Journal of Dental Sciences 18 (2023) 1822–1829

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Original Article

Developing and assessing the efficiency of VOSER software in recording dental caries according to WHO's criteria 2013

Khoa Dang Nguyen [a], Hong Thi-Phuong Doan [a], Hung Trong Hoang [a*], Nam Cong-Nhat Huynh [a], Ming-Lun Hsu [b], May Chun Mei Wong [c]

[a] *Faculty of Odonto-Stomatology, University of Medicine and Pharmacy at Ho Chi Minh City, Viet Nam*
[b] *Department of Dentistry, National Yang Ming Chiao Tung University, Taipei, Taiwan*
[c] *Division of Applied Oral Sciences & Community Dental Care, Faculty of Dentistry, The University of Hong Kong, Pok Fu Lam, Hong Kong*

Received 6 May 2023; Final revision received 19 June 2023
Available online 18 July 2023

KEYWORDS
Dental caries;
DMF index;
Oral health;
Software;
Surveys and questionnaires

Abstract *Background/purpose:* World Health Organization (WHO) oral health survey manual is the main guideline for most oral health surveys worldwide. It has been updated several times since 1971; however, using papers and pens for data recording remains unchanged. This study aimed to develop the Vietnam Oral Survey Electronics Recorder (VOSER) to record dental caries data based on the WHO 2013 criteria and assess its reliability and efficiency.
Materials and methods: VOSER was developed and tested for reliability and efficiency by performing clinical examinations on 365 school children in three key indicator age groups: 120 5-year-old students with primary dentition, 123 8-year-old students with mixed dentition, and 122 12-year-old students with permanent dentition. One gold standard examiner and two trained clerks examined these children using either WHO's paper survey form or VOSER's digital form for dental caries. Recording time, spreadsheet time, DMFT/S, and dmft/s were analyzed to compare the efficiency of VOSER to the paper form. Cohen's Kappa, intraclass correlation coefficient, and Wilcoxon signed-rank test were adopted in the data analyses.
Results: Median time of using VOSER was significantly shorter than the standard time in all three dentitions ($P < 0.001$). Cohen's Kappa values between data collected by VOSER and paper form showed almost perfect agreements (0.927–0.958). DMFT/S and dmft/s values calculated from data collected by both methods had good to excellent reliabilities (0.791–0.997).

* Corresponding author. Faculty of Odonto-Stomatology, University of Medicine and Pharmacy at Ho Chi Minh City 652 Nguyen Trai, Ward 11, District 05, Ho Chi Minh City, 700000, Viet Nam.
E-mail address: htrhung@ump.edu.vn (H.T. Hoang).

https://doi.org/10.1016/j.jds.2023.06.019

Conclusion: VOSER is efficient and reliable for conducting dental caries surveys according to the WHO 2013 criteria and should be utilized in the era of digital technology.

Introduction

Dental caries is one of the most common oral diseases worldwide.[1] Many large-scale interventions have been applied and proven effective in preventing the disease.[2,3] Data collection on dental caries plays a vital role to assess and manage dental caries in communities.

World Health Organization (WHO) Oral Health Surveys – Basic Methods provide standardized and comparable measurements of oral disease data across regions and countries.[4,5] These oral surveys' outcomes are compiled and regularly updated in the online accessible WHO Oral Health Country/Area Profile Project.[6]

Despite advancements in evaluation criteria and clinical methods, paper forms persist for primary data recording. This mandates a steady supply of assessment forms, hardboard bases, clips, and pencils.[4] Recording data on paper involves two steps: writing the survey form and subsequently entering the data into spreadsheet software for statistical analysis, which is time-consuming and increases the likelihood of recording and inputting errors.[4]

The Decayed, Missing and Filled Teeth/Surfaces (DMFT/DMFS) index, introduced in the 1930s, remains the most used epidemiological index for caries measurement.[7,8] It quantifies the total count of an individual's decayed, missing, and filled permanent teeth or surfaces.[9] Similarly, the lower-case abbreviations dmft and dmfs represent decayed, missing, and filled primary teeth or surfaces, respectively.

