Use of Smartphone for Verbal Autopsy: Results From a Pilot Study in Rural China

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Abstract

Traditionally, verbal autopsies (VA) are collected on paper-based questionnaires and reviewed by physicians for cause of death assignment, it is resource intensive and time consuming. The Population Health Metrics Research Consortium VA questionnaires was made available on an Android-based application and cause of death was derived using the Tariff method. Over one year, all adult deaths occurring in 48 villages in 4 counties were identified and a VA interview was conducted using the smartphone VA application. A total of 507 adult deaths were recorded and VA interviews were conducted. Cardiovascular disease was the leading cause of death (35.3%) followed by injury (14.6%) and neoplasms (13.5%). The total cost of the pilot study was USD28835 (USD0.42 per capita). The interviewers found use of smartphones to conduct interviews to be easier. The study showed that using a smartphone application for VA interviews was feasible for implementation in rural China.

Keywords

verbal autopsy, demography, epidemiology, health informatics, global health

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Introduction

In rural and remote China where approximately a population of 650 million people reside, 80% of all deaths occur at home[1] and most of these deaths do not get registered or medically certified.[2] Hence, accurate information about the causes of death is not available for majority of the population that resides in rural regions of China. The Disease Surveillance Point (DSP) System was introduced in 1980 by Ministry of Health to generate cause specific mortality data from a nationally representative sample of the population using a verbal autopsy (VA) method.[2] VA is a technique that helps determine causes of death in situations where no medical records are available or no formal medical attention at the time of death is sought. A VA consists of an interview with a close relative or carer of the deceased to gather information about signs and symptoms and events that lead to death. Traditional surveillance systems using VA for cause of death statistics, including the DSP, use paper-based questionnaires to interview a relative of the deceased and send the complete questionnaire to 2 or more physicians trained in VA methods to review and assign a cause of death. From a data collection perspective, paper-based tools require manual data checks to maintain the quality of the data.

Physician-certified VA is resource intensive and time consuming and distracts physicians from essential health service delivery where they are most needed.[3] Over the past couple of years, several methodological improvements in probabilistic approaches to cause of death assignment have occurred. These methods include the Simplified Symptom Pattern (SSP),[4] InterVA,[5] InSilico,[6] the Tariff method,[7] and the Random Forest (RF) method.[8] Computer-coded VA (CCVA) is a promising alternative to the standard approach of physician certification of cause of death, because of its high speed, low cost, and reliability.[7] Innovative data collection method such as tablet- and smartphone-based surveys can potentially reduce the time and cost involved in large-scale surveys and increase efficiencies around data management.[9]

The aim of this pilot study was to test the feasibility of an Android-based VA application using a smartphone and derive cause-specific mortality patterns using the Tariff method[7] for a rural population in China.

Materials and Methods

Study Area and Subjects

This project was conducted as a collaboration between 6 institutions (listed in the Acknowledgments section). The study protocol was approved by the Ethics Committee of Peking University Health Science Center (IRB00001052-11082). The study was performed according to the guidelines of Helsinki Declaration. Written informed consent was sought from all participants before the interviews after they received written and verbal information about study.

The study was conducted in Hebei Province and Ningxia Hui Ethnic Group Autonomous Region in Northern China. Two counties from each province involved in a larger cardiovascular study entitled "China Rural Health Initiative"[10] were selected to participate in the study. From each of these counties (with the number of towns ranging from 12 to 25), 12 towns were selected and 1 centrally located village in each town was included in the study. The study covered a population of 67 899 adults from 48 villages, generally representative of the 4 counties. A survey conducted in the participating villages showed that 16% of the population was illiterate and about 75% of the population was engaged in agriculture.[11]

Training of VA Interviewers

Expert trainers from the University of Queensland and University of Washington conducted a 2-day training of trainer's session for the research fellows who then trained the interviewers in

