Interoperability in Pervasive Health: Is It Tackled as a Priority?

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Abstract: For the electronic health record (EHR) to be considered a true clinical decision support system, it must be possible to access and integrate the patients' clinical information collected throughout their lives, guaranteeing up-to-date, safe and congruent information, immediately accessible at the place of care. Moreover, there is a considerable capacity to develop and manufacture personal health devices (PHD) highly integrated and miniaturized, which facilitate the home monitoring of patients with chronic diseases. Since the information collected by PHD should be integrated in existing EHR, interoperability is an essential requirement of eHealth to allow the integration of care into a diversity of settings and care providers. The purpose of this systematic review was to identify and analyse references related to the topic of home monitoring that reveal an explicit concern with interoperability requirements. Regarding the results and considering the initial 2778 references, only 2% (61 references) explicitly mentioned interoperability issues and, within these 61 references, only eight reported end-to-end solutions that can be integrated and usable in care service provision. Therefore, the issue of interoperability of PHD, both semantic and technological, a priority for the establishment of a remote patient monitoring solution market, is discussed in this review.

1 BACKGROUNG

Progresses attained in the last decades in health information technology (HIT) are undeniable; however, some goals apparently have not yet been achieved. Efforts to link and aggregate patients' clinical information collected throughout the care process have been hampered by factors such as technological "heritage", proprietary technology, obsolete regulation, incomplete specification of end-to-end standards and financial concerns (Perlin, 2016). The design and implementation of HIT has not yet reached its potential in terms of impact it can have on health care provision and interoperability is assumed as being an essential requirement to integrate health care into a diversity of settings and care providers (Kuziemsky et al., 2016).

In health care delivery, there is significant amount of information available, so the problem is less the volume and more the value that is created with the available information. Major difficulties are related to the aggregation of information from different sources, with different formats and meanings, as well as the lack of tools to recognise, within all the available information, which is relevant for each particular situation and to make it useful rather than just being visible (Halevy, 2011).

Due to the growing importance of the eHealth paradigm (Eysenbach, 2001) and related concepts (e.g. connected health (Kvedar et al., 2014), holistic health (Rossi et al., 2013) or pervasive health (Connelly et al., 2017)), contexts regarding health care delivery have evolved. Particularly, health care delivery has evolved from hospital to home, and home monitoring of patients' clinical information together with context information resulting from their environment might be incorporated in the characterization of their health conditions. In this pervasive context, different groups of technologies assume an important role, namely telecare, mobile health (mHealth) and ambient assisted living (AAL): telecare include solutions such as monitoring devices or medical alert devices to support patients in their environments (Emery et al., 2002) or rehabilitation activities (Cruz et al., 2013; Teixeira et al., 2013);

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mHealth is related to the use of mobile communication devices for the health care provision (WHO, 2011); and AAL intends to respond to the specific needs and major diseases of older adults in their domestic spaces, increasing their autonomy, confidence and participation ability (Queirós et al., 2015).

The information is no longer stored and exclusively managed by the electronic health records (EHR) of the health care institutions. Although EHR are adequate for the presentation of information from patients, collected and aggregated in local HIT, the reality is that the provision of health care is not restricted to an institution or even to a single care provision system (Queirós et al., 2013). All caregivers need comprehensive, up-to-date, safe and congruent information from the patient, immediately accessible at the place of care, to ensure the highest levels of clinical quality. For instance, when considering the home monitoring of a patient with a chronic disease (e.g. diabetes, heart failure or chronic obstructive pulmonary disease), the resulting monitoring information should be distributed within an information network ranging from clinicians, social care network, and family members to the patients themselves. These requirements promote the emergence of new technological approaches such as personal health record (PHR) (Krukowski et al., 2015) that aimed at electronic management of information between the patients and their formal and informal health care providers, and that might contribute to the availability of the patients' clinical information that is collected throughout their lives (Halevy, 2011).

