

Surveillance and Outbreak Response Management System (SORMAS) to support the control of the Ebola virus disease outbreak in West Africa

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In the context of controlling the current outbreak of Ebola virus disease (EVD), the World Health Organization claimed that 'critical determinant of epidemic size appears to be the speed of implementation of rigorous control measures', i.e. immediate follow-up of contact persons during 21 days after exposure, isolation and treatment of cases, decontamination, and safe burials. We developed the Surveillance and Outbreak Response Management System (SORMAS) to improve efficiency and timeliness of these measures. We used the Design Thinking methodology to systematically analyse experiences from field workers and the Ebola Emergency Operations Centre (EOC) after successful control of the EVD outbreak in Nigeria. We developed a process model with seven personas representing the procedures of EVD outbreak control. The SORMAS system architecture combines latest In-Memory Database (IMDB) technology via SAP HANA (in-memory, relational database management system), enabling interactive data analyses, and established SAP cloud tools, such as SAP Afaria (a mobile device management software). The user interface consists of specific front-ends for smartphones and tablet devices, which are independent from physical configurations. SORMAS allows real-time, bidirectional information exchange between field workers and the EOC, ensures supervision of contact follow-up, automated status reports, and GPS tracking. SORMAS may become a platform for outbreak management and improved routine surveillance of any infectious disease. Furthermore, the SORMAS process model may serve as framework for EVD outbreak modelling.

Introduction

The spread of the current outbreak of Ebola virus disease (EVD) in West Africa has slowed down in most affected areas, but daily case numbers are still high as of 11 March 2015 [1]. Even enhanced awareness and increasing international support did not prevent contacts of known cases from travelling to unaffected areas causing further spread. As a consequence, although the rise of new EVD cases slowed down, the number of foci has increased, causing new operational challenges for health officials and field epidemiologists [1]. The interruption of person-to-person transmission includes proactive case finding i.e., supervision of timely isolation, diagnosis and treatment, as well as identification and prospective monitoring of contact persons [2]. High population mobility, stigmatisation of persons considered infectious and fears of persons who had been in contact with them, require a large number of staff to reach out and maintain contact to patients and contact persons. At the same time, a large amount of rumours entering the public health service through a variety of channels and formats need to be validated. Existing surveillance systems are usually not built to address such challenges. In addition, uncertainty and delay of surveillance data due to different information sources and infrastructural hurdles such as irregular availability of communication or transportation services in the affected countries have led to limited reliability of epidemiological analyses. This was exemplified by the fact that the World Health Organization (WHO) needed to retrospectively correct the official outbreak reports in week 45/2014, resulting in 299 fewer cases than previously reported [3].

TABLE 1

User and system requirements for management systems to support the Ebola virus disease outbreak response

Priority system requirements
Authorised persons should be able to immediately report on suspected EVD cases.
Reporting of case status including results from laboratory tests should be supported.
Monitoring of contacts and management of contact tracing activities should be supported.
Monitoring of infection prevention measures (e.g. decontamination, safe burials) should be enabled.
User requirements
Information on suspected EVD cases needs to reach simultaneously the health authorities in charge at district, state and national level and the Ebola Outbreak Emergency Operations Centre.
Changes in case status and changes from contact status to a suspected case need to be administered without generating new datasets.
Incoming information on suspected cases including unstructured information and unverified rumours and the respective decisions of further follow up need to be documented.
Status reports on cases, contacts and their respective classifications and follow up status need to be generated by the system automatically.
Reports should be compatible with reporting requirements of the International Health Regulations of the WHO [28], but should also allow for higher resolution epidemiological analyses via mapping, histograms etc. as exemplified by the current WHO and national situation reports on the EVD outbreak.
Variables included in existing standard forms on haemorrhagic fever as well as in the module for viral haemorrhagic fevers of EpiInfo [29] need to be reflected in the system.
The system needs to support supervisors in assuring that all contact persons are identified, documented and that their respective fever monitoring is executed without interruption.
The system needs to support supervisors in assuring that infection control measures and social mobilisation in affected districts have been carried out.
Technical requirements
Data exchange with existing surveillance systems is necessary, at least through a standardised output format to enable integration with the Integrated Disease Surveillance and Response System.
The system should be available as mobile application without a need for special configuration or installation.
Desktop applications for supervisors are required.
The system should be runnable on Android mobile devices (Jelly Bean Android OS, large touch screen interfaces or QWERTY keys).
Efficient network providers for mobile devices and tablets are required.
GPS tracking software for locating stolen devices is necessary.

