**Title: Cost-effectiveness analysis of the NIRUDAK clinical diagnostic model for dehydration severity in patients over five years**

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**DECLARATIONS**

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**Data Sharing:** The deidentified datasets for the NIRUDAK study are freely available with no restrictions via Open Science Framework and can be accessed at https://osf.io/pncms/.

**Abstract**

**Objective:** To compare the cost-effectiveness of the World Health Organization algorithm and the NIRUDAK model for treatment of severe dehydration due to diarrhea in patient over five years of age.

**Methods:**

**Results:**

**Conclusions:**

**Introduction**

Accounting for over 6.5 billion cases and 1.4 million deaths in 2019, diarrheal diseases are a major cause of morbidity and mortality and exert a heavy burden on health care systems worldwide (1). As the severity of diarrheal disease can vary widely, accurately assessing dehydration status remains the most critical step in acute diarrhea management. Accurate assessment of dehydration status can reduce the morbidity and mortality that results from inappropriate hydration of patients. Episodes of acute diarrhea can lead to dehydration, and existing care guidelines, namely from the World Health Organization (WHO), base treatment on categorical estimates for fluid resuscitation. More specifically, patients with severe dehydration require immediate resuscitation with intravenous (IV) fluids, while those with moderate dehydration can safely treated with oral rehydration solution (ORS) and those without any dehydration can be provided with instructions for expectant management at home. Accurate assessment of dehydration status can thus improve the cost-effectiveness of diarrhea treatment by ensuring that ORS, which can be administered in an outpatient setting, is used for the treatment of appropriate patients instead of more costly IV fluids, which require inpatient beds and skilled nursing staff.

ORS has been shown to reduce mortality from diarrheal illnesses by 93%, and is a less expensive treatment option compared than IV fluids in the management of dehydration, resulting in fewer admissions and shorter lengths of stay. To better understand the inpatient versus outpatient treatment costs of treating diarrheal disease, a cost analysis study in Bangladesh found that the average total societal cost of diarrhea illness per episode was $67.18, while inpatient and outpatient costs were $110.51 and $23.62 respectively with the average monthly income being $249.72 and overall cost burden being significantly higher for the poorest households compared to the richest quintile. Such studies highlight the necessity of accurate dehydration assessment.

The Novel, Innovative Research for Understanding Dehydration in Adults and Kids (NIRUDAK, meaning dehydrated in Bangla) model was developed to more accurately assess the dehydration severity level of patients with acute diarrhea and avoid the potential sequelae of over or under resuscitation. Unlike the WHO Integrated Management of Adolescent and Adult Illness (IMAI) algorithm, the NIRUDAK model employs clinical measurements as inputs into a machine learning model (2). Previous analyses have demonstrated that the NIRUDAK model outperforms the current WHO algorithm in terms of accuracy and reliability (3). Employing more accurate clinical diagnostic models, like NIRUDAK, is especially critical in settings where resources are limited and the financial burden of treating acute diarrhea in an inpatient versus outpatient setting are significantly higher. The aim of this study is to compare the cost-effectiveness of the NIRUDAK model to the WHO algorithm in treating patients over five years of age experiencing acute dehydration due to diarrhea. This study represents the first comparison of the cost effectiveness of the NIRUDAK model and the WHO algorithm.

**Materials and Methods**

*Study Procedures*

Data were collected as part of the NIRUDAK study, a prospective cohort study of patients over five years presenting with acute diarrhea to the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) Dhaka Hospital in Bangladesh between March 2019 and March 2020 (1). All patients admitted to Dhaka Hospital’s Emergency Ward were screened and randomly selected for participation in the study upon arrival to the hospital. Selected patients were excluded if they met the following criteria: diarrhea lasting more than seven days, having fewer than three loose stools in the past 24 hours, and having a definitive diagnosis other than acute gastroenteritis. Previously enrolled patients were also excluded from the study. Upon consent, two research nurses independently assessed patients for symptoms of dehydration on arrival and continued to collect and record patient weight and amount of fluid administered every four hours until the patients were discharged. All patients were managed according to icddr,b’s hospital protocols, which follow WHO’s IMAI and Integrated Management of Childhood Illness (IMCI) guidelines. Percent weight change with rehydration was used as the criterion standard for percent dehydration, which has been the standard method for assessing percent dehydration in patients over five years of age by several studies. Percent dehydration was calculated using the following formula:

