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Digitizing the ECG Workflow A State-of-the-Art Analysis

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Abstract. ECG is one of the most common examinations in hospitals, e.g. for diagnosing cardiovascular diseases - the most frequent cause of death worldwide. Goal of this paper was to identify and describe the typical digitized workflow, IT systems and data formats for ECG in hospitals: A survey on current ECG-data management practices was conducted with four German speaking hospitals. A generic model of ECG data management was drafted. Today, these hospitals do not use DICOM as exchange format nor do they implement IHE profiles such as REWF for the ECG. Reasons include missing IT infrastructure such as Master Patient Index or electronic archive. ECG data management could be improved at different levels, with the chance to reduce error sources and to improves in patient safety. Storage of ECG raw data promises better diagnoses based on big data and machine learning technologies.

Keywords. Interoperability, IHE, ECG data

1. Introduction

Bern University of Applied Sciences (BFH) provides a Medical Informatics Study of 180 ECTS and maintains a medical informatics living lab [1] with a Schiller AT170 ECG and SEMA ECG Software as well as an Orchestra integration server and a Synedra image archive. In a student project the task was to implement a use case for inpatient ECG ordering and results communication (CPOE) in the lab. For the background, we wanted to know which ECG modalities, IT systems and communication standards are today typical for German speaking hospitals. Any obstacles to implementation were to be identified, alternatives highlighted and suggestions for improvement defined.

2. Methods

A questionnaire with 20 questions regarding IT architecture, existing hard- and software as well as details on how ECG recordings and data are managed was distributed to 9 hospitals in Germany, Austria and Switzerland (DACH region). Four hospitals (2 Swiss, 1 German, 1 Austrian) agreed to either provide written feedback or a semi structured telephone interview. Results were analysed and compared and an architectural concept for ECG integration was drafted. In addition, a functional use case was implemented in the BFH medical informatics lab.

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3. Results

Results of the survey have been condensed to an integration architecture (Fig 1). The participating Swiss hospitals A and B had 200 respectively 285 beds. An Austrian hospital with 1500 beds (C) and a German hospital with 1400 beds (D) co-operated. Three hospitals used SAP IS-H, one Nexus Hospis for ADT data <2>. Patients are registered on admission and data is sent using HL7 to the subsystems including the ECG management system (EMS) <1>.

For ECG recording, PC-based systems with LAN connection, ECG printers and mixed functionality systems from Schiller, Custo Med, GE and Siemens are used <3>. Patients are identified by barcode ID, which is either typed or scanned at the modality. ECG printers used in the ED and shock room typically have no connection to the EMS. Instead, recordings are printed to support rapid diagnosing. In one institution, devices with both functionalities are used in the ED. Reports are printed and sent to the EMS.

All hospitals used a proprietary EMS <1> as the "hub" for the entire data exchange between the subsystems of the hospital information system (HIS) and the ECG modalities. Systems in use were Muse (GE), Sema (Schiller) and Customed (Custo Med). Furthermore, all hospitals stored PDF files of the ECG in an archive system <4>. Typically, the EMS converts the proprietary format of modalities into a pdf file and transmits this file, encapsulated in an ORU or MDM message to the archive solution of the institution (Synedra AIM Universal Archive respectively Doxis4/SER group). Depending on the institution, the organizational unit and the EMS, ECG reporting and validation is performed either in the EMS or a clinical workstation (CWS) <5> of the HIS (Kisim/Cistec, Soarian/Cerner, IS-H*Med/SAP, Phoenix/CGM) using front end integration with the archive solution (n=2). One hospital sends ECG PDF files directly to the CWS for temporal storage. One institution transmits ECG measurement data to the CWS via HL7-ORU.