EVD: Ebola virus disease; GPS: global positioning system; WHO: World Health Organization.

The first case of EVD was imported to Nigeria in August 2014 resulting in 19 additional secondary infections. Tremendous intensity, rigour, and timely control measures together with beneficial circumstances around the case identification led to the control of the outbreak and allowed WHO to declare the end of the Ebola outbreak for this country by 20 October 2014 [4].

Systematic analyses and review of the experiences of Shuaib et al. [5] revealed that a comprehensive management system needs to be in place already to ensure successful containment of similar emergencies even if they occur under less beneficial circumstances. At the time of the outbreak, the Ebola reporting tool, called Open Data Kit (ODK) [6] was established to document visits of contact persons, but it did not address case finding, bidirectional information flow and other aspects of outbreak response.

To address this need, a consortium of Nigerian and German public health and research institutions and a global software company have developed the Surveillance and Outbreak Response Management System (SORMAS). The objective of SORMAS is to ensure availability of validated real-time surveillance data and to manage the verification of cases as well as tracing and monitoring of their contacts as it is typically needed during an EVD and other disease outbreaks. This report describes the generic requirements, process models, and technical infrastructure of SORMAS.

Development of SORMAS

We identified the user requirements in Design Thinking [7] workshops and by reviewing the reports of Shuaib et al. [5]. Additionally, we took into account requirements identified in reviews and analyses on contact tracing, outbreak management and electronic surveillance systems for other diseases also, not only EVD [8-12]. The identified requirements to be addressed by an outbreak management system are listed in Table 1.

Specification of personas

By reviewing the processes of the EVD outbreak management in Nigeria, we identified the different SORMAS user types, i.e. personas, involved in the process. Regular staff or volunteers of different hierarchical levels and with different job descriptions may be summarised within one persona, if their respective role and interaction with SORMAS are the same [13]. We defined the role, the needs with respect to the system, the interaction with other personas and the required artefacts (e.g. checklists and forms) for each persona. We consider an artefact a specification of a physical piece of information that is used or produced by a software development process, or by deployment and operation of a system. By systematically analysing the processes and roles, we were able to condense the number of originally 15 personas to seven personas. Some of these represent officers with different professions and training background. The process of defining the personas and their system expectations allowed us to design SORMAS according to users' needs.

Table 2 depicts the identified and defined seven personas that are directly interacting with SORMAS. Additionally, there is the persona case officer who is involved in the process, but will not directly interact with SORMAS since they wear protective clothes and are thus unable to use a mobile device for entering

TABLE 2

Persona of SORMAS with their respective activities, artefacts and interactions

Persona	Activities	Artefacts	Interaction
Informant	Looks for disease rumours in the population Collects information on death or sickness among healthcare workers	<ul style="list-style-type: none"> Checklist on standard operating procedures Rumour information (demographics, travel, contact) 	Reports to surveillance officer
Rumour officer	Conducts initial triage on all incoming rumours on possible cases	<ul style="list-style-type: none"> Checklist with required information on rumour Rumour information 	Reports to the surveillance supervisor
Surveillance officer	Reports notifiable diseases to state epidemiologist, receives rumours on cases and forwards them to surveillance supervisor to decide on further investigation Conducts investigation to verify status of case, e.g. suspect or confirmed and is responsible for active case finding	<ul style="list-style-type: none"> EVD active surveillance form Checklist on rumour triage Contact list of healthcare facilities Rumour information 	Reports to surveillance supervisor Supervises informant
Surveillance supervisor	Coordinates the input from rumour officers and surveillance officers Supports rumour officer in deciding on the investigation on a new rumour	<ul style="list-style-type: none"> Alert investigation form Checklist for incoming rumours 	Reports to the heads of the unit (Epidemiology/Surveillance and Case Management) who are in turn reporting to the incident manager Supervises surveillance officer
Case supervisor	Coordinates all necessary steps of handling cases, e.g. triage, transport, laboratory tests, decontamination Forwards information about a suspected case to the contact and surveillance supervisor	<ul style="list-style-type: none"> Checklist with tasks for case handling Case investigation form / case report (available in folder artefacts) Task list for case officers 	Reports to the heads of the unit (Epidemiology/Surveillance and Case Management) who are in turn reporting to the Incident manager. Supervises case officer
Contact officer	Conducts contact tracing within a particular district	<ul style="list-style-type: none"> Contact list for the day / week Daily report for contact supervisor Case report relevant for currently followed contact Suspected case information Contact tracing form Interview guide for contact interview Meeting calendar Contact list of new potential contacts to be traced 	Reports to contact supervisor
Contact supervisor	Coordinates the work of the contact officers Informs the case supervisor about suspected cases	<ul style="list-style-type: none"> Information on traced contacts List of contacts to trace and their details List of contact officers Task list for each contact officer Meeting protocol from daily meeting with all contact officers Daily reports from each contact officer Information on suspected case 	Reports to case supervisor Supervises contact officers

