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Updated KidZ Health Castle Formula for Multichannel Intraluminal Impedance-pH Monitoring Probe Positioning

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Conflict of Interest
The authors have no financial conflicts of interest.

ABSTRACT

Purpose: The KidZ Health Castle Formula (KHC-F) was developed to improve the positioning of multichannel intraluminal impedance-pH probes (MII-pH). We hypothesized that the updated formula KHC-Fv2 would performs better than the original formula. This study aimed to evaluate the reliability of KHC-Fv2.
Methods: A prospective cohort study was conducted to assess MII-pH probe positioning in patients aged 1 month to 18 years. Margins of error within 1 cm above or below the target position, as determined using KHC-Fv2 and compared with fluoroscopy, were accepted.
Results: Eighty-four children were included in the study. The mean difference between the KHC-Fv2 and target positions was +0.25 cm cranially. The KHC-Fv2 insertion length fell within the accepted difference of ±1 cm of the target position in 67.9% of the children. This percentage increased in infants under 1 year of age (79.5%) or shorter than 100 cm (74.0%) in height.
Conclusion: KHC-Fv2 demonstrated strong agreement with correct positioning and significantly reduced the need for a second radiologic control after probe repositioning, particularly in infants or children shorter than 100 cm.

Keywords: Gastroesophageal reflux; Multiple intraluminal impedance; pH monitoring; pH-probe; Radiography

INTRODUCTION

Multichannel intraluminal impedance-pH (MII-pH) monitoring is a diagnostic tool for gastro-esophageal reflux disease (GERD) [1]. EThe esophageal MII-pH measuresthe acidic, weakly acidic, and non-acidic GER of liquids, solids, and air [2]. Compared to standard pH monitoring, impedance offers the detection of recordingall reflux episodes, regardless of pH [3]. Currently, MII-pH is proposed as an effective method for measuring the frequency and duration of GER episodes and their correlations with symptoms [4].

The MII-pH catheter is inserted transnasally and consists of impedance measurement rings and an esophageal pH sensor. In adults and older children, the catheter includes an additional pH sensor to measure gastric pH. The esophageal pH sensor is positioned between the two distal impedance rings [2]. According to consensus, the standard positioning of the esophageal pH sensor is two vertebrae above the diaphragm [5]. To estimate this location, Strobel et al. [6] developed a formula (0.252×body length [cm]+5), which has been recommended by the ESPGHAN EURO-PIG [6,7]. However, studies have indicated that the accuracy of this formula decreases with larger body sizes, as it tends to overestimate the esophageal length [8]. Consequently, the precise placement of the pH sensor must be confirmed radiologically via fluoroscopy or X-ray [7].

Various formulas have been developed to determine the optimal position of the MII-pH catheter; however, the outcomes have remainedve been unsatisfactory. A simple formula, known as the KidZ Health Castle formula (KHC-F), was introduced by the nursing staff at the KidZ Health Castle, UZ Brussel. This formula calculates the distance from the tip of the nose to the ear canal (in cm) and the distance from the nose tip (with the head in a neutral position) to the midpoint of the nipple line (in cm) [9].

Vandercruys et al. [9] evaluated the reliability of the KHC-F by comparing it to radiologic positioning. The correct position was achieved in two-thirds of patients using the KHC-F, with a mean difference of 0.44 cm from the target position. Notably, KHC-F demonstrated significantly higher accuracy in infants during the first year of life and in children shorter than 100 cm [9].

Based on the mean difference (−0.44 cm on the Bland–Altman plot), an updated formula, KHC-F version 2 (KHC-Fv2), was developed. A prospective study was designed to evaluate the reliability of the KHC-Fv2 compared to the radiologic positioning of the pH sensor.