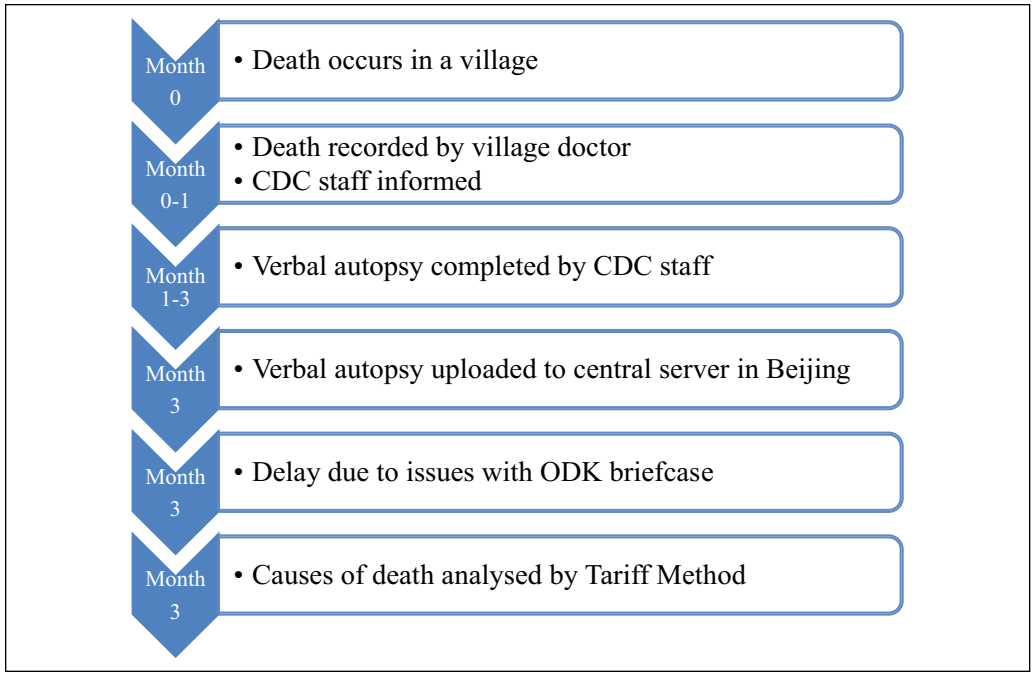

Figure 1. Implementation framework and timelines of the Smartphone verbal autopsy (VA) pilot study.

the 4 counties over a 1-day training session. The interviewers were full-time employees of the county Center for Disease Control and Prevention (CDC), who were mainly responsible for daily operations and providing technical support to health authorities. CDC staff was chosen as the interviewers because of their ability to use the smartphone-based VA application, speak the local dialect, and their familiarity with the villages. Sixteen CDC staff in 4 counties, with a minimum of 5 years' experience in the field and within the age group of 35 to 55 years was recruited as VA interviewers. The majority of the interviewers had diploma training in medical science, nursing, or public health and had experience in interviewing and computer skills. The training included introduction and background to VA, familiarization with the questionnaire, and practical training on how to collect data using smartphones. This was followed by field training in the villages to train the interviewers in each county. Interviewers were paid an incentive of RMB50 (approximately USD8) for each VA conducted. The average monthly salary for these staff was approximately RMB2000 (USD320).

Identification of Deaths and Data Collection

The study systematically and prospectively aimed to identify all adult deaths occurring between January 1 and December 31, 2012 in the selected villages. In each village, the village doctor, a rural health care practitioner, was the primary person to identify and report deaths. The women and children's service provider was responsible for reporting maternal deaths in each village. An incentive of RMB5.00 was provided for each death reported. Residents of the villages were informed about the study and encouraged to notify deaths in their villages. A list of all the deaths recorded was sent to the county CDC mortality surveillance unit by the village doctor. Figure 1 provides a flow diagram of all the steps and time period involved in the feasibility study.

For each death recorded, a trained CDC VA interviewer visited the family of the deceased after 1 month and in most cases, within a period of 3 months after the death and identified a suitable respondent for the interview, typically next of kin who was familiar with the decedent and the events that led to the death. Appointments were scheduled and written informed consent was sought from all participants before the interviews.

The Smartphone VA App Development

The project staff at The George Institute China tested several brands of smartphones for battery life, screen glare, and user acceptability before deciding on the Samsung smartphone (model GT-5830). Data were collected using an Android-based application of VA questionnaire developed by the Institute of Health Metrics Evaluation at the University of Washington.[12] This application was based on Population Health Metrics Research Consortium (PHMRC) VA full questionnaire[13] and was translated into Chinese with local adaptation. The PHMRC VA questionnaire was initially developed for use in the PHMRC gold standard VA validation study[13] and was based on the 2007 World Health Organization–standardized VA instrument with modifications made by the principal investigators of the PHMRC based on prior experience with the World Health Organization instrument. The questionnaire consisted of 3 modules. A "general" module was incorporated to assist the interviewers in obtaining consent to perform the survey and background information about the interview, the respondent, and the deceased. The adult questionnaire was administered for decedents aged 12 years and older. A final section was included where interviewers were asked to evaluate the performance of the respondents after administering the rest of the survey. The VA survey was programmed for mobile devices using the Open Data Kit (ODK) Collect tool. ODK is a free and open-source set of tools that help manage mobile data collection solutions.[14]