At our institute, annual large-scale oral health surveys have been conducted since 2005, following WHO criteria, as part of the undergraduate core course. To streamline data collection, various software options were evaluated, including EpiData 3 (EpiData Association, Odense, Denmark), EpiInfo 7 (Centers for Disease Control and Prevention, Atlanta, GA, USA), and ODK (Get ODK Inc, San Diego, CA, USA).[10] The ODK open-source ecosystem and related projects such as ODK Collect (Get ODK Inc) and Enketo (Enketo LLC, Denver, CO, USA) are widely used and allow off-the-grid survey data collection.[11] However, replicating the dental arch layout commonly used in dental charts and oral survey forms in a user-friendly manner posed significant challenges. Therefore, this project aimed to develop a tailored software package to record oral health data using digital forms based on WHO Oral Health Assessment forms.[4] In the initial stage, the focus was on dental caries recording. This paper presents findings on the reliability and efficiency of collecting caries data using digital forms compared to paper forms.

Materials and methods

This study has two phases

Phase 1: Developing the software to record the oral health data

We developed the VOSER (Vietnam Oral Health Survey Electronics Recorder) program, which utilizes digital survey forms based on WHO Oral Health Assessment forms.[4] The program (Fig. 1A–F) is implemented as a web application using HTML5, JavaScript (ECMAScript 2018), Typescript, and React.[12–15] VOSER is compatible with modern web browsers such as Chrome, Firefox, Edge, and Safari, allowing its use on various devices like laptops, tablets, and smartphones. Notably, VOSER can function offline thanks to HTML5 features like Service Worker and IndexedDB, making it convenient for data collection in areas with no internet connectivity.

The VOSER software simplified the two-step process of paper forms (Fig. 1G) into a single-step one (Fig. 1H). The user interface closely resembles the Oral Health Assessment Form for Children (by tooth surface) (Fig. 1A), offering synchronization capability (Fig. 1B). To expedite data input and minimize errors, VOSER incorporates several features, such as directly inputting the value of the focused field by using keyboard buttons (Fig. 1C), selecting valid codes from a dropdown menu (Fig. 1D), and quickly filling common tooth statuses (Fig. 1E). These features are also available in the mobile version of VOSER (Fig. 1F).

Phase 2: Assessing VOSER's digital forms on accuracy, reliability, and time compared to paper forms

This study was approved by the Ethics Committee of the university (Approval 287 on May 15th, 2019).

Data collection

This study recruited 365 students from fluoridated zones in Ho Chi Minh City, Viet Nam, representing three indicator age groups: 120 students aged 5, 123 students aged 8–9, and 122 students aged 12. These groups corresponded to primary, mixed, and permanent dentition, respectively.

The WHO Oral Health Assessment Form for Children by tooth surface (Fig. 2A) was translated into Vietnamese (Fig. 2B) and utilized in this study. A single examiner assessed all students, while two clerks, one using a paper form, and the other using VOSER's digital form, recorded the clinical data. Both clerks received training from the