EVD: Ebola virus disease; SORMAS: Surveillance and Outbreak Response Management System.

data. The complete listing of needs of the respective personas as well as the detailed process model is available at <http://www.helmholtz-hzi.de/sormas>.

Information flow and interactions between personas

Figure 1 indicates the interactions between the personas, the information flow and interactions in more detail, reflecting the information from the process model.

The informant can be a volunteer functioning as community informant, an Ebola focal person in a private healthcare facility, or a community healthcare worker. Therefore, the educational level and institutional

affiliation may differ widely. The rumour officer is part of the EOC team and collects all rumours on possible cases that come in through different channels, e.g. phone, mail, media reports etc. from citizen, healthcare workers, or indirectly via the hotline.

The surveillance supervisor may be a disease surveillance and notification officer (DSNO). They decide if and what kind of verification action is to be taken upon incoming rumours or notifications and direct this task to the surveillance officer in the field. They apply the criteria of the case definition and takes decision of the respective case classification based on available clinical epidemiological and laboratory data. Once a suspected case is identified by a rumour officer, the

surveillance supervisor informs the case supervisor to initiate isolation and treatment, laboratory confirmation and decontamination. Besides receiving hints on potential cases, the surveillance officer also reaches out to hospitals to assure zero reporting and may verify on site whether criteria of case definitions apply for a possible case.

The contact officer reports contacts as ‘suspected cases’ to the contact supervisor, as soon as the contact develops symptoms. Contacts or relatives of contacts who have issues with stigmatisation, rejection or are difficult to deal with are also referred to the case supervisor. The contact officers are often DSNOs, staff members from the Ministry of Health, graduates and residents from the Nigeria Field Epidemiology and Laboratory Training Programme, Red Cross Volunteers, or surveillance officers from WHO.

The case supervisor coordinates the activities of several case officers by assigning tasks such as clinical management of cases at the isolation facility, decontamination of residences and facilities, safe burial of corpses, psychosocial support of cases, contacts and relatives.