MATERIALS AND METHODS

This prospective cohort study was conducted to evaluate the MII-pH probe positioning. Children aged 1 month to 18 years, referred by their healthcare providers for GER assessment were included. The inclusion period spanned from October 2022 to August 2023. Patients with a history of esophageal or thoracic surgery and/or severe scoliosis were excluded. The impedance probes used were ZIN-BS-51 and ZPN-BG-07 (Diversatek Healthcare). A standardized protocol was followed by our nurses to insert the catheters transnasally following the KHC-Fv2. The distance from the nose tip to the ear canal (in cm) was added to the distance from the nose tip (with the head in a horizontal position) to the midpoint of the nipple line (in cm), with a subtraction of 0.5 cm. Following insertion, fluoroscopy was performed to verify pH sensor positioning, and adjustments were made if necessary.

The insertion lengths obtained using KHC-Fv2 and the radiologically confirmed correct length were recorded for each patient. Details regarding the age (months), height (cm), weight (kg), and probe type were recorded. A variation of up to 1 cm above or below the final position, owing to changes in head position and breathing, was accepted between the KHC-Fv2 and radiological control by fluoroscopy.

Statistical analyses were performed using R v 4.0.3. The distribution of catheter positions was assessed visually using QQ plots and formally tested using standard distribution tests. Spearman's correlations were used to evaluate the relationship between the distance to the correct position and clinical factors. Bland–Altman plots were constructed to assess the agreement between the KHC-Fv2-derived insertion length and correct position by calculating the mean error and 95% limits of agreement. Nonparametric and chi-square tests were used to evaluate the association between child-related factors, including age, height, height for age (HFA), and weight for age (WFA), and the correct position according to the KHC-Fv2. A p-value of 0.05 was considered statistically significant.

The study protocol was approved by the UZ Brussel ethics committee (EC number: EC-2022-192; BUN: 1432022000141). Informed consent was waived because the MII-pH investigation was performed based on clinical indications and the results were anonymized.

RESULTS

Study population

A total of 84 children were included, of whom 39 (47%) were boys. The median age (Q1:Q3) was 14 months (5.0; 98.3), with 55% of the children being less than 1 year old. Fifty-four (64.2%) patients had tumors measuring <100 cm. The median age (Q1:Q3) of patients less than 100 cm was 5 (2–6) months, and the median age of patients >100 cm was 86 (29; 145) months. The mean (SD) WFA and HFA z-scores for all included children were -0.29 (1.3) and -0.28 (1.5), respectively.

Evaluation of the KHC-Fv2 formula

A strong correlation was observed between the catheter insertion length determined by the KHC-Fv2 formula and the exact radiological position (ρ=0.97; *p*<0.001). The mean difference between the KHC-Fv2 insertion length and radiologically confirmed position was +0.25 cm cranially, with a lower confidence limit of -3.1 cm caudally and an upper confidence limit of 3.5 cm cranially (Appendix **Fig. 1**). The pre-defined accepted difference of ±1 cm from the target position was met in 68.0% (57/84) of the children. Among children under the age of 1 year, this percentage increased to 79.5%. Similarly, when only children shorter than 1 m were considered, the percentage increased to 74.0%.

Using the original KHC-F, the pH sensor was correctly placed in 65% of cases, compared to 68% with the updated formula. The mean error of both formulas remained within the margin of error (KHC-Fv2: +0.25 cm and KHC: −0.44 cm); however, neither formula achieved upper and lower limits of agreement below 1 cm.

Influencing factors

The percentage of children with a correct sensor-position using the KHC-Fv2 was significantly higher in children younger than 1 year (79.5% vs. 67.9%, *p*=0.036) and in children less than 100 cm (74% vs. 67.9%, *p*=0.032). No significant difference was observed in the mean WFA z-score (95% CI of mean difference -0.025;0.389, *p*=0.082) or HFA z-score (95% CI of mean difference -0.125;0.300, *p*=0.405) between children with correct or incorrect probe positioning based on the KHC-Fv2 method.

