

# Can verbal autopsy improve the diagnostic accuracy of Physicians in Shanghai? Application of SmartVA

**Lei Chen**

Shanghai Municipal Center for Disease Control and Prevention

**Tian Xia**

Shanghai Institute of Preventive Medicine: Shanghai Municipal Center for Disease Control and Prevention

**Rasika Rampatige**

The University of Melbourne

**Hang Li**

The University of Melbourne

**Tim Adair**

The University of Melbourne

**Rohina Joshi**

The George Institute for Global Health

**Zhen Gu**

Vital Strategies

**Huiting Yu**

Shanghai Municipal Center for Disease Control and Prevention

**Bo Fang**

Shanghai Municipal Center for Disease Control and Prevention

**Deirdre McLaughlin**

The University of Melbourne

**Alan D. Lopez**

The University of Melbourne

**Chunfang Wang**

Shanghai Municipal Center for Disease Control and Prevention

**Zheng'an Yuan** (✉ [yuanzhengan@scdc.sh.cn](mailto:yuanzhengan@scdc.sh.cn))

<https://orcid.org/0000-0003-4570-0871>

---

**Research**

**Keywords:** Smart Verbal Autopsy, Cause of Death, CRVS system

**Posted Date:** March 11th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-226018/v1>

**License:** © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

---

## Abstract

## Background

Accurate data on causes of death are essential for policy makers and public health experts to plan appropriate health policies and interventions to improve population health. Whereas approximately 30% deaths of Shanghai either occur at home or are not medically attended; the recorded cause of death in these cases may be less reliable than for a hospital death. Verbal Autopsy is a practical method that can help determine causes of death in regions where medical records are insufficient or unavailable. In this research, the smart VA tool was adopted to assign the cause of death of home deaths and to validate the accuracy and efficiency of the tool, the results were compared with routine practice to ascertain the value, if any, of incorporating VA into the diagnostic practices of physician in Shanghai certifying the cause of home deaths.

## Methods

This pilot study selected home deaths certified by 16 community health centers from 3 districts represent urban, suburb, and urban-suburb areas in Shanghai, from December 2017 to June 2018. The medical records for all deaths for which a VA was carried out in these 3 districts during same period were carefully evaluated an independent Medical Record Review (MRR) team. Causes of death from both the SmartVA sample and the UCOD from the MRR were transformed to the SmartVA cause list for comparison. The concordance between the initial diagnosis and MRR UCOD and post-VA diagnosis and MRR UCOD was assessed using Chance Corrected Concordance.

## Results

Overall CSMF accuracy improved from 0.93, based on the initial diagnosis, to 0.96 after the application of SmartVA. The misclassification of the initial diagnosis compared to that from the MRR. 86.3% of the initial diagnoses assigned the correct CODs, after the VA investigation, 90.5% of the post-VA diagnosis assigned the correct CODs.

## Conclusions

Although Shanghai has an established and well-functioning CRVS system, SmartVA for Physicians contributed to an improvement in the accuracy of death certification. In addition, SmartVA may be a useful tool for inferring some special causes of death, such as those CODs classified as undetermined.

## Background

Accurate data on causes of death are essential for policy makers and public health experts to plan appropriate health policies and interventions to improve population health. In Shanghai, a mega-city with a population of 24 million, the vital statistics registration system registers almost all deaths of the resident (Hukou) population<sup>[1]</sup>. Deaths that occur in hospital are certified by the attending doctor. For deaths that are not medically attended, the family members of the deceased present to Community Health Centers (CHC), usually with available medical documentation such as discharge summaries, medical records and laboratory test results, and the CHC doctor on duty reviews the records and issues a death certificate. Nonetheless, approximately 30% of all deaths still either occur at home or are not medically attended; the recorded cause of death in these cases may be less reliable than for a hospital death.

Verbal Autopsy (VA) is a practical method that can help determine causes of death in regions where most deaths occur at home or medical certification practices are unreliable because only outpatient medical records are available<sup>[2,3]</sup>. Automated VA tool involves a questionnaire to ascertain signs and symptoms preceding death and the application of a diagnostic algorithm to interpret the interview data in order to assign the most probable cause. To enable physicians to immediately review the outputs of a verbal autopsy, SmartVA for Physicians has been developed. This innovation produces a summary of all endorsed symptoms, as reported by family members, providing more information for the certifying physician to determine the cause of death (COD) for each decedent<sup>[4, 5]</sup>.