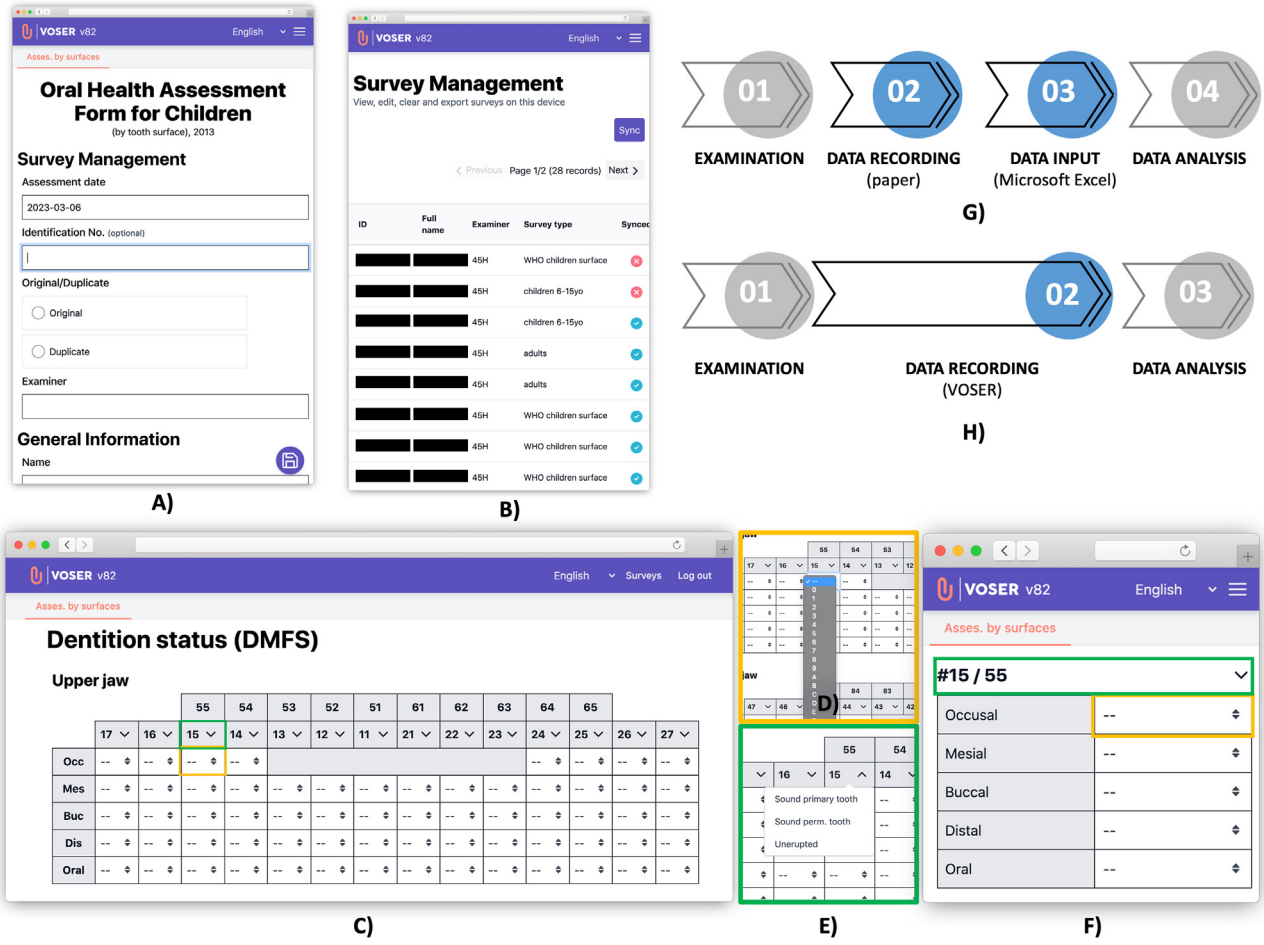


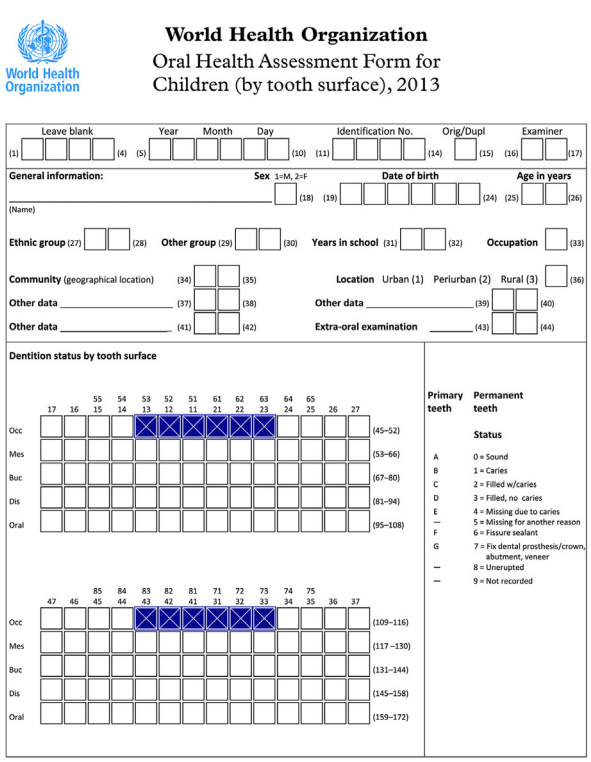
Figure 1 VOSER software interface and data collecting protocol compared to paper forms. A) Interface for inputting new survey data. Blue borders around "Identification No." field indicate focused status. Users can use Tab and Shift-Tab shortcuts to change the focused field. B) Survey management page allows users to view, edit, and synchronize surveys saved on their device's storage to the cloud. C) Interface for DMFS input on tablets or laptops. This replicates the usual layout of representing dental arches. The currently focused field is the occlusal surface of tooth #15, which is indicated by the blue borders. If the device has a keyboard, users can key in an appropriate value, such as numbers from 0 to 9 or letters from A-G, to change the value of the focused field. D) List of available values for the current field after clicking on the yellow box area in C) and F). E) Menu for quickly filling common DMFS values (sound primary tooth, sound permanent tooth, or unerupted tooth) for tooth #15. This menu appears after clicking on the green box area in C) and F). F) Interface for DMFS input on smartphones with the same functionalities. G) and H) Comparison of data collection protocol between digital and paper forms. G) Data collecting protocol of paper forms: record data into paper forms and input data to a spreadsheet software later. H) Data collecting protocol of VOSER's digital forms: input data into the software and export digital data. Abbreviation: DMFS: decayed, missing, and filled tooth surfaces for permanent tooth surfaces; VOSER: Vietnam Oral Survey Electronics Recorder.