DISCUSSION

KHC-Fv2 resulted in a mean error of +0.25 cm cranially and accurately positioned the probe in 68% of the cohort, with accuracy increasing to 80% in children <1 year old. The updated formula is more reliable for children younger than 1 year and those shorter than 100 cm. This procedure was most commonly performed in this age group. Moreover, this group was more prone to reflux, primarily due to spending more time sleeping, which reduces acid clearance through swallowing and primary peristalsis [15,16].

The Strobel formula (0.252×height in cm+ 5), published in 1971, was proposed by the ESPGHAN EURO-PIG Working Group for pH sensor positioning [6,7]. This formula is based on esophageal length. Most pH-sensor positioning formulas are based on esophageal length. However, the taller the patient, the greater the prediction effect [8,10]. Tinawi and Stringer [11] conducted a prospective study to report a predictive equation for accurately estimating esophageal length in children; however, this has not yet resulted in a more reliable formula.

Another approach to estimate the insertion length of the electrode involves determining the position of the pH sensor. By consensus the ESPGHAN EURO-PIG Working Group proposed positioning the sensor "two vertebrae above the diaphragm" [7]. The KHC-Fv2 is based on this approach. A shortcoming of most studies using this method is that they do not report the margin of error [12-14]. A key strength of our setup is the strict margin of error (±1 cm)that was accepted, resulting in accurate positioning in 68% of cases using the KHC-Fv2. Another strength of the KHC-Fv2 is its ease of use because it does not require extensive calculations.

Vandecruys et al. [9] reported the percentage of correct insertion lengths, mean error, 95% limits of agreement (Bland–Altman plots), and Spearman correlation for the original KHC-F. KHC-F demonstrated superior performance compared to the other formulas [9]. Considering that the KHC-Fv2 scores were better than those of the original KHC-F, we may conclude that this updated formula outperforms all existing formulas. Additionally, our study population had a better distribution in terms of age, with 55% of the children being younger than 1 year, compared to the study by Vandecruys et al. [9], where children younger than 1 year were overrepresented (70.3%).

Given the mean error of +0.25 cm cranially, an alternative post-hoc adjustment to the KHC-Fv2, subtracting 0.3 cm instead of 0.5 cm, could be considered. Nevertheless, the KHC-Fv2 formula demonstrated consistent and robust results, showing good agreement with the radiological target position and reducing the need for a second radiological control after probe repositioning, particularly in children under 1 year of age or shorter than 100 cm in height. These findings confirm that KHC-Fv2 is suitable for impedance testing, especially in children under 1 year of age. This formula can be safely and effectively applied to patients undergoing MII-pH monitoring; however, radiological confirmation of the correct position remains recommended.

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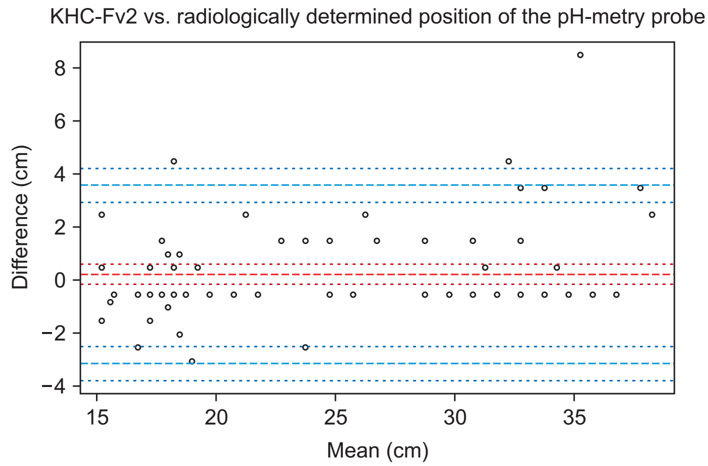

Appendix Fig. 1. Bland–Altman plot of KHC-Fv2 vs. radiologic positioning. The red dashed line with surrounding red dotted lines represents the mean difference with a 95% confidence interval. The blue dashed line with surrounding blue dotted lines indicates upper and lower limits of agreement with respective 95% confidence intervals.

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