However, the implementation of this vision is bounded by a set of problems: for instance, clinical information is blocked in HIT silos, generated and stored in different systems that either do not communicate with one another or are unable to synthesize information to make it meaningful and usable. Therefore, interoperability must be ensured, in terms of communications protocols and semantic normalization, between a wide range of information sources and eHealth applications. Hence, initiatives efforts carried out by international institutions such as the Continua Health Alliance, the Health Care Information and Management Systems Society (HIMSS), the National Institute of Standards and Technology (NIST), and the Integrating the Healthcare Enterprise (IHE) are crucial to overcome interoperability difficulties and to promote a homogeneous eHealth ecosystem (Aragüés et al, 2011).

Given this background, the main purpose of the systematic review reported in the present article was to explore if interoperability is a real concern when developing concrete pervasive solutions (e.g. telehealth, mHealth or AAL applications) to gather patients' information, both clinical and contextual information.

2 METHODS

The purpose of this systematic review was to identify and analyse in more detail references related to home monitoring, which reveal an explicit concern with interoperability requirements. The general goals of this systematic review were to identify, within the selected references, how interoperability is addressed in the solutions being proposed, how they are validated and if there is effective technological and semantic interoperability. The ultimate goal of this analysis was to assess if, in addition to allowing information sharing, the solutions proposed are able to produce meaningful and contextualized information that can be integrated into EHR, that is, if the information they collect is qualified to be integrated and usable in the care service provision. Moreover, if this is the case, it is important to identify standards that are most commonly used.

2.1 Study Design

Considered the aforementioned purposes, the systematic review of the present study was informed by the following research question: is there an explicit concern related to interoperability during the development of new eHealth applications to gather patients' information in their home environments?

Within references selected as expressing an effective concern related to interoperability, some sub-questions were raised:

- What are the problems being addressed?
- Which types of interoperability computational support were provided?
- How the proposed solutions addressed interoperability?
- Which technical implementation has been used?
- Which methods were used to validate the proposed interoperability implementations?
- Is the resulting information ready to be integrated into the health care service provision? If yes, which standards are being used?

To achieve these goals, initially, a systematic review of literature published between 2011 and 2016 was performed.

Exclusively the references that had the keywords “interoperability” or “interoperable” in title or abstract were considered for further assessment and classification, being excluded the first group of references.

Subsequently, the references included for analysis were assessed and some more were excluded reflecting specified criteria, which is described below. The remaining references were then categorized according to the degree of significance to answer the questions posed within this research, that is to say the option was to analyse in greater detail the references that proposed solutions in which it was considered relevant that the information produced could be integrated into the health care service provision.

The methods used to conduct this systematic review of literature as well as the subsequent categorization of search results is described in the following subsections.

2.2 Data Sources and Searches

The research was carried out using the Scopus, Web of Science and IEEE Xplore Digital Library databases, in the publications titles, abstracts and keywords.

The keywords used in the search, simultaneously, were: “monitoring” and “pervasive health”, since these are the topics around which it is important to evaluate the centrality of the interoperability issue. Pervasive health is seen as a contribution to a more personalized model of care allowing individuals to be more actively involved in their care process. A classic pervasive health care application is home monitoring of health conditions, particularly patients with chronic diseases. However, it is important to note that pervasive health is more than monitoring applications as it can also include preventive applications (e.g. elderly people to live independently) (Queirós et al., 2015).

The remaining keywords were: “mobile health”, “mhealth” and “ambient assisted living”. These keywords were combined so that at least one of them corresponded to the subject of the search.

2.3 Inclusion and Exclusion Criteria

References with no author, no abstract, not written in English, duplicates and editorials were excluded. References selected for review were all written in English and all who had a date of publication between 2011 and 2016. Then, all the references that did not explicitly mention the “interoperability” or “interoperable” keywords in tittle and/or in abstract were also rejected.

Subsequently, within the references’ full texts revised, those that corresponded to items out of ambit of this systematic review were also excluded. Then, in the group of references within the scope of this systematic review, were also identified and excluded those references that corresponded to categories to be rejected in view of the objectives of this analysis, specifically: overviews, political perspectives, position papers, reviews and systematic reviews.

Then, the remaining references were clustered in ascending order of importance for this study: connection between devices; intermediate components between devices and client applications for handling the storage and sharing of the information being gathered (e.g. architectures, gateways, middleware or data hubs); intermediate components but incorporating medical devices specificities; and end-to-end solutions.