examiner and then tested using ten sample cases to ensure the accuracy of the recorded result. A stopwatch operator positioned between the two clerks measured the recording time of each clerk simultaneously (Fig. 3A). The clinical oral health examination protocol is outlined in Fig. 3B.

During the study, 259 data points were collected for each student. These data points included 128 boxes in Fig. 2B, simultaneously recorded by two clerks using both a paper form and VOSER's digital form. The time taken for data input using VOSER's digital form and the paper form was denoted as *VOSER time* and *paper time*, respectively. The duration for inputting data into spreadsheet software (Excel, Microsoft Corp., Redmond, WA, USA) was also recorded as *spreadsheet time*. The *standard time*, representing the total time using the paper form, was the sum of *paper time* and *spreadsheet time*.

Decayed, missing, and filled indices

The WHO Oral Health Assessment Form for Children (by tooth surface) has 128 boxes (from boxes 45 to 172). Letters from A to G denoted the primary teeth's status, and digits from 0 to 9 denoted the permanent teeth's status (Fig. 2A).



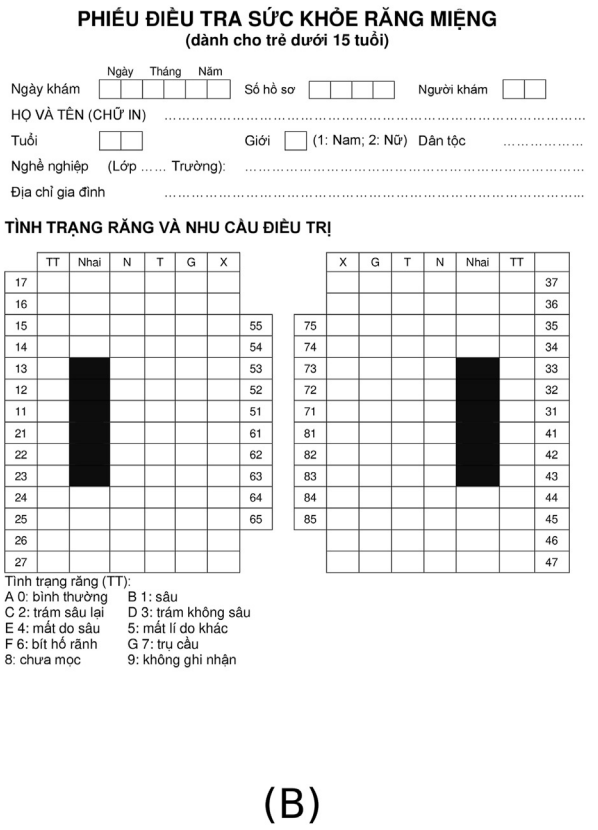


Figure 2 A) WHO Oral Health Assessment Form for Children (by tooth surface).[4] B) Vietnamese translation of the WHO Oral Health Assessment Form for Children (by tooth surface) used in this study. Abbreviation: WHO: World Health Organization.

To calculate the dmft index for an individual, we counted the occurrences of B, C, D, and E codes in the Oral rows (boxes 95-108 and boxes 159-172, Fig. 2A). Details on calculating dmft/DMFT and dmfs/DMFS are specified in Table 1.

Statistical analysis

The level of significance was set at 0.05. The sample size was calculated based on a minimum acceptable kappa value of 0.8 and expected kappa value of 0.9, a statistic power of 0.8.[19] The proportions of caries in children within the respective age groups were estimated to be 0.60, 0.60, and 0.38 based on previous studies.[16–18] Therefore, a minimum of 300 participants were required. Considering an anticipated dropout rate of 10%, at least 334 students were needed for the study.