Automatic skip patterns, date checks, and value restrictions were programmed into the survey. Photos of symptoms (such as rash), and sounds (such as wheezing) were also programmed into the survey and could be displayed on the phone screen for the respondent to view, or played for the respondent to hear. The ODK collection system also had the capability of capturing photos and videos as part of the data. The purpose of the multimedia was to assist the interviewer when describing medical signs such as wheezing, and grunting because these different sounds are distinctive, but hard to explain. Having a standardized, accurate wheezing sound helped standardize the interview and ensured that accurate information about symptoms leading up to death was recorded. Although the ODK platform has the ability to disallow editing of saved surveys, for this study interviewers were allowed to save an incomplete survey and reopen it at a later time. This functionality was included in the case of a partially finished survey or if responses needed to be edited after initially saving a completed survey.

Data Management

Interviewers were instructed to transfer all completed questionnaires from the smartphone to a computer on the same day via email to the CDC office. In the absence of Internet connection, completed questionnaires were backed-up on Secure Digital (SD) memory cards, and all the data on computers located in the rural villages were backed up once a month. This was done to prevent data loss in case of device crash/loss. Deidentified data were transferred to the Beijing coordinating center on a quarterly basis by email and was protected by a password. The original data were stored in html format. Because of technical difficulty, all data had to be manually extracted using ODK Briefcase to a readable format (Microsoft Access based). All the data were deidentified and completed VAs were transferred by email to the University of Washington during the midpoint and at the end of the study. The database could only be accessed by the study researchers and was password protected. After data quality checks at the Institute for Health

Metrics and Evaluation (IHME), causes of death were assigned using Tariff 2.0 method,[15] according to the PHMRC cause list.[13] These causes are mutually exclusive and collectively exhaustive for the adult age group and were derived from the 2010 version of the International Classification of Diseases, 10th Revision (ICD-10).[16]

Quality Assurance

All interviewers were assessed by the number and quality of surveys they conducted every quarter. The first 5 interviews completed by each interviewer were recorded and evaluated by the research team. Thereafter, every tenth VA was voice recorded on the smartphone for quality evaluation. Feedback was provided to the interviewers on their performance by the research team. There was a midterm evaluation with a 100-point scoring system based on the number and quality of survey conducted by each interviewer. Top 2 interviewers (based on the score they got in midterm evaluation) received an additional 20% of their baseline payment (RMB50 for each case).

Analysis

The Tariff method[7] is an algorithm that assigns a cause of death to a VA. The Tariff method has been developed using a set of "validated" verbal autopsies whose causes of death were known from "gold standard" medical record data.[13] The Tariff method calculates "tariff scores" for every individual VA to determine the most likely cause of death. The score of each VA in the study data set is then compared against the scores for the validated VAs to determine the highest ranked cause of death for that individual. If the Tariff score for an individual VA did not rank high enough when compared with the validated VAs for any cause of death, a cause of "indeterminate" was assigned to that observation.[15]

$$Tariff_{cause\,i,\ symptom\,j} = \frac{Endorsement\ Rate_{cause\,i,symptom\,j} - Median\ Endorsement\ Rate_{symptom\,j}}{Interquartile\ Range_{symptom\,j}}$$

Only adults older than 20 years (inclusive) were included in the analysis of cause of death. Results are expressed as rates per 1000 for the 12 months. Proportions of deaths are calculated by dividing the number of deaths for which a cause was assigned by the number of deaths for which a VA was done and these results are expressed as percentage. SPSS software (version 14.0, SPSS, Chicago, IL) was used for all statistical analyses.

Cost Analysis

All costs were analyzed for adult population only. Total costs were calculated for all the processes involved in the pilot study. This included training of the interviewers, staff salaries, project management, purchase of smartphones and monthly connection fee, cost for local transport, collaboration fee, and incentives for death recording and data collection.

Results

The pilot study took place from January 1 2012 to December 31, 2012. Over the study period, 509 adult deaths were identified by the village doctors. VAs were completed for 99.7% (n = 507) of these deaths. Two VAs interviews were not conducted due to refusals. Of all the VAs completed, 12.6% could not be assigned a definitive cause of death due to lack of adequate information from the relatives of the deceased. The majority of death (80%) for whom a specific cause of death could not be determined occurred in the age group of >60 years.