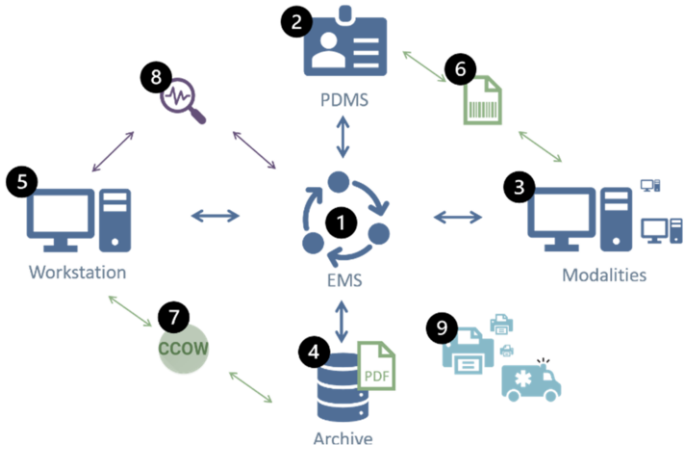

Figure 1. Typical ECG recording architecture within the DACH region. References in brackets

In the two largest institutions, C and D, order communication has been implemented for ECG. These orders are sent to the EMS and a task list can be retrieved on the modality. None of the four hospitals used IHE profiles in the ECG workflow. Reasons comprised

high complexity and implementation effort combined with missing functionality. Neither was DICOM used in any of the hospitals for data exchange or storage.

4. Discussion and conclusion

The IHE initiative provides the profiles Resting ECG Workflow (REWF) and Scheduled Workflow B (SWF.b) for ECG integration [3,4]. REWF, a supplement of the Cardiology Technical Framework (CTF), is still in trial implementation dating back to 2013. It covers three use cases such as scheduled ECG recording using order management, recordings of non-identified patients with subsequent identification and scheduled ECGs recorded offline. Furthermore, the diagnostic process is part of the profile as well. REWF defines specific DICOM tags for transmitting additional ECG data but does not cover long-term or stress ECG. The permanent trial status, missing functionalities, and no update of CTF since 2013 may discourage institutions from implementing REWF.

SWF.b was included in the Radiology Technical Framework (RTF) in its latest revision in 2020. It defines generic use cases including order management and fulfilment of identified and unidentified patients as well as various exceptions and corrections. In contrast to REWF, diagnosis and display of ECG recordings are not part of SWF.b but defined in other RTF profiles and no ECG-specific DICOM tags are defined. In comparison, SWF.b seems to be the better choice: it covers many use cases whose implementation in REWF would not be possible, e.g., update of obsolete /missing patient master data. The generic specification of SWF.b profile should enable long-term and stress ECGs in future.

In our survey, none of the four hospitals used DICOM or IHE for the digital ECG workflow. Instead, data exchange is based upon HL7 and PDF files. Although this is a small sample, other studies suggest that in addition important systems such as MPI or digital archives may be unavailable in many hospitals in the DACH region [2]. Besides, respondents in our survey saw no added value in the use of IHE and DICOM compared to the PDF based solution. Thus, for SWF.b the "Results Distribution" profile would be needed to support export of the examination results as a PDF or CDA document, encapsulated in an HL7 ORU message.

Stamenov et al. identify four common ECG data formats [5]. Plain pdf has the disadvantage to lose most of the acquired numerical data [6]. An effective way to preserve raw data while having minimal impact on existing processes is provided by Sassi et al. with the PDF-ECG format. With only minimal changes to the workflow and a file size increase of ~27% on average, this format enables the preservation of the original measurement data [7-9].

Based on our findings, we would like to present the following recommendations: First, the missing IT infrastructure components that hinder the implementation of IHE profiles should be identified and measures to reduce or remove these barriers defined. In Germany, such investments could be financed based on the Krankenhauszukunftsgesetz, a state-funded investment program to promote digitalization of hospitals [10]. For institutions that want to increase the data quality and availability of ECG recordings or are considering changing their system(s), the following options with increasing complexity are available:

- Implementation of the PDF-ECG format with minimal impact on current processes [9].

- Review of the current infrastructure and realization of missing components such as MPI, electronic archive and order communication [2].
- Parallel implementation of DICOM data exchange based on the SWF.b profile. A good overview of this is provided in [11,12].
- Full implementation of the SWF.b profile at process and semantic level.

The preservation of ECG raw data and measurements provides various future analysis options, e.g., data mining and machine learning, which may generate new medical knowledge and better diagnostic and treatment options [13-15].

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