We analyzed VOSER time, standard time, dmft/DMFT, and dmfs/DMFS to compare the two methods. Data analysis was performed using SPSS 20 (IBM Corp., Armonk, NY, USA), and graphs were created using Prism 9 (GraphPad Software, San Diego, CA, USA). Inter-rater reliability between the recording clerks of each method was assessed using unweighted Cohen's kappa value.[20] The reliability of the computerized dmft/DMFT and dmfs/DMFS was further assessed using the intraclass correlation coefficient (ICC). As the data did not follow normal distributions (checked by the Shapiro-Wilk test), Wilcoxon signed-rank test was adopted to compare the difference between the VOSER time and standard time.

Results

Data collection time

For primary dentition (n = 120), the median time (interquartile range) of using VOSER and standard method were 111.0 s (90.3–134.0) and 282.5 (255.5–308.8), respectively. There was a statistically significant difference in the median time between VOSER and standard one ($P < 0.001$) (Fig. 4). Similarly, statistically significant differences were found in the median time between VOSER and standard method in the mixed (n = 123) and permanent dentitions (n = 122) ($P < 0.001$). The median times were 114.0 (94.0–154.0) and 302.0 (266.0–353.0) for mixed dentition; 112.0 (99.0–128.5), and 248.5 (220.0–293.0) for permanent dentition, for VOSER and standard method, respectively (Fig. 4). In summary, the median time of using VOSER was statistically shorter than the standard time regardless of the dentition. Additionally, the median time of using VOSER was statistically shorter than the record time for paper form regardless of the dentition ($P < 0.001$).

Reliability

dmft/s and DMFT/S

Table 2 shows the mean of dmft/s and DMFT/S of the data recorded by VOSER and standard method amongst 5-year-old, 8-9-year-old, and 12-year-old school children in Ho Chi Minh City. This table also indicated ICC values between