In order to improve the quality of death certification in Shanghai (especially for deaths occurring outside health facilities) and to reduce uncertainty about data quality among policymakers, SmartVA for Physicians was applied to a sample of community deaths to inform the certification of COD. The findings were compared with routine practice to ascertain the value, if any, of incorporating VA into the diagnostic practices of physician in Shanghai certifying the cause of home deaths.

## Methods

### SmartVA Auto-Analyze package

SmartVA Auto-Analyze is a software package that builds on SmartVA Analyze<sup>[6-8]</sup> and includes the Population Health Metrics Research Consortium (PHMRC) shortened VA questionnaire, the Open Data Kit (ODK) suite for data collection, and the modified Tariff 2.0 algorithm for computer analysis of the verbal autopsy interview responses. SmartVA Auto-Analyze was developed to be used by physicians in real time, produces a list of up to three most likely causes of death at the individual level and is commonly referred to as Smart VA for Physicians (for brevity, we use the term Smart VA in this paper).

## Training and administration

A local VA team with support from the University of Melbourne Technical Team trained 32 CHC doctors as VA interviewers. User manuals with detailed instructions and Standard Operating Procedures (SOP) were introduced during the training and were made available to Shanghai Municipal Center for Disease Control and Prevention (SCDC). The interviewers also received training on standard death certification practices as well as training on operating Android based tablets to conduct SmartVA interviews and troubleshooting. After the training, the interviewers underwent supervised field practice to ensure they had the requisite skills and knowledge of the concepts.

A local IT technical/ data management staff member, with support from the University of Melbourne technical team, installed Open Data Kit Collect software, and the electronic SmartVA questionnaire and media file onto tablets, and SmartVA-Auto-Analyse onto computers, to prepare all devices for SmartVA data collection.

## The intervention

This pilot study took place in 16 community health centers (CHC) from 3 districts selected to represent urban, suburb, and urban-suburb areas in Shanghai. From December 2017 to June 2018, each home death was investigated by a trained CHC doctor on duty. Doctors identified an appropriate respondent (>18 years of age, cared for the deceased, or most familiar with the deceased) from among the family members reporting the death, requested their consent to participate in the pilot study and interviewed them. At the end of the interview, the CHC doctor assigned a provisional diagnosis with underlying cause of death (UCOD), and then ran the SmartVA-Auto-Analyse program for each death to receive up to 3 suggested UCOD. The doctor then reviewed the provisional UCOD, the cause(s) from SmartVA-Auto-Analyse and the endorsed symptoms and used this information to assign the final UCOD (Fig 1).

Fig1. The field implementation procedures for this study. Legend: Initial Diagnosis represents the provisional diagnosis assigned by the CHC doctors after reviewing the deceased's medical history. Tariff1/2/3 represent 3 suggested UCODs assigned from the SmartVA tool. Final UCOD represents the UCOD of the CHC doctor combined all the messages and assigned a final UCOD to fill out the death certificate. The medical record of all deaths was also reviewed by a Medical Record Review (MRR) team who reviewed the medical records where available, the MRR UCOD was assigned by the team.

## Monitoring and evaluation

Each CHC doctor was asked to complete a Microsoft Excel spreadsheet ("COD information form" box in Figure 1) with the data on demographics, provisional COD, Tariff CODs and the post-VA UCOD for each case. This spreadsheet was submitted to SCDC by the CHC doctor at the end of each month, for monitoring the progress and quality of the study implementation. After 6 months of data collection, a program manager from SCDC integrated the data from all 16 CHCs and performed further analysis.

## Gold Standard (GS) UCOD and data analysis

The medical records for all deaths for which a VA was carried out in these 3 districts during same period were carefully evaluated an independent Medical Record Review (MRR) team. The MRR team assigned each death a 'gold standard' (GS) UCOD, based on the GS criteria for classification of COD developed by the PHMRC<sup>[4, 9, 10]</sup>. Under these criteria GS1 refers to the highest standard of diagnostic accuracy of UCOD and GS4, the lowest (Figure 1). For example, the GS1 criteria of lung cancer is histological confirmation whereas the GS4 of that is unsupported clinical diagnosis.

