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Arthur LAURIOT DIT PREVOST[a,b], Raphaël BENTEGEAC[a], Audrey DEQUESNES[c], Adrien BILLIAU[a], Emmanuel BAUDELET[a], Rémi LEGLEYE[a], Marc-Antoine HUBAUT[e], Michel CASSAGNOU[a], Philippe PUECH[d], Rémi BESSON[b], Emmanuel CHAZARD[a]

[a] Univ. Lille, CHU Lille, CERIM ULR 2694 