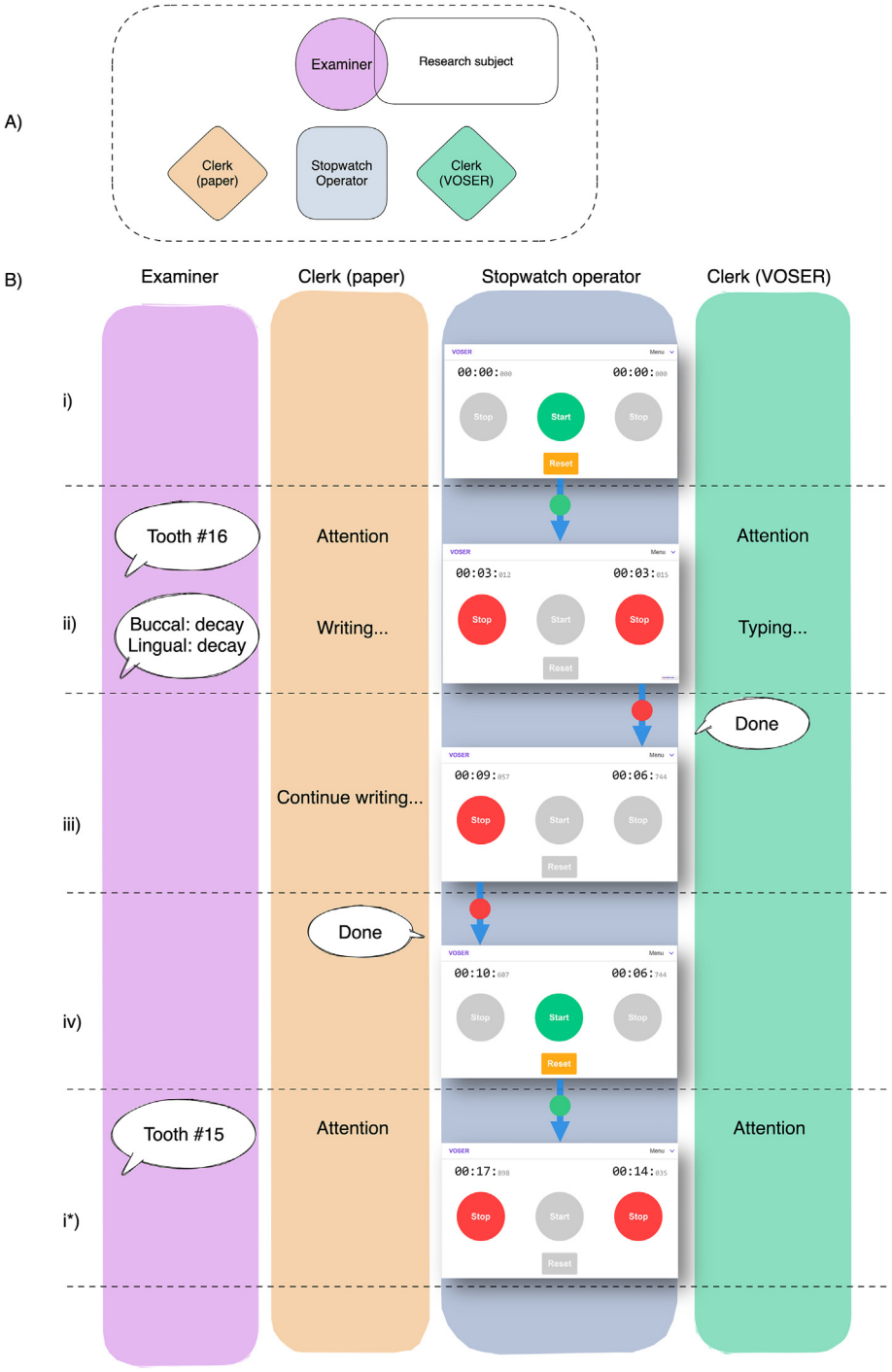


Figure 3 A) Examination table layout. B) Examination protocol: i) In the beginning, both sides of the stopwatch started at zero. ii) The examiner started to say the finding out loud, for example, "Tooth #16," the stopwatch operator pressed **START** to start both clocks simultaneously. Both clerks listened to the examiner and wrote data in paper form or typed it in digital form. iii) When a clerk said "Done", the stopwatch operator would press the **STOP** button on that clerk's side. In this case, the VOSER clerk said, "Done", so his/her clock stopped at 6 s while the clock of the paper clerk was continuing. The clock of the VOSER clerk could not be started again if the other clock was still running. iv) Same as iii), but on the paper clerk's side, the stopwatch stopped at 10 s after the signal was given to the operator. VOSER clerk's stopwatch stayed at 6 s, as mentioned in the previous step. Only then the **START** button was enabled. i*)When the examiner moved to the next tooth, the stopwatch operator would press **START** to start both clocks at the same time again. However, the clocks did not re-set at zero now but rather the accumulated time of each clerk on previous teeth. This protocol was repeated until the end of the examination. The final time on each side was recorded at either VOSER time or paper time.

Table 1 Codes and box numbers in calculating dmft/DMFT and dmfs/DMFS in WHO Oral Health Assessment Form for Children (by tooth surface).

Index	Codes[a]	Box numbers
dmft	B, C, D, and E	#95-#108 and #159-#172
DMFT	1, 2, 3, and 4	#95-#108 and #159-#172
dmfs	B, C, D, and E	#45-#94 and #109-#158
DMFS	1, 2, 3, and 4	#45-#94 and #109-#158

[a] Codes explanation in Fig. 2A. Abbreviation: DMFT and dmft: decayed, missing, and filled teeth for permanent and primary teeth; DMFS and dmfs: decayed, missing, and filled tooth surfaces for permanent and primary tooth surfaces.

data collected by VOSER and the standard method per children age group.

The mean of dmft/dmfs in VOSER and standard method were 6.7 ± 5.1/13.5 ± 14.3 and 6.7 ± 5.1/13.5 ± 14.4 in primary dentition; 3.1 ± 3.2/7.0 ± 8.6 and 3.1 ± 3.2/6.8 ± 8.6 in mixed dentition. Their ICC values were 0.994/0.997 ($P < 0.001$) and 0.975/0.986 ($P < 0.001$) in primary and mixed ones, respectively. These values indicated excellent reliabilities in dmft/dmfs results regardless of the dentition.

Similarly, in the permanent dentition, excellent reliabilities were found in the ICC values of DMFT/DMFS results between VOSER and standard method, 0.952 and 0.993 ($P < 0.001$). In mixed dentition, ICC values DMFT/DMFS results indicated good reliabilities: 0.861/0.791 ($P < 0.001$).

Cohen's kappa

Cohen's Kappa was used to assess the agreement between the numerical codes for permanent teeth and letters for primary teeth, as shown in Table 3. The percentage of agreed boxes between the two methods in primary dentition ranged from 97.8% to 98.5% and Cohen's Kappa agreement ranged from 0.953 to 0.958. Similarly, Cohen's Kappa agreements were 0.927–0.935 in mixed dentition and 0.947–0.952 in permanent one. These results showed almost perfect agreements.