2.4 Study Selection

After the first screening, one author assessed all titles for relevance. Those clearly not meeting the inclusion criteria were removed.

Afterwards, the abstracts of the retrieved articles were assessed against the inclusion and exclusion criteria, by two authors. Any disagreements were discussed with a third reviewer and resolved by consensus. Abstracts were then subject to a first classification and grouping.

Finally, the references that were selected by the superior interest for this study were gathered and analysed in more detail. Two authors, according to the outlines criteria, then assessed again these full texts thought to be of relevance, and any divergences were also discussed with a third reviewer and agreed by consensus.

3 RESULTS AND DISCUSSION

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009) as described in Figure 1.

A total of 2778 references were retrieved from the initial search of the selected databases. Then, 2717 of these references were rejected because they did not explicitly mention "interoperability" or "interoperable" in the tittle and/or in the abstract.

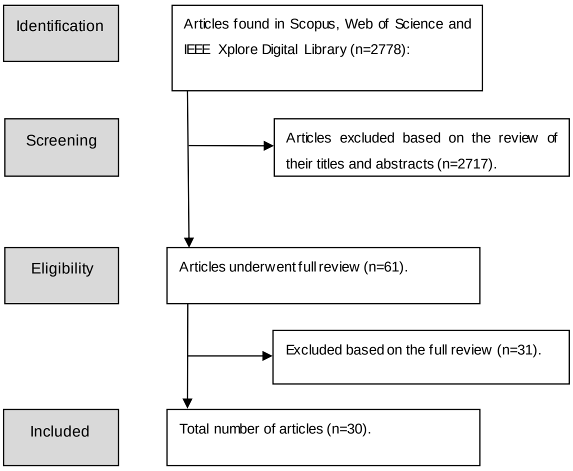

Figure 1: PRISMA flowchart.

Afterwards, by reviewing these 61 references' full-texts, 31 were excluded: the first 17 references grouped and classified are articles assumed as out of the scope of this study; other cluster (n=14) are references that, although within the ambit of the present analysis, were also excluded because they correspond to position papers (n=5), systematic reviews (n=3), reviews (n=1), overviews (n=2) and political standpoints (n=3).

The remaining 30 references were first clustered in ascending order of importance for this study: five references deal with the connection between devices; 14 references are related to the intermediate components between different types of sensors and the client applications for handling the storage and sharing of the devices' information; three references are similar to the previous, but incorporating medical devices specificities; and the latter cluster (eight references) comprises the references that propose end-to-end solutions.

The group of references related to the connection between devices (n=5) include those that describe solutions providing communication protocols to network sensors. The remaining three categories have an ascendant interest to answer the questions raised in this systematic review, going from ways to guarantee connection between sensors to end-to-end solutions. The group of 14 references contains articles that report solutions with different designations (e.g. architectures, gateways, middleware or data hubs) but with the same purpose, which is to aggregate data from various sources to provide it in an integrated way to client applications. These references, although being related to health care applications, they do not allude to interoperability standards used in health care applications. As for the three references incorporated in the other cluster, they describe the same type of solutions proposed in the last group, but explicitly referring the use of health care standards.

Finally, the references that were selected by the superior interest for this study (n=8), because referring to end-to-end applications, allowing connections to EHR and based on standards such as Health Level Seven (HL7), were analysed in more detail in the study reported by the present article.

3.1 Characteristics of the Studies

Within the 30 references selected and categorized according to the degree of relevance for this systematic review, there are several aspects to be highlighted and analysed in this section.

Five references (Elsaadi et al, 2016; Escobar et al., 2015; Fong, 2011; Grossi et al, 2012, Palma et al., 2016) describe solutions providing communication protocols to connect a large number of sensors.