Causes of death from both the SmartVA sample and the UCOD from the MRR were transformed to the SmartVA cause list for comparison, given this was an abbreviated list of causes as appropriate for VA. The statistical analysis was performed using R 3.6 software.

## Results

Based on our rigorous respondent choosing criteria and the on-duty status of participating doctors in this research. A total of 619 (37.6%) out of 1648 community deaths were included in this study. Of the 619 deaths for which a SmartVA interview was conducted, 570 also had available medical records for further MRR.

There was no significant difference in the age and sex composition between the 570 deaths and the total number of CHC deaths in same area and time period (Table 1) ( $p=0.862$  for sex) ( $p=0.135$  for age). The majority of deaths were in the 70 years and above age-group.

**Table 1 Age-sex distribution of home deaths and deaths investigated by SmartVA in the 16 CHCs**

Age	Total deaths reported by CHCs				Smart VA completed			
	Male(%)	Female(%)	Total		Male(%)	Female(%)	Total	
			N	%			N	%
<49	4.2	1.3	46	2.8	2.1	2.1	12	2.1
50-69	20.5	10.1	253	15.3	23.9	13.3	106	18.6
70~	75.3	88.5	1349	81.9	73.9	84.6	452	79.3
Total (%)	50.4	49.6	49.8	50.2				
Total (N)	830	818	1648	284	286	570		

For all home deaths in the 16 selected areas in 2017, the causes of death were classified into causes from the Smart VA cause list (see from Additional File 1). The cause specific mortality fractions (CSMF) for all the home deaths in the 16 CHCs in 2017 and the CSMFs for the collected VA results from this study, conducted in the same 16 regions in 2018, showed a similar COD distribution (see Table 2).

From the MRR of the deaths analysed by SmartVA for Physicians, stroke was the leading cause of death, accounting for 17.8% of deaths, followed by other cancers (15.6%) and ischaemic heart disease, lung cancer and chronic respiratory diseases, accounting for 12.6%, 12.1% and 11.2% of deaths, respectively. All other causes accounted for less than 5% of the CODs. Broadly speaking, causes of death diagnosed by SmartVA were similar to those before implementation, with only slight changes in the ranking of causes of death (Table 2).

**Table 2 CSMFs of home deaths in the 16 regions of Shanghai in 2017 and in 2018**

Rank	Home deaths in 2017 (before VA)		Home deaths in 2018 (Smart VA)	
	Leading cause of death	(%)	Leading cause of death	(%)
1	Stroke	19.2	Stroke	17.8
2	Ischaemic Heart Diseases	15.2	Other Cancers	15.6
3	Chronic Respiratory diseases	12.3	Ischaemic Heart Diseases	12.6
4	Other Cancers	11.7	Lung Cancer	12.1
5	Lung Cancer	7.8	Chronic Respiratory diseases	11.2
6	Other Non-communicable Diseases	6.4	Stomach Cancer	4.9
7	Diabetes	4.3	Other Non-communicable Diseases	4.5
8	Undetermined	4.2	Colorectal Cancer	3.3
9	Stomach Cancer	3.6	Other Cardiovascular Diseases	3.0
10	Colorectal Cancer	2.7	Falls	2.8
11	Falls	2.7	Diabetes	2.4
12	Other Cardiovascular Diseases	1.9	Esophageal Cancer	1.7
13	Esophageal Cancer	1.2	Leukemia/Lymphoma	1.7
14	Leukemia/Lymphoma	1.2	Other Infectious Diseases	1.4
15	Prostate Cancer	1.1	Other Injuries	1.4

The concordance between the initial diagnosis and MRR UCOD and post-VA diagnosis and MRR UCOD was assessed using Chance Corrected Concordance (CCC) (Table 3). This metric evaluates the average sensitivity weighted by the number of diseases, which makes the study comparable with other studies. CSMF accuracy was also evaluated by measuring the absolute deviation of the initial diagnosis CSMFs and the SmartVA CSMFs from MRR UCOD. The closer this value is to 1, the higher the concordance of the results<sup>[7, 11, 12]</sup>.