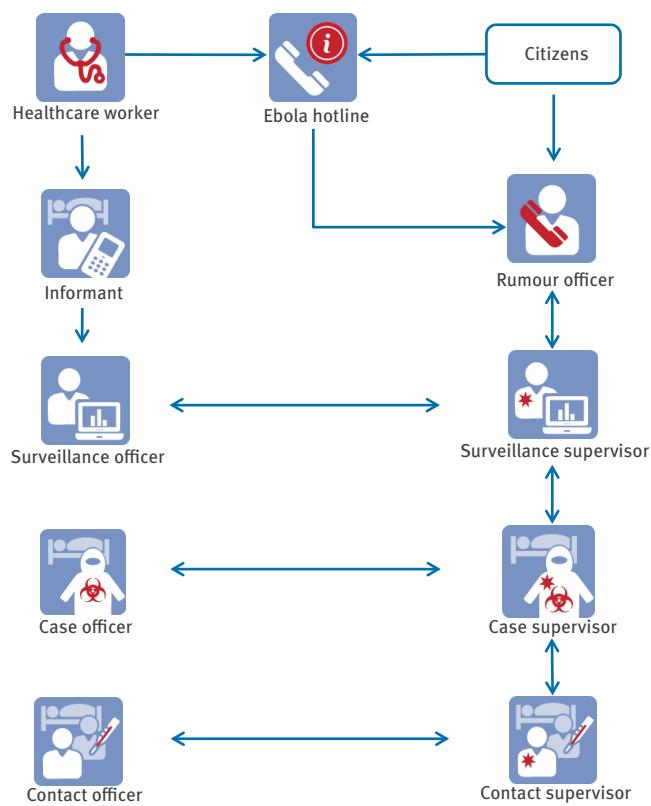
Technical infrastructure

We specified the technical infrastructure addressing the needs and tasks of the personas. We decided to focus on applications for mobile devices for the front end since the cellular network has become the first choice for Internet access in West Africa [14]. We further chose a scalable, cloud-based software architecture to allow non-dedicated computing resources on-site and to leave required maintenance to the cloud service provider.

The back end of the system is based on a cloud-based SAP HANA applying In-Memory Database (IMDB) technology [15]. A selected IMDB building block is the columnar database layout in order to enable real-time processing of analytical queries and lightweight data compression techniques. With the insert-only or append-only paradigm, IMDBs store the complete history of data changes to reconstruct the database state for any given point in time. Figure 2 depicts the software system architecture modelled as Fundamental Modelling Concepts block diagram [16]. Field workers use mobile devices to document acquired information directly in the cloud system. Available devices are registered in the cloud-based device management software SAP Afaria. The local cellular phone network provider provides data transfer to the Internet. All data exchange is encrypted using latest web standards, e.g. HTTPS protocol. All applications are configured by the cloud service provider and incorporate latest IMDB technology which allows storing all data in an encrypted format [17]. In case the mobile devices are to be used at times or in areas without mobile phone connectivity, the data entered will be automatically uploaded to the system as soon as connectivity is

FIGURE 1

Interactions between SORMAS users involved in the Ebola virus disease containment process



SORMAS: Surveillance and Outbreak Response Management System.
Arrows between personas represent the information flow.

available again. As a back-up option, data can also be downloaded from the encrypted SIM card.

User interface

The user interface was designed to fulfill all data collection and information needs of the seven personas, i.e. the artefacts have been implemented through corresponding screens. Bootstrap, a set of software tools for creating web applications based on HyperText Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript [18-20], has been used for this purpose. Some examples of screen shots for mobile devices are shown in Figure 3. The design of the icons, depicting the different personas and functions, went through six modifications to assure universally applicable, immediately understandable, and culturally sensitive design.

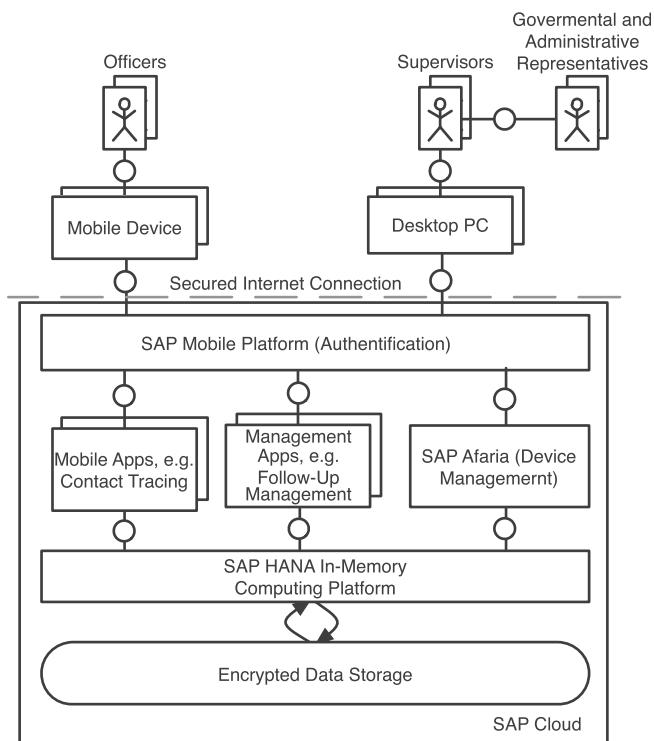
Comparison with other systems

The four main characteristics of SORMAS presented here are (i) its focus on the multilevel management functionality designed on the basis of systematic and in-depth analyses of the actual processes and personas involved in the successful EVD control in Nigeria,

(ii) its concept to ensure real-time synchronisation with surveillance systems already existing in many African countries such as IDSR and transfer interfaces to other EVD related database systems such as the EpilInfo Viral Haemorrhagic Fever application, (iii) its centralised back-end IT architecture using established software and database components with big data capacity, in combination with (iv) its mobile interface for bi-directional information exchange for staff in the field applicable on standard smart phones without any further configuration.

