_2X_2+b_3X_1\Phi^{-1}(t)+b_4X_2\Phi^{-1}(t))$$
.(2)

The above model reduced to $ROC(t)=\Phi(2.22+0.87\Phi^{-1}(t))$ for this set of data, which implies that ROC curves for different techniques is the same and there is no difference in the accuracy of the three measuring techniques and none of them is more accurate than the others.

Discussion

In this study, there was a close agreement between the results that we obtained from comparing the area under curves and those from ROC regression analysis. In both of these two techniques, we found out that there was no difference in the accuracy of the three measuring techniques and none of them is more accurate than the others.

The model (2) is very flexible in that it allows the effects of each technique on the ROC curves to differ by varying amounts depending on the FPR t. Bootstrap resampling, with each child as the sampling unit, yielded standard errors and variance– covariance estimates. With backward elimination method, parameter estimation suggested that interactions be-

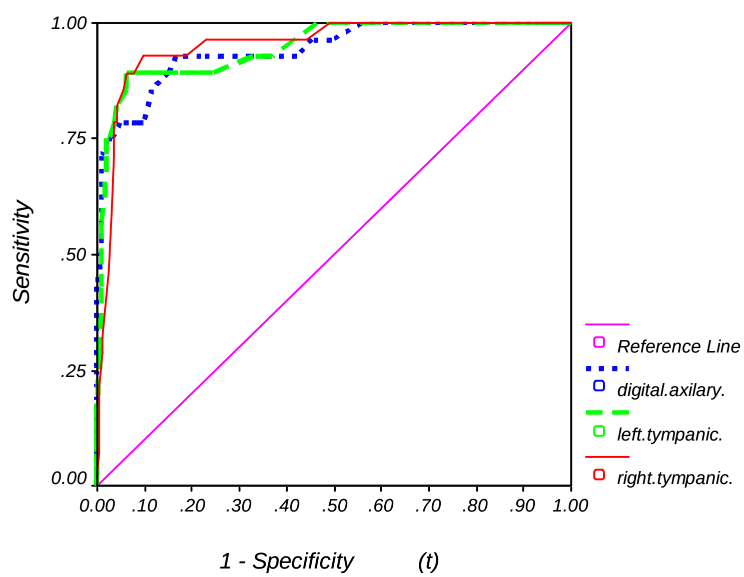

Fig. 1: ROC curves of body measurement techniques, right tympanic, left tympanic and axillary for prediction of fever in children

tween the measuring technique and $\Phi^{-1}(t)$ were not significant and, thus, the following reduced model was more appropriate: $ROC(t)=\Phi(2.22+0.87\Phi^{-1}(t))$.This model implies that ROC curves for different techniques is the same and there is no difference in the accuracy of the three measuring techniques and none of them is more accurate than the others.

In summary, in this study we propose using a modified parametric distribution-free ROC estimator which is conceptually easy and is simple to implement with the existing software packages. This procedure is conceptually and computationally simplified in comparison with the existing procedures. Simulation study results indicate that this approach has fairly high statistical efficiency.[14]

In agreement with our study, Weiss in 1991 compared the tympanic temperature in both ears with axillary temperature, concluding that their accuracy as an estimation of body temperature in the neonate was similar.[17] Asadi in 2006 studied 196 in-patients aged two months to five years, suggesting that temperature measured at the axilla is convenient, painless, and safe and it closely reflects the rectal temperature.[4]

El-Radhi and Patel in 2006 concluded that tympanic thermometry is more accurate than measurement of temperature with an electronic axillary thermometer. It is also quick and safe; thus, it is recommended in the pediatric emergency setting.[18] Hebbar K *et al.* in 2005 reported that the sensitivity and specificity of both temporal artery and axillary for diagnosing fever were similar. It is not sufficiently accurate to recommend replacing rectal or other invasive methods. As temporal artery and axillary provide similar accuracy, temporal artery thermometers may serve as a suitable alternative for patients in whom invasive thermometry is contraindicated.[19] In a review article written by Lisa and Houlder, it was found out that the sensitivity of tympanic and axillary techniques in detecting fever was less than desired.[5]

In agreement with our study, Childs and Harrison found out that there was no significant difference in the results of the two ears.[20] Using the measuring technique as a stratification covariate, we allow the difference between the ROC curves on a probit scale to be changed with false positive rate (t). Indeed, this regression model is simply a representation of the three separate parametric binormal models fit to the ROC curves for the three techniques.

Our results showed that none of these techniques is more accurate than the others and it is better to use a technique for measuring the child's body temperature that is more convenient, painless, and safer than rectal temperature. We also propose using a modified parametric distribution-free ROC estimator which is conceptually easy and is simple to implement with the existing software packages for measuring and comparing the accuracy of medical tests. The convenience sampling may decrease the generalizability of the findings. Less febrile subjects were another shortcoming.

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