The sensitivity and positive predictive value (PPV) were both high for the top six CODs. PPV was low for diabetes and other infectious diseases, which shows that a small number of original causes which were not diabetes or other infectious diseases were reallocated to other diseases after the VA investigation.

Although not dramatic, overall CSMF accuracy improved from 0.93, based on the initial diagnosis, to 0.96 after the application of SmartVA (see Table 3). As for specific causes, the CCCs for the top six causes of death (stroke, other cancers, IHD, lung cancer, CRD, and stomach cancer, accounting for over 75% of deaths) all increased to higher than 0.90 after VA-assisted diagnosis. Detailed metrics are shown in Tables 3-5. Some of the CODs have noticeable increases in CCC, especially other non-communicable diseases and other infectious diseases, after Smart VA. Of interest is the change in CCC of other cardiovascular diseases and falls; both decreased after the VA investigation. This may be because many deaths may initially, mistakenly be attributed to cardiovascular diseases, a COD that may not be supported after systematic and comprehensive investigations.

**Table 3 Validation metrics comparing initial diagnosis or post-VA diagnosis with MRR UCOD (top 15 specific UCOD)**

Rank	UCOD	Initial diagnosis					Post-VA diagnosis						
		Sensitivity	PPV	Kappa	CCC	CSMF	CSMF accuracy	Sensitivity	PPV	Kappa	CCC	CSMF	CSMF accuracy
1	Stroke	0.94	0.87	0.88	0.94	19.30	0.96	0.88	0.90	0.96	19.50		
2	Other Cancers	0.88	0.96	0.90	0.87	14.20	0.94	0.93	0.93	0.94	15.80		
3	Ischaemic Heart Diseases	0.89	0.85	0.85	0.88	13.20	0.93	0.89	0.90	0.93	13.20		
4	Lung Cancer	0.97	0.99	0.98	0.97	11.90	0.97	1.00	0.98	0.97	11.80		
5	Chronic Respiratory diseases	0.83	0.93	0.86	0.82	10.00	0.91	0.95	0.92	0.90	10.70		
6	Stomach Cancer	0.96	0.90	0.93	0.96	5.30	1.00	0.93	0.96	1.00	5.30		
7	Other Non-communicable Diseases	0.58	0.83	0.67	0.55	3.20	0.81	0.78	0.78	0.79	4.70		
8	Colorectal Cancer	0.95	0.86	0.90	0.94	3.70	1.00	0.95	0.97	1.00	3.50		
9	Other Cardiovascular Diseases	0.29	0.71	0.41	0.25	1.20	0.24	0.67	0.34	0.18	1.10		
10	Falls	0.81	0.81	0.81	0.80	2.80	0.69	0.85	0.75	0.67	2.30		
11	Diabetes	0.71	0.67	0.68	0.70	2.60	0.79	0.65	0.70	0.77	3.00		
12	Leukemia/Lymphoma	0.90	0.90	0.90	0.89	1.80	1.00	0.91	0.95	1.00	1.90		
13	Esophageal Cancer	0.90	0.90	0.90	0.89	1.80	0.90	1.00	0.95	0.89	1.60		
14	Other Injuries	1.00	0.73	0.84	1.00	1.90	1.00	0.89	0.94	1.00	1.60		
15	Other Infectious Diseases	0.38	0.60	0.46	0.33	0.90	0.75	0.86	0.80	0.73	1.20		
16	Others	0.94	0.47	0.61	0.94	6.30	0.83	0.88	0.85	0.82	3.00		
Total	0.80	0.93	0.85	0.96									

Table 4 shows the misclassification matrix of the initial diagnosis compared to that from the MRR. The values in the yellow boxes are the CODs that were correctly classified after initial diagnosis; 86.3% (492/570) of the initial diagnoses assigned the correct CODs. Some of the misclassifications were adjusted after the VA investigation (Tables 4, 5), leading to correct classification of 90.5% (516/570) of the post-VA diagnosis.

From the results of the initial diagnosis before VA investigation, other cardiovascular diseases and other infectious diseases were more likely to be misassigned to other causes. Among these, nearly one third of other cardiovascular diseases were misclassified as stroke (6/17) (Table 4).