Table 1. Cause of Death by Sex in the Smartphone VA Pilot Study.

	Male (N = 284)		Female (N = 223)		Total (N = 507)	
	n	%	n	%	n	%
A00-A99 Infectious and parasitic diseases	16	5.6	11	4.9	27	5.3
C00-D48 Neoplasms	41	14.4	28	12.6	69	13.6
E00-E90 Endocrine, nutritional and metabolic diseases	22	7.7	9	4.0	31	6.1
G00-G99 Diseases of the nervous system	4	1.4	3	1.3	7	1.4
I00-I99 Diseases of the circulatory system	74	26.1	105	47.1	179	35.3
J00-J99 Diseases of the respiratory system	22	7.7	13	5.8	35	6.9
K00-K93 Diseases of the digestive system	4	1.4	1	0.4	5	1.0
N00-N99 Diseases of the genitourinary system	1	0.4	3	1.3	4	0.8
O00-O99 Pregnancy, childbirth and the puerperium	0	0.0	4	1.8	4	0.8
Other noncommunicable diseases	7	2.5	1	0.4	8	1.6
Indeterminant	38	13.4	26	11.7	64	12.6
S00-T98 Injury, poisoning and certain other consequences of external causes	26	9.2	5	2.2	31	6.1
V01-Y98 External causes of morbidity and mortality	29	10.2	14	6.3	43	8.5

Of the 507 deaths with VA interviews, 1 in 4 deaths occurred at age <60 years. There was excess male mortality for all causes of death except for diseases of the circulatory system, which was responsible for a greater proportion of deaths in women (47.1%) compared with men (26.1%). Diseases of the circulatory system were the leading cause of death, responsible for 35.3% of all adult deaths, followed by neoplasms (13.6%). Four maternal deaths were recorded over the study period (Table 1).

Interviewers were trained in 1 session and did not require retraining. On average, it took approximately 40 minutes to complete an interview for an adult death.

A midterm evaluation was conducted to check the quality of the completed VAs and to identify any issues with the VA process. The evaluation revealed that 13 out of 16 interviewers receiving scores more than 80 points in a scoring system with 100 points being the highest.

Costs for a Smartphone-Based Mortality Surveillance

The total costs associated with establishing the smartphone VA pilot study were RMB176 760 (USD28 835—based on exchange rate in 2012). These costs included training of the staff (USD3130), data collection (USD16 027), project management (USD829), purchase of smartphones (USD6262), and other infrastructure costs (USD2586) (Table 2). The cost of the smartphone-based mortality surveillance was USD56.86 per death or USD0.42 per capita.

Discussion

This study was able to demonstrate that using a smartphone application for VA data collection, data transfer and cause of death identification is feasible. The study shows a very low refusal rate (0.3%), thereby indicating acceptability of the technology by the community. While Internet connection was not available in remote regions, data could be transferred from the phone to the central server and finally to the University of Washington. The proportion of causes of death that could not be assigned a specific cause was similar to other VA studies.[17-19] For populations that do not

Table 2. Cost of the Smartphone VA Pilot Study.

Process	Cost per Death		Cost per Capita		Total Cost	
	Chinese RMB	US Dollar	Chinese RMB	US Dollar	Chinese RMB	US Dollar
Training						
a. Material printing cost (protocol, manuals, questionnaires)	0.50	0.08	0.00	0.00	254.14	41.51
b. Cost for running workshop (including transporting 2 local coordinators to visit Beijing for the training and 2 Beijing staff to provide site training and associated meal costs)	36.34	5.93	0.27	0.04	18424.81	3005.57
c. User experience test	1.00	0.16	0.01	0.00	508.27	83.02
Data collection						
a. Incentives for death information reporting	7.02	1.14	0.05	0.01	3557.89	580.28
b. Labor fee to village leaders for accompanying surveyors to do in-house survey	28.07	4.58	0.21	0.03	14231.58	2321.95
c. Labor fee to CDC surveyors (RMB50 for each death + incentive for performance)	72.68	11.86	0.54	0.09	36849.62	6011.15
d. Material printing and gifts to respondents	32.55	5.31	0.24	0.04	16501.85	2692.14
e. Local travel cost for doing home visit survey	53.47	8.72	0.40	0.07	27107.77	4421.95
Cause of death assignment	0.00	0.00	0.00	0.00	0.00	0.00
Project management						
a. Salary of project coordinator (0.5FTE)	0.00	0.00	0.00	0.00	0.00	0.00
b. Salary of 2 field coordinators	10.03	1.64	0.07	0.01	5082.71	829.33
Infrastructure	0.00	0.00	0.00	0.00	0.00	0.00
a. Smartphones (23 phones)	75.71	12.35	0.56	0.09	38382.91	6261.89
b. Smartphone bill compensation (12 months for 16 surveyors)	11.23	1.83	0.08	0.01	5692.63	928.44
d. Ethic application	1.67	0.27	0.01	0.00	847.12	138.08
e. Collaboration fee for local CDC	18.38	3.00	0.14	0.02	9318.30	1519.73
Total	348.64	56.87	2.60	0.42	176759.60	28835.04