Discussion

WHO's guidelines recommend one examiner and one recording clerk per examining station for oral health surveys.[4] In our study, we specifically chose to have a single experienced examiner specialized in DMFT examination performed all the clinical examinations. It is important to note that the examination results were not utilized for comparison or decision-making purposes. The primary objective was to assess VOSER's recording of caries status compared to paper-based records. WHO's guidelines also state that clerks should undergo training conducted by the examiner prior to the examination process. In our study, we paired the examiner with two clerks who were trained and tested on 10 sample cases to ensure accuracy. Both clerks achieved a perfect 100% accuracy on the test cases. The principle of VOSER was also aligned with WHO's guidelines, with digital devices replacing paper forms. To replicate a real-world scenario, we used different clerks to record data using different methods. Typically, a clerk listens to the examiner and writes or types the corresponding code. However, having the same clerk performs both tasks may introduce recall bias. To mitigate this, we assigned separate clerks to each task, enabling them to concentrate on either writing or typing the code they heard, without tasks switching.

At the time this research was conducted, there was a lack of published evidence on software solutions for efficient direct-entry digital-device systems for oral health surveys. Therefore, an automated process to collect and aggregate oral health survey data is unattainable at national and international levels. Despite using the same coding system, the absence of a direct-entry digital-device system prevented the centralized storage of oral health data.

Digital data collection method has shown promising results in various public health domains. For instance, in seasonal malaria chemoprevention campaigns in Africa's Sahel region, digital data collection reduced working time and costs compared to paper-based tools.[21] Similarly, a study from Zanzibar found that direct data entry via personal digital assistants was faster and cheaper than the

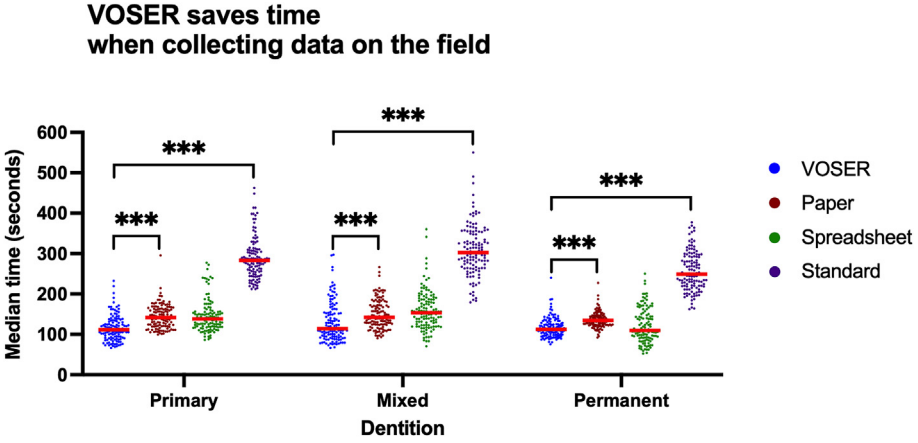


Figure 4 Comparison of time (in seconds) between standard method and VOSER for recording and inputting data (***: $P < 0.001$).

Table 2 Mean and standard deviation (SD) of dmft/DMFT and dmfs/DMFS of the data recorded by VOSER and standard method grouped by age groups.

Age (dentition)	Index	Method	Mean ± SD	Intraclass correlation coefficient	*P*-value
5 (primary dentition)	dmft	Standard	6.7 ± 5.1	0.994	<0.001
		VOSER	6.7 ± 5.1		
	dmfs	Standard	13.5 ± 14.4	0.997 (highest)	<0.001
		VOSER	13.5 ± 14.3		
8-9 (mixed dentition)	dmft	Standard	3.1 ± 3.2	0.975	<0.001
		VOSER	3.1 ± 3.2		
	dmfs	Standard	6.8 ± 8.6	0.986	<0.001
		VOSER	7.0 ± 8.6		
	DMFT	Standard	0.7 ± 1.4	0.861	<0.001
		VOSER	0.6 ± 1.2		
	DMFS	Standard	0.9 ± 2.1	0.791 (lowest)	<0.001
		VOSER	0.9 ± 1.9		
12 (permanent dentition)	DMFT	Standard	2.2 ± 2.3	0.952	<0.001
		VOSER	2.2 ± 2.3		
	DMFS	Standard	3.3 ± 4.0	0.993	<0.001
		VOSER	3.3 ± 4.0		