Percent dehydration = 100%\*[(Post-illness weight – admission weight)/Post-illness weight]

The two highest consecutive weight measurements that differed by less than 2% were averaged to determine a patient’s stable weight, which was used as their post-illness weight. For those who did not reach a stable weight prior to discharge, their return weight was used as their post-illness weight. Based on international guidelines developed by WHO and the United States Center for Disease Control, patients with a percent dehydration >9% were categorized as having severe dehydration, 3-9% as some dehydration, and <3% as no dehydration.

Ethical approval was obtained from icddr,b’s Ethical Review Committee and Rhode Island Hospital’s Institutional Review Board.

The true dehydration status (percent dehydration) was determined based on the patient’s weight at the time of admission to the hospital and their “post-illness” weight at the time of discharge from the hospital. Calculated percent dehydration was stratified into three categories of dehydration severity — no, some, and severe — based on current standards in the literature (5–7). The WHO algorithm and NIRUDAK model both attempt to predict patients’ true dehydration status by classifying patients into one of three predicted categories of dehydration severity — no, some, or severe — analogous to the true dehydration categories of dehydration severity.

*Data Analysis*

A decision tree (Figure 1) was constructed to demonstrate expected DALYs and expected costs for each possible combination of true dehydration status and model-assigned dehydration status. Expected cost was calculated for each branch of the decision tree by taking the mean cost of all patients in that branch and multiplying by branch probability. Costs for treatment were calculated using data from icddr,b. Total costs for each individual patient in the study were calculated based on the type and total amount of fluid each patient received, associated equipment costs, length of stay at the hospital, and wages lost while in the hospital. All costs were received directly from icddr,b. All exchange rate conversions from Bangladeshi taka (BDT) to United States dollar (USD) were conducted using data from the World Bank (8,9). Costs are summarized in Table 1.

DALYs were calculated as a sum of years of life lost due to illness and years lived with disability. Per convention, years of life lost for each patient were based on Japanese life tables which outline life expectancies at specified ages (10,11). Years lived with disability were calculated based on estimates from the Global Burden of Disease study and prior literature on the effects of over- and undertreatment of severe dehydration (12–14). Expected DALYs for each branch of the decision tree were calculated by taking the mean number of DALYs for all patients in that branch and multiplying by the branch probability.

**[QUESTION FOR JP — INCLUDE TABLE DEMONSTRATING DALY CALCULATION?]**

For the base case analysis, the probability of death from serious cases of undertreatment (i.e., if a patient had severe dehydration but was predicted to have some or no dehydration) and probability of death from serious cases of overtreatment (e.g., if the patient has some or no dehydration but was predicted to have severe dehydration) were estimated based on clinical input from physicians who have practiced at icddr,b and on prior studies of undertreatment in the context of dehydration due to diarrheal illness (14). An initial incremental cost-effectiveness ratio (ICER) was calculated using these data.

Two-way sensitivity analyses were then conducted; here, the probability of death from under- and overtreatment were both taken as variable. Per WHO recommendations, two willingness-to-pay thresholds were used in analysis: two- and three-times the 2019 Bangladeshi gross domestic product (GDP) per capita in USD (15).

**[JP: METHODS — PSA & COST-EFFECTIVENESS ACCEPTABILITY CURVE/FRONTIER METHODS]**

**Results**

Median age for enrolled patients was 35. Median household income was $447. Children, adults, and elderly patients each account for about one-third of our study population; age categories were based on WHO classification (16,17). Demographic information is summarized in Table 2.