Fourteen references report solutions to aggregate data from various sources to provide it in an integrated way to client applications (Carr et al., 2013; Costa et al., 2014; Denkovski et al, 2015; Ding et al. 2016; Ferreira et al., 2012; Kilintzis, et al., 2013; Norgall et al., 2013; Pradilla et al, 2015; Rossi et al., 2014; Ruiz-Zafra et al., 2013; Smirek, et al., 2016; Su et al., 2011; Xiao et al., 2016; Woznowski et al., 2015). These articles, though being related to health care applications, they do not allude to interoperability standards used in health care, inhibiting the information that is produced from being integrated into the health care service provision. However, what is described in the type of solutions proposed in three references (Damas et al., 2013; Norgall et al., 2012; Pereira et al., 2014), explicitly refer the use of health care standards, considering the specificity of medical devices (e.g. the already established ISO/IEEE 11073 standards-based Continua personal health ecosystem - X73 protocol (Damas et al., 2013)).

The main problem being addressed here is the lack of interoperability among different levels of available technologies which restricts a wider deployment among intermediate and end-users (Pereira et al., 2014), therefore the demand for interoperability among devices is emphasized as most commercially available devices include their own software and communication protocols, which cause serious problems and hinder the application of a standard (Damas et al., 2013). Therefore, the shortfalls of dominating insulated available products are highlighted (Norgall et al., 2012).

To address interoperability, the references reported different communication protocols, including Bluetooth Health Device Profile (HDP) (Pereira et al., 2014) and Open Services Gateway initiative (OSGi), a framework for modular systems that simplifies building, deploying, and managing complex applications. OSGi is complemented with the X73 standard data model, which allowed, for instance, the modelling of the information being gathered (Damas et al., 2013) so that the information resulting from different AAL systems might be integrated (Norgall et al., 2012).

Concerning the type of interoperability computational support, different solutions' designations are reported although they pursue the same objective, which is the aggregation of data from multiple sources to provide them in an integrated way to client applications, namely: architectures (Costa et al., 2014, Ding et al., 2016, Norgall et al., 2013, Ruiz-Zafra et al., 2013; Xiao et al., 2016; Woznowski et al., 2015), gateways (Costa et al., 2014, Denkovski et al, 2015, Ding et al., 2016, Smirek, et al., 2016), middleware (Carr et al., 2013, Kilintzis, et al., 2013) or data hub (Woznowski et al., 2015).

Regarding the validation of the proposed interoperability solution, the following methods are reported: prototype (Ruiz-Zafra et al., 2013; Xiao et al., 2016), case study (Kilintzis, et al., 2013; Pradilla et al, 2015), proof of concept (Costa et al., 2014) and scenarios implementation (Su et al., 2011).

3.2 Interoperability

The results presented and discussed in this section relate to the eight articles (within the 61 references assessed for inclusion) that have been highlighted by this systematic review. These eight articles correspond to end-to-end solutions and they report an effective concern related to the interoperability issue, proposing concrete solutions to ensure that the information produced could be integrated into the health care provision, as summarized in Tables 1, 2 and 3.

Concerning Table 1, it gives a global perspective on how the subject of interoperability is addressed in the references analysed herein, namely the problems to be solved, the interoperability computational support and the proposed technical solutions. In particular, and with regard to the problems addressed in literature, one of them are the difficulties experienced in the sharing of information between personal health devices (PHD) and care providers. This reinforces the need to provide data in proven standard form (Mihaylov et al., 2015), as well as the requirement to ensure the interoperability of various PHD and EHR for continuous self-management of chronic disease patients. However, reliability, interoperability, and scalability between different PHD imply additional costs during the healthcare applications development (Park et al., 2016). Another difficulties that were tackled in literature was the need to integrate data from different eHealth applications, for instance to maximize the access to better therapies and advanced medical devices (Torres Zenteno et al., 2016) as well as the demand for the information sharing between the PHR and the EHR, namely to allow patients to alert health care professionals automatically in real time when necessary (Galligioni et al., 2015).

Considering the references which were subject to a depth analysis (Alberts et al., 2014; Galligioni et al., 2015; Gietzelt et al., 2014; Jung et al., 2014; Lee et al., 2013; Mihaylov et al., 2015; Park et al., 2016; Torres Zenteno et al., 2016), in all the solutions reported the focus is on guaranteeing integration of information, being reported in every case that the resulting information is ready to be integrated in the health care service provision. However, concerning this issue, in some cases this is more explicit and detailed (Lee et al., 2013; Mihaylov et al., 2015; Park et al., 2016; Torres Zenteno et al., 2016) than others (Alberts et al., 2014; Galligioni et al., 2015; Gietzelt et al., 2014; Jung et al., 2014).The integration of information from existing eHealth applications to provide integrated data analysis is a central concern (Alberts et al., 2014).