In the CSMFs after SmartVA, misclassification was reduced, except for the categories of other cardiovascular diseases and falls (Table 3). As before, other cardiovascular diseases were often misclassified as stroke, which accounted for 41% (7/17) of that diagnosis from MRR (Table 5).

Analysis of the VA results with SmartVA Auto analyse resulted in the causes of 53 deaths, or just under 10% of the sample, being reclassified from their initially assigned causes. This was particularly the case for chronic kidney diseases (CKD), chronic respiratory diseases, and cirrhosis, as well as falls, ischemic heart diseases (IHD), other CVD (Cardiovascular Diseases), and undetermined causes. Among these corrected CODs, CKD (5), cirrhosis (4) and IHD (3) were most often correctly classified after VA.

Among the 53 changed CODs, only 22.6% (12/53) of causes were assigned correctly before VA (Table 6), whereas 67.9% (36/53) of the new CODs were assigned correctly according to MRR (Table 7). The number of misclassified conditions, compared to MRR, were also reduced. In the 53 changed cases, all the causes assigned before VA (Table 6) had a high degree of misclassification, except for cirrhosis and falls. After VA, misclassification was greatly reduced, except for falls and other cardiovascular diseases (Table 7). Four undetermined deaths were reallocated to other diagnoses. (The concordance and validation metrics of comparing initial/VA diagnosis with MRR results can be seen from additional file 2 and 3).

For the 53 deaths with changed UCOD after SmartVA, the initially assigned CODs were distributed randomly between the 15 diseases/causes. In the initially assigned CODs, no cases were assigned to leukemia/lymphoma or other cancers, however, according to the MRR results other cancers should be the 3<sup>rd</sup> leading COD. Chronic kidney disease, undetermined, other injuries, pneumonia, cervical cancer and esophageal cancer were also not on the MRR disease list,

while the CHC doctors assigned them as UCODs after initial diagnosis. This suggests a need for greater care when assigning these diseases as UCODs (see Table 8 for details).

With the assistance of SmartVA, the majority of deaths were assigned to other NCD (20.8%), chronic respiratory diseases (17.0%), and other cancers (17.0%). Though a small degree of misclassification persisted, the post-VA diagnosis of the UCOD agreed more closely with the reference standard (MRR) than the initial diagnosis (see Table 8).

**Table 8 The distribution of UCOD for 53 changed causes**

Changed cause	Initial(%)	Post-VA(%)	MRR(%)	
1	Cervical Cancer	1.9	0.0	0.0
2	Chronic Kidney Disease	9.4	0.0	0.0
3	Chronic Respiratory diseases	9.4	17.0	17.0
4	Cirrhosis	9.4	1.9	1.9
5	Colorectal Cancer	3.8	1.9	1.9
6	Esophageal Cancer	1.9	0.0	0.0
7	Falls	7.5	1.9	7.5
8	Ischaemic Heart Diseases	7.5	7.5	11.3
9	Lung Cancer	3.8	1.9	3.8
10	Other Cardiovascular Diseases	7.5	5.7	7.5
11	Other Infectious Diseases	3.8	7.5	5.7
12	Other Injuries	5.7	1.9	0.0
13	Other Non-communicable Diseases	3.8	20.8	17.0
14	Pneumonia	3.8	0.0	0.0
15	Prostate Cancer	5.7	0.0	3.8
16	Stomach Cancer	1.9	1.9	1.9
17	Stroke	5.7	7.5	3.8
18	Undetermined	7.5	0.0	0.0
19	Diabetes	0.0	3.8	0.0
20	Leukemia/Lymphoma	0.0	1.9	1.9
21	Other Cancers	0.0	17.0	13.2

## Discussion

The cases examined in this study are representative of the home deaths in Shanghai, as the age-sex distribution and cause-specific mortality fraction had the same distribution as that seen in the home death database in Shanghai.

Although Shanghai has an established and well-functioning CRVS system, SmartVA for Physicians contributed to an improvement in the accuracy of death certification, as demonstrated by the increase in overall cause of death CSMF accuracy, from 0.93 to 0.96 after the introduction of SmartVA. In addition, SmartVA may be a useful tool for inferring some special causes of death, such as those CODs classified as undetermined, which while less of an issue for Shanghai, is a common problem in civil registration systems worldwide<sup>[13-16]</sup>. During this study, four undetermined CODs were revised after the SmartVA investigation. With the help of this tool, the Shanghai CRVS system could reduce the fraction of undetermined deaths.