**[JP: RESULTS — PSA & COST-EFFECTIVENESS ACCEPTABILITY CURVE/FRONTIER]**

**Discussion**

*Limitations*

*Future Directions*

**Conclusion**

**REFERENCES**

1. Levine AC, Barry MA, Gainey M, Nasrin S, Qu K, Schmid CH, et al. Derivation of the first clinical diagnostic models for dehydration severity in patients over five years with acute diarrhea. PLoS Negl Trop Dis. 2021 Mar 10;15(3):e0009266.

2. Acute Care: Integrated Management of Adolescent and Adult Illness. World Health Organization; 2004.

3. Gainey M, Qu K, Garbern SC, Barry MA, Lee JA, Nasrin S, et al. Assessing the performance of clinical diagnostic models for dehydration among patients with cholera and undernutrition in Bangladesh. Trop Med Int Health. 2021;26(11):1512–25.

4. Fonseca BK, Holdgate A, Craig JC. Enteral vs Intravenous Rehydration Therapy for Children With Gastroenteritis: A Meta-analysis of Randomized Controlled Trials. Arch Pediatr Adolesc Med. 2004 May 1;158(5):483–90.

5. Duggan C, Santosham M, Glass R. The Management of Acute Diarrhea in Children: Oral Rehydration, Maintenance, and Nutritional Therapy [Internet]. [cited 2023 Jul 28]. Available from: https://www.cdc.gov/mmwr/preview/mmwrhtml/00018677.htm

6. Levine AC, Glavis-Bloom J, Modi P, Nasrin S, Rege S, Chu C, et al. Empirically Derived Dehydration Scoring and Decision Tree Models for Children With Diarrhea: Assessment and Internal Validation in a Prospective Cohort Study in Dhaka, Bangladesh. Glob Health Sci Pract. 2015 Sep 10;3(3):405–18.

7. Levine AC, Glavis-Bloom J, Modi P, Nasrin S, Atika B, Rege S, et al. External validation of the DHAKA score and comparison with the current IMCI algorithm for the assessment of dehydration in children with diarrhoea: a prospective cohort study. Lancet Glob Health. 2016 Oct 1;4(10):e744–51.

8. World Bank Open Data [Internet]. [cited 2023 Jul 27]. GDP, PPP (current international $) - Bangladesh. Available from: https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD?locations=BD

9. World Bank Open Data [Internet]. [cited 2023 Jul 27]. GDP Per Capita (current US$) - Bangladesh. Available from: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=BD

10. Abridged Life Tables for Japan 2019. Ministry of Health, Labour and Welfare, Government of Japan;

11. Menken M, Munsat TL, Toole JF. The Global Burden of Disease Study: Implications for Neurology. Arch Neurol. 2000 Mar 1;57(3):418–20.

12. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Disability Weights [Internet]. Institute for Health Metrics and Evaluation (IHME); 2020 [cited 2023 Jul 28]. Available from: http://ghdx.healthdata.org/record/ihme-data/gbd-2019-disability-weights

13. Vos T, Flaxman AD, Naghavi M, Lozano R, Michaud C, Ezzati M, et al. Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet. 2012 Dec 15;380(9859):2163–96.

14. Sharifi J, Ghavami F, Nowrouzi Z, Fouladvand B, Malek M, Rezaeian M, et al. Oral versus intravenous rehydration therapy in severe gastroenteritis. Arch Dis Child. 1985 Sep 1;60(9):856–60.

15. Making Choices in Health: WHO Guide to Cost-effectiveness Analysis. World Health Organization; 2003. 364 p.

16. Adolescent health [Internet]. [cited 2023 Jul 28]. Available from: https://www.who.int/health-topics/adolescent-health

17. Faruque ASG, Malek MA, Khan AI, Huq S, Salam MA, Sack DA. Diarrhoea in Elderly People: Aetiology, and Clinical Characteristics. Scand J Infect Dis. 2004 Apr 1;36(3):204–8.