Through the combination of those four characteristics, SORMAS is distinct from various other tools aiming to support the control of the EVD and other outbreaks by means of mobile phone based applications. Detailed technical information on the existing systems is still available only to a limited extent. However, the existing tools do not support bidirectional information exchange and a task management as designed for SORMAS. For example, during the outbreak in Nigeria in August / September 2014, an Ebola reporting tool, called Open Data Kit (ODK) [6] was established running on Android phones. It allows reporting suspected cases, and sending of GPS data of cases/contacts, and integrated laboratory results with feedback to field workers. The ODK mainly digitised the data collection forms. ODK concentrated on contact tracing and follow-up. Only the contact officers had access to the system.

FIGURE 2
SORMAS software architecture



SORMAS: Surveillance and Outbreak Response Management System; VM: virtual machine.

In contrast, SORMAS will be made available to several relevant personas, is more detailed and focuses on active case finding and surveillance.

The Centers for Disease Control and Prevention (CDC) developed a VHF module based on EpilInfo for contact tracing [21]. It provides support in case management, analysis, and reporting during outbreaks of EVD, Marburg virus, Lassa virus, Rift Valley Fever, and Crimean-Congo haemorrhagic fever. This module allows users to link cases with contacts and track those contacts continually over a 14- or 21-day follow-up window and to set up databases of patient information including names, sex, ages, locations, status, e.g. such as dead or alive, and case classification, for suspected case, confirmed case or no case. In contrast to SORMAS, the EpilInfo VHF module is not designed for bidirectional information exchange and does not address the challenge of information exchange.

The Ebola Care App supports contact tracing, patient data collection by ambulance teams, and Ebola education as well as observation and evaluation of children under quarantine [14]. Basing upon cloud data storage, it further gives decision makers real-time access to data from the field. It is currently tested by the Liberian government. CommCare is an open source mobile platform that supports a range of Ebola management needs. It has been developed and pilot tested to assist community healthcare workers [22,23]. CommCare operates through the use of Java-enabled phones or high-end Android smartphones. The system intends to provide a range of functions (some of them are still under development): household visit tracking, data collection, record keeping, day planning, and data exploration. Additionally, systems were developed that try to stimulate reporting by citizens or to provide citizens with information on prevention measures. EbolaTracks is an automated SMS system designed for monitoring persons potentially exposed to EVD, including travellers returning from Ebola-affected countries [24]. It enables monitoring of EVD contacts by SMS to inquire about development of symptoms.

SORMAS, as well as most of the above mentioned IT-based tools to support the EVD outbreak control, makes use of the mobility and widespread availability of mobile phones in West Africa. This allows independence from variable wire-based IT and telecommunication infrastructure. In contrast to some of these approaches, SORMAS does not require any special configuration on the mobile devices which has proven to be a major obstacle when the ODK was used during the outbreak in Nigeria in August 2014. The use of SAP Afaria enables remote management of devices including their automated update as well as track and wipe of lost devices to ensure a high level of data security [25]. Using a cloud service provider also eliminates the need for local IT management. Data are uploaded to the cloud when an Internet connection is available. Otherwise SORMAS works in an offline mode where

FIGURE 3

Screenshots of the mobile SORMAS user interface



SORMAS: Surveillance and Outbreak Response Management System.

The name of the person is fictitious.

data are stored locally until an Internet connection is available.

Discussion and conclusion

An advantage of SORMAS is the usage of the IMBD technology that was applied successfully in the analysis of big enterprise data and medical data, e.g. in supporting the identification of similar patient cases and the protection of markets from injecting pharmaceutical counterfeits [26,27]. We consider IMDB technology as a toolbox of IT building blocks enabling real-time analysis of big datasets [15]. IMDB technology also provides combined processing of structured data, e.g. relational database tables, and unstructured data, e.g. text documents. Furthermore, IMDB technology integrates statistical tools, such as clustering and machine learning algorithms. These functionalities would at a later stage allow development of complementary functionalities into SORMAS such as identification of social media messages and their linkage to reported cases.