In the 53 cases with changed COD after the VA investigation, of the top three causes of death, the most misclassified causes were chronic respiratory diseases (17%), other non-communicable disease (17%), as well as other cancers (13.2%), suggesting that for causes such as these a more careful examination of the available medical history may be needed by the certifier before assigning the UCOD.

The improvement in COD data following SmartVA in this study could be attributed to two factors. Firstly, the standardised operating procedures (SOPs) for COD assignment that were followed during the SmartVA investigation ensured a structured and consistent approach, leading to more accurate COD assignment. Secondly, the SmartVA procedure has systematic and comprehensive questions, which can ensure that all relevant medical information regarding the decedent's conditions are captured. Considering all of the diseases and conditions the individual may have suffered from together enabled the certifier to assign a more accurate UCOD.

As Shanghai is highly developed with a relatively advanced CRVS system, using SmartVA as a supplementary tool can work well as shown by this pilot study. However, as a routine procedure, the use of SmartVA may not result in a significant improvement in death registration data in the Shanghai system, nor be a cost-effective way to do so. Moreover, Shanghai CHC doctors' routine work already comprises checking and correcting MCCOD data, including re-interviewing the family of the deceased. In contrast, for other cities in China, especially in the remote areas in the west, that don't have a well-functioning death registration system, SmartVA may be more beneficial.

This SmartVA study has some limitations. Firstly, the SmartVA tool, especially the cause list, is not perfectly suited to the actual mortality fractions observed in Shanghai<sup>[17]</sup>. For example, liver cancer is not on the SmartVA cause list, and therefore the program does not assign it as a COD to any deaths, whereas liver cancer accounted for more than 2.6% of deaths in Shanghai in 2018. Secondly, while standard VA procedures are adapted to conditions where there is no medical history available for out of facility deaths<sup>[7, 18-20]</sup>, in this study, the VA investigations were conducted after the certifier reviewed the previous outpatient medical histories of the deceased. This may cause some misconceptions based on the results of the outpatient records. Thirdly, in this study in Shanghai, the SmartVA procedure was implemented in 16 communities. Because the number of deaths in these communities was not very high and may not be representative of the whole population, further research should be done to determine the generalisability of SmartVA for Physicians, before it can be extended to all districts and counties.

In the future, SCDC will plan to adjust the workflow and operation specifications of the application of SmartVA in Shanghai, to maximize the effectiveness of VA in improving cause of death inference and further reduce the proportion of undetermined causes of death, through selective application and integration into the existing CRVS system. In addition, SCDC shall also consider using Smart VA to identify the possible causes of death in cases with incomplete medical history information.

## Conclusion

Although Shanghai has an established and well-functioning CRVS system, SmartVA for Physicians contributed to an improvement in the accuracy of death certification. In addition, SmartVA may be a useful tool for inferring some special causes of death, such as those CODs classified as undetermined.

## Declarations

## Ethics approval and consent to participate

Ethics approval was obtained from Shanghai CDC (Ethics ID: 2016-28) and The University of Melbourne Ethics Committees (Ethics ID: 1647517.1.1). All participants were provided with a participant information sheet and consent forms in the local language.

## Consent for publication

Written informed consent for publication was obtained.

### Availability of data and materials

The data that support the findings of this study are available from Shanghai Municipal Center for Disease Control and Prevention (Shanghai CDC) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Shanghai CDC.

## Competing interests

The authors declare that they have no competing interests.

## Funding

The research was funded by the Bloomberg Philanthropies Data for Health Initiative. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

## Authors' contributions

RJ and AL conceived the study design of the research, ZY, TX and CW oversaw the research. LC and HL were members of the writing group. HL, TA, CW, HY and AL provided feedback on data analysis, results and discussion. RR, ZG, BF and DM revised the manuscript critically for important intellectual content. All authors contributed to the framework construction, results interpretation, manuscript revision, and approved the final version of the manuscript. The corresponding authors attest that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

## Acknowledgements

The authors would like to acknowledge the contributions of the following who provided contributions in designing and conducting the whole research and feedback and comments on various iterations of this paper: Megha Rajasekhar from the University of Melbourne and Romain Santon, from Vital Strategies. Chen Jun from Shanghai Putuo District Center for Disease Control and Prevention.