Abbreviations: CDC, Center for Disease Control; FTE, full-time equivalent.

have routine medical certification of the cause of death, handheld mobile devices that support VA can be used as an alternative method to conduct VA interviews and generate cause of death data.

This study shows that once all the processes are in place, using smartphones to collect data for VA decreases time delays and increases efficiency as data checks are inbuilt, as compared with traditional paper-based methods relying on physician adjudication. Using smartphones to collect and transfer data meant that there was no printing, posting, sorting, and storing of paper forms involved in the study. Previous research has shown that computer algorithm–based Tariff method reduced the time and costs taken for analysis needed by physician-certified VA, as well as associated bias in cause of death ascertainment.[7]

The use of physicians to review VA questionnaires to diagnose the cause of death is challenging for a number of reasons. In resource-poor settings, physician availability is a major issue and the available physicians are busy, costly and likely to result in long processing delays in diagnosing causes of death. Moreover, using them for this type of work diverts them from the provision of essential health services. Using automated computer methods to identify patterns among reported symptoms has the advantage of standardizing VA diagnoses within and across countries quickly and at low cost. The Inter-VA was the first step in automated cause of death assignment.[5] Subsequent research using the PHMRC validation dataset identified accurate diagnostic methods (Tariff method) and has demonstrated that the Tariff method provides diagnosis of the cause of death that is more accurate than physicians.[7]

Establishing the VA study using smartphones and Tariff method cost USD28 835 over a 12-month period for adult population. The cost of USD0.42 per capita is much higher than the costs of establishing a traditional mortality surveillance system with paper-based data collection and physician assigned cause of death (USD0.12 per capita).[3] Approximately one-fifth of the costs in establishing the VA study were attributable to the purchase of smartphones. These costs would be substantially lower in subsequent years. The cost did not include research costs involved in developing the application and Tariff method by the University of Washington. All of those supports were in kind and for future research, tools can be downloaded and used free of charge (http://www.healthdata.org/verbal-autopsy/tools).

The main limitation of this study is that it did not include a process evaluation to gather feedback from interviewers and respondents. Informal feedback from the interviewers indicated the acceptance of this method and advantages of using the smartphone application over traditional means. In addition, feasibility of this method in rural China was demonstrated by the high response rate and the timeliness and quality of the VA interviews.

There were several practical issues encountered in the study. Interviewers entered very limited amount on free text in the open narrative section. This may be because they found it challenging to enter free text on the phone. Some of the minor issues with the smartphone were around short battery life and glare from the screen during the day time. These issues can be resolved with updated smartphone technology in the future and use of portable chargers, which are now available for smartphones. Because of poor Internet connectivity in the villages, the interviewers were not able to upload directly from the smartphone after the survey. All data had to be extracted securely from the smartphone first and sent through email. Also, the ODK Briefcase used to extract data had issues and needed to be resolved, this process caused delays in sending the files to the University of Washington. Building up from the experience of this study, the researchers are currently developing an application called SmartVA that that will automatically run the Tariff method to analyze the data as soon as the VA is complete. This new development will further decrease the time taken to upload the completed VAs.

The findings of this study have been a major step forward in VA methods in 2 ways. Using smartphones facilitated data collection and provided quality assurance regarding the data collected. Using the Tariff method for cause of death ascertainment reduced the cost and processing delays associated with traditional VA. Automation of the process from interviews to cause of death assignment directly on the smartphones can further improve the usability of the application. With the dramatic increase in the availability and affordability of smartphones, technology such as smartphone applications for data collection and automated VA methods are ready for widespread application.

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Authors' Note

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