In particular the demand to ensure interoperability of various PHD and EHR for continuous monitoring and self-management of patients with chronic diseases (Galligioni et al., 2015; Gietzelt et al., 2014; Jung et al., 2014; Lee et al., 2013; Mihaylov et al., 2015; Park et al., 2016; Torres Zenteno et al., 2016).The need to provide sensor data in proven standard form is denoted, as the existing coding systems do not appear to be sufficient to encode the data resulting from a variety of sensors (Gietzelt et al., 2014). Thus, current solutions are considered to lack interoperability and obstruct the establishment of a remote patient monitoring solution market (Mihaylov et al., 2015).

Table 1: Problem addressed, solution and computational support.

ID	Problem addressed	Interoperability computational support	Proposed solutions
Lee et al., 2013	Sharing of information from PHD to care providers.	Middleware	A multi-agent platform that transmits patient clinical data for services based on interoperability standards.
Alberts et al., 2014	Information sharing between eHealth applications.	Middleware	An Integrated eHealth platform that consists of two sub-platforms: the health integration and analysis sub-platform and the communications sub-platform.
Jung et al., 2014	Information sharing between PHR and EHR.	Application	A mHealth application that interfaces with hospital EHR
Gietzelt et al., 2014	Information sharing between eHealth applications.	Architecture	Centralized registration of placeholder-documents together with a decentralized data storage at peoples' home.
Galligioni et al., 2015	Information sharing between PHR and EHR.	Architecture	Web-based, multi-tier architecture with the following components: electronic oncological patient record (eOPR), RFID bar code reader, bar-coded drug labels, disposable RFID bracelets for patients, RFID tags for nurses and a mobile device.
Mihaylov et al., 2015	Sharing of information from PHD.	Application	Design and implementation of an interoperable, intelligent caring home system offering personalized context-aware applications.
Torres Zenteno et al., 2016	Information sharing between eHealth applications.	Platform	A technological platform that supports the predefined process following an interoperability model based on standards and implemented by a service-oriented architecture.
Park et al., 2016	Sharing of information from PHD.	Application	The application for continuous self-management of chronic disease patients that communicates with PHD.

Table 2: Standards being reported.

ID	Standards used for integration
Alberts et al., 2014; Jung et al., 2014; Galligioni et al., 2015	Not reported
Gietzelt et al., 2014	HL7 CDA; HL7 Arden syntax; SNOCAP-HET; MQTT protocol
Lee et al., 2013	HL7 V2.5 Messages
Mihaylov et al., 2015	HL7 V3 CDA; X73
Park et al., 2016	HL7 V2.6; CCR; CCD; X73; HDP
Torres Zenteno et al., 2016	CEN/ISO 13606; IHE

Table 3: Validation.

ID	Validation
Alberts et al., 2014; Jung et al., 2014	Not reported
Galligioni et al., 2015	Laboratory tests
Gietzelt et al., 2014	Future work
Lee et al., 2013	Meaningful use
Mihaylov et al., 2015	Proof of concept
Park et al., 2016	Clinical trial
Torres Zenteno et al., 2016	Simulation

Three references are particularly focused on the need to find more advanced solutions to guarantee interconnection with the EHR as well as to improve, optimize and reduce the time in care in particular pathologies, specifically diabetes (Jung et al., 2014), cancer (Galligioni et al., 2015) and stroke (Torres Zenteno et al., 2016).