## Abbreviations

**CHC:** Community Health Centers

**VA:** Verbal Autopsy

**COD:** cause of death

**PHMRC:** Population Health Metrics Research Consortium

**ODK:** Open Data Kit

**SOP:** Standard Operating Procedures

**SCDC:** Shanghai Municipal Center for Disease Control and Prevention

**UCOD:** underlying cause of death

**GS:** Gold Standard

**MRR:** Medical Record Review

**CSMF:** Cause-specific mortality fraction

**CCC:** Chance-corrected concordance

**CKD:** chronic kidney diseases

**IHD:** ischemic heart diseases

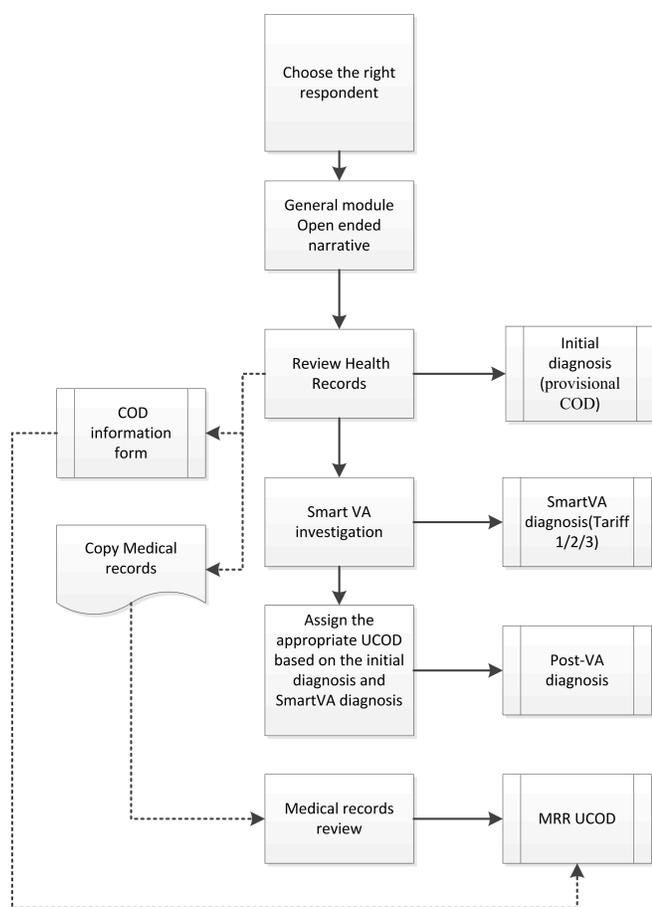
**CVD:** Cardiovascular Diseases

## References

1. Shanghai TNBoSi. 2018 Shanghai Statistical Yearbook. Shanghai: China Statistics Press; 2018.
2. Nichols EK, Byass P, Chandramohan D, Clark SJ, Flaxman AD, Jakob R, et al. The WHO 2016 verbal autopsy instrument: An international standard suitable for automated analysis by InterVA, InSilicoVA, and Tariff 2.0. *PLOS Medicine*. 2018;15(1):e1002486.
3. Leitao J, Desai N, Aleksandrowicz L, Byass P, Miasnikof P, Tollman S, et al. Comparison of physician-certified verbal autopsy with computer-coded verbal autopsy for cause of death assignment in hospitalized patients in low- and middle-income countries: systematic review. *BMC Med*. 2014;12:22.
4. James SL, Flaxman AD, Murray CJ. Performance of the Tariff Method: validation of a simple additive algorithm for analysis of verbal autopsies. *Population Health Metrics*. 2011;9(1):31.
5. Lozano R, Lopez AD, Atkinson C, Naghavi M, Flaxman AD, Murray CJ. Performance of physician-certified verbal autopsies: multisite validation study using clinical diagnostic gold standards. *Population Health Metrics*. 2011;9(1):32.
6. Serina P, Riley I, Stewart A, James SL, Flaxman AD, Lozano R, et al. Improving performance of the Tariff Method for assigning causes of death to verbal autopsies. *BMC Med*. 2015;13:291.
7. Murray CJ, Lopez AD, Black R, Ahuja R, Ali SM, Baqui A, et al. Population Health Metrics Research Consortium gold standard verbal autopsy validation study: design, implementation, and development of analysis datasets. *Popul Health Metr*. 2011;9:27.
8. Murray CJL, Lozano R, Flaxman AD, Serina P, Phillips D, Stewart A, et al. Using verbal autopsy to measure causes of death: the comparative performance of existing methods. *BMC medicine*. 2014;12:5.
9. Murray CJ, James SL, Birnbaum JK, Freeman MK, Lozano R, Lopez AD. Simplified Symptom Pattern Method for verbal autopsy analysis: multisite validation study using clinical diagnostic gold standards. *Population Health Metrics*. 2011;9(1):30.
10. McCormick TH, Li ZR, Calvert C, Crampin AC, Kahn K, Clark SJ. Probabilistic Cause-of-death Assignment using Verbal Autopsies. *J Am Stat Assoc*. 2016;111(515):1036-49.