Using such advanced IT technology might be perceived as a risk to acceptability and sustainability in countries in which computer systems may not work reliably due to lack of qualified maintenance or technical infrastructure. However, the use of a high performance architecture built with established components reduces the risk of break-down due to overload, allows flexible adaptation to country-specific needs and ensures a high level of data protection.

The process model has different dimensions:

1. centralised vs. field-based activities, carried out by respective personas who would in turn also use mobile devices vs desktop PC for their work.
2. the differentiation between

- intake of information (in form of rumours, notifications and reports of suspect cases),
- case verification,
- isolation management of the case, and
- identification and follow up of contacts of that case,
- monitoring of infection control measures (decontamination, safe burial) and social mobilisation.

SORMAS supports realising these control measures by providing reminders and check-lists to the user and confirming completed tasks. Standard operating procedures are thus automated as much as possible. This will hopefully help reduce the time for action-taking and provide accountability. Another dimension of the process is the distinction between supervision and decision making (as represented by surveillance supervisor, case supervisor and contact supervisor) and the execution of these tasks by the respective personas.

Since the process model was based on the practical experience in the field it might serve as basis for epidemiological models on the impact of different intervention strategies.

One limitation is that SORMAS has not been used in the field yet. It remains to be seen until the foreseen pilot phase whether SORMAS can truly improve the control of EVD or other outbreaks. A table top prototype test based on two simulated scenarios was performed in February 2015 to evaluate the functionality of the system. A four-week pilot phase in Nigeria is planned for May 2015 to systematically evaluate SORMAS under field conditions. In order to allow proper piloting in the absence of EVD, we have identified alternative notifiable diseases and developed respective process models so that SORMAS will soon also contain functionalities

for surveillance and case management of additional epidemic prone diseases. In the Nigerian context, this would encompass measles, cerebrospinal meningitis, cholera, Lassa fever, rabies, acute flaccid paralysis, bloody diarrhoea/shigellosis, and Dengue fever. In order to realise this, the process model and data structures need to be redesigned taking existing public health guidelines and the respective surveillance processes into account.

Since SORMAS is designed to export information for integration in the IDSR forms, it may help to improve quality and efficiency of routine disease surveillance and control even in the absence of large epidemics. Possibly, SORMAS will only become available for implementation after the current EVD outbreak in West Africa has diminished in size. However, SORMAS is likely to be a very useful instrument to enhance routine surveillance of epidemic prone diseases as well as inhibiting the speed with which the disease is spreading. Currently we concentrate our work on adapting the system to surveillance tasks associated with other diseases such as measles and avian influenza A(H5N1). Beyond the actual system development, our work resulted in a better in-depth understanding of the processes and personas involved in the case management and surveillance tasks of EVD.

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Conflicts of interest

RR is employed by SAP, the provider of the platform used in this study. All other authors declare that there are no conflicts of interest.

Authors' contributions

Cindy Fähnrich, Kerstin Denecke and Gérard Krause drafted the manuscript. Cindy Fähnrich developed the process model and user interface, with contributions of Kerstin Denecke, Justus Benzler, Hermann Claus and Göran Kirchner, Olawunmi Olubunmi Adeoye, Sabine Mall, Daniel Tom-Aba, Gabriele Poggensee and Norbert Schwarz. Matthieu-P. Schapranow reviewed the process model. Cindy Fähnrich defined and specified the persona with contributions and discussions with Daniel Tom-Aba, Kerstin Denecke, Justus Benzler, Hermann Claus and Göran Kirchner, Olawunmi Olubunmi Adeoye, Sabine Mall, Gabriele Poggensee and Norbert Schwarz. Justus Benzler, Hermann Claus, Göran Kirchner and Kerstin Denecke developed the data model with contributions from Daniel Tom-Aba and Gabriele Poggensee. Ralph Richter, Matthieu-P. Schapranow and Matthias Uflacker designed the technical infrastructure. Kerstin Denecke discussed the results in comparison to related work. Gabriele Poggensee and Daniel Tom-Aba analysed the SORMAS requirements. Gérard Krause supervised the project and contributed to all

developments. All authors commented on the manuscript at all stages.

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