In order to address interoperability, the reported solutions include, for instance: an application, the Self-Management mobile PHR that communicates with PHD (e.g. blood pressure monitor or pulse oximeter) that have implemented standard protocols so that stored vital signs are converted to HL7 and are transmitted to PHR (Park et al., 2016); a PHR service, interconnected with mHealth applications that use clinical information from the EHR system of a tertiary hospital to provide services to support patients with chronic diseases, such as diabetes patients (Jung et al., 2014); an architectural approach to integrate Home-Centred Health-Enabling Technology into Regional Health Information Systems, a centralized registration of placeholder-documents with a decentralized data storage at patients' home, using the Systematic Nomenclature for Contexts, Analysis methods and Problems in Health Enabling Technologies (SNOCAP-HET), which is a nomenclature to describe the context of sensor-based measurements in health-enabling technologies (Gietzelt et al., 2014).

Regarding the standards applied in the proposed solutions (Table 2), the choice of HL7 was made in most of the solutions in which standardized solutions are reported (Gietzelt et al., 2014; Lee et al., 2013; Mihaylov et al., 2015; Park et al., 2016): X73 with HL7 V2.6 was used in two cases (Mihaylov et al., 2015; Park et al., 2016), being stated others such as Continuity of Care Document (CCD) and Continuity of Care Record (CCR) (Park et al., 2016), Message Queue Telemetry Transport protocol (MQTT) (Gietzelt et al., 2014) and the CEN/ISO 13606, which has been designed to support the semantic interoperability of the communications between EHR (Torres Zenteno et al., 2016). The standards applied were not reported in three cases (Alberts et al., 2014; Galligioni et al., 2015; Jung et al., 2014).

Finally, concerning the methods used to validate the proposed interoperability solutions (Table 3): in one of the cases, the evaluation was carried out by meaningful use (Lee et al., 2013); in another case, after laboratory tested, it was adopted as a routine in two hospitals, having also been investigated its usability and acceptance within professionals using the system (Galligioni et al., 2015); and in other cases the options were the proof of concept (Mihaylov et al., 2015), simulation (Torres Zenteno et al., 2016) and clinical trial (Park et al., 2016). In the remaining three cases (Alberts et al., 2014; Gietzelt et al., 2014; Jung et al., 2014) the validation methods were not reported.

As an example, a clinical trial was carried out to evaluate the transmission error rate for the measured vital signs transmitted from PHD to a mHealth application and from this to PHR Systems (Park et al., 2016). Another case was the technological platform that was tested with clinician staff, researchers, electronic support staff and actors playing patients role, having been defined several scenarios to test the technological structure, being stated that, after this phase, the platform would be tested with patients suffering from clinical suspicion of stroke (Torres Zenteno et al., 2016).

4 CONCLUSIONS

The first relevant conclusion concerning the retrieved references is that in all the solutions reported the focus is on guaranteeing integration of information, being stated in every case that the resulting information is ready to be integrated in the health care service provision, although in only half of the cases the details concerning this issue, are given more objectively. The integration of information from existing eHealth applications to provide integrated data analysis is a central concern and current solutions are considered to lack interoperability and obstruct the establishment of a remote patient monitoring solution market.

The design and implementation of eHealth applications has not yet reached its potential in terms of impact it can have on health care provision, and interoperability is assumed as being an essential requirement of HIT for the need to integrate patient care into a diversity of settings and care providers. Therefore, EHR systems should not only provide access to patients' clinical information, but also as a true clinical decision support method, have the ability to access and integrate patients' clinical information that is collected throughout their lives.

This is particularly important when dealing with home monitoring of clinical and non-clinical parameters recorded in daily life using various PHD. So that the provision of remote medical services is possible, the PHD should be connected in conjunction with the institutional EHR systems as the occasion demands.

This envisaged scenario is constrained by the lack of implementations based on standardized information models that have same information content and transmission purposes.

The results of the systematic review presented in this article show that interoperability is not the major concern of a significant number of current technological developments. Indeed, it should be emphasized that of the 2778 initial references only 2% (61 references) explicitly mentioned the issue of interoperability. Moreover, within these 61 references assessed for inclusion, only eight corresponded to end-to-end solutions, since the information produced could be integrated into the health care service provision, where interoperability was considered an effective concern. Furthermore, within these eight references only one refers standards specifically related to semantic interoperability, used in a system whose validation is not yet reported.

So, and despite the developments that have been made in this area, there seems to be a lack of integration in the care chain, which may indicate the need to give greater priority to the issue of interoperability of PHD, both semantic and technological.

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