11. Hernandez B, Ramirez-Villalobos D, Romero M, Gomez S, Atkinson C, Lozano R. Assessing quality of medical death certification: Concordance between gold standard diagnosis and underlying cause of death in selected Mexican hospitals. *Popul Health Metr*. 2011;9:38.
12. Flaxman AD, Serina PT, Hernandez B, Murray CJ, Riley I, Lopez AD. Measuring causes of death in populations: a new metric that corrects cause-specific mortality fractions for chance. *Popul Health Metr*. 2015;13:28.
13. Breiding MJ, Wiersema B. Variability of undetermined manner of death classification in the US. *Inj Prev*. 2006;12 Suppl 2:ii49-ii54.

14. Fanaroff AC, Clare R, Pieper KS, Mahaffey KW, Melloni C, Green JB, et al. Frequency, Regional Variation, and Predictors of Undetermined Cause of Death in Cardiometabolic Clinical Trials: A Pooled Analysis of 9259 Deaths in 9 Trials. *Circulation*. 2019;139(7):863-73.
15. Advenier AS, Guillard N, Alvarez JC, Martrille L, Lorin de la Grandmaison G. Undetermined Manner of Death: An Autopsy Series. *J Forensic Sci*. 2016;61 Suppl 1:S154-8.
16. Baumert JJ, Erazo N, Ladwig KH. Sex- and age-specific trends in mortality from suicide and undetermined death in Germany 1991-2002. *BMC Public Health*. 2005;5:61.
17. Yang G, Rao C, Ma J, Wang L, Wan X, Dubrovsky G, et al. Validation of verbal autopsy procedures for adult deaths in China. *International Journal of Epidemiology*. 2005;35(3):741-8.
18. Thomas LM, D'Ambruso L, Balabanova D. Use of verbal autopsy and social autopsy in humanitarian crises. *BMJ Glob Health*. 2018;3(3):e000640.
19. The University of Melbourne. Guidelines for interpreting verbal autopsy data Melbourne, Australia: Bloomberg Philanthropies Data for Health Initiative, Civil Registration and Vital Statistics Improvement, the University of Melbourne; 2019 [Available from: [https://crvsgateway\\_info.myudo.net/file/11243/3231](https://crvsgateway_info.myudo.net/file/11243/3231)].
20. Sankoh O, Byass P. Time for civil registration with verbal autopsy. *The Lancet Global health*. 2014;2(12):e693-e4.

## Figures



**Figure 1**

The field implementation procedures for this study. Legend: Initial Diagnosis represents the provisional diagnosis assigned by the CHC doctors after reviewing the deceased's medical history. Tariff1/2/3 represent 3 suggested UCODs assigned from the SmartVA tool. Final UCOD represents the UCOD of the CHC doctor combined all the messages and assigned a final UCOD to fill out the death certificate. The medical record of all deaths was also reviewed by a Medical Record Review (MRR) team who reviewed the medical records where available, the MRR UCOD was assigned by the team.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Additionalfile1.pdf](#)
- [Additionalfile2.xlsx](#)
- [Additionalfile3.xlsx](#)