Abbreviation: DMFT and dmft: decayed, missing, and filled teeth for permanent and primary teeth; DMFS and dmfs: decayed, missing, and filled tooth surfaces for permanent and primary tooth surfaces; VOSER: Vietnam Oral Survey Electronics Recorder.

paper-based system, while also avoiding common errors associated with the manual process.[22]

In Viet Nam, three national oral health surveys were conducted using WHO's criteria, but the data were recorded on paper and then typed into spreadsheet software.[23,24] Unfortunately, the lack of a centralized digital storage system and a long-term preservation plan has led to the loss of raw data which hinders the ability to conduct inter-study analyses or examine trends over time.

In contrast, countries like the United States have established programs like the National Health and Nutrition Examination Survey (NHANES), which has been collecting and storing digital data on health and nutritional status of the population since the 1960s.[25] The availability and long-term storage of digital data in the US can be attributed to policies and practices that prioritize standardization and centralized storage. Using software like VOSER allows data to be in a uniform format and facilitates uploading survey data to a centralized storage platform. However, researchers using VOSER have the flexibility to choose whether they want to share their data, as the default option is to store data locally on their own devices.

VOSER demonstrated high reliability and efficiency in recording and analyzing dental caries databased on WHO's criteria. Cohen's Kappa agreement between VOSER and paper forms indicated almost perfect agreement, suggesting that VOSER produces equally accurate data compared to the standard paper-based method. Ultimately, the aim of updating data collection methods is to minimize errors. Although human error is inevitable, using VOSER has the benefit of reducing data collection errors from two occurrences to one.

When comparing the two recording methods, it is important to consider the advantages and drawbacks of each method. Paper forms are simple and accessible, providing a reliable method for data collection. However, it requires physical transportation and additional data entry step, which could be time-consuming. On the other hand, VOSER has the potential to streamline the data collection process and eliminate the need for transportation. However, it requires technical proficiency and access to a power source for recharging, making it less feasible for large-scale surveys, especially in remote places. As a recommendation, it is suggested to keep a minimal amount of paper forms for backup rather than eliminate them.

The data collected from both methods showed high correlations (ICC 0.791 to 0.997, $P < 0.001$), with six of the ICC results indicating excellent reliability, while two

Table 3 Unweighted Kappa between the data recorded by VOSER and standard method.

Dentition	Code for	Boxes with the same code in both methods/total boxes (%)			Kappa
Primary dentition	Tooth	2348	/2400	(97.8%)	0.958
	Surfaces	10,399	/10,560	(98.5%)	0.953
Mixed dentition	Tooth	3292	/3444	(95.6%)	0.935
	Surfaces	14,983	/15,744	(95.2%)	0.927
Permanent dentition	Tooth	3358	/3416	(98.3%)	0.947
	Surfaces	15,432	/15,616	(98.8%)	0.952

Abbreviation: VOSER: Vietnam Oral Survey Electronics Recorder.

indicated good reliability. These drops in reliability were observed in the DMFS and DMFT groups of mixed dentitions, which could be attributed to the low DMFT/S values probably due to high percentages of sound permanent teeth (70.7%) among mixed dentitions (Table 2). The short exposure time of permanent teeth in children aged 8—9 and the fluoridated water in Ho Chi Minh City could explain this correlation.[26,27]

Besides the reliability and efficiency, the ergonomics of VOSER were proven via the recording time. Statistically significant differences in median time between VOSER and standard time were found in all three dentitions ($P < 0.001$). Given that oral health surveys often involve hundreds of participants, even a small saving in time can result in significant resource savings.

VOSER was originally designed for the Vietnamese form (Fig. 2B) and has been further improved based on user feedback. VOSER has both English and Vietnamese versions, adhering to the WHO 2013 criteria, and can be applied worldwide. A live demo of VOSER is available at https://paper.voser.vn.

This manuscript focuses on objective assessments of VOSER's time-saving and accuracy in recording caries data. Future investigations are planned to collect user feedback from clinical doctors, oral epidemiologists, and oral health researchers in Vietnam and the Asia Pacific region. The goal of these investigations is to objectively assess the usability, applicability, and effectiveness of VOSER in oral health survey research.

VOSER provides a reliable and efficient solution for conducting dental caries surveys according to the WHO 2013 criteria, and it should be utilized in the era of digital technology.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgements

The authors received no financial support for the research, authorship, and/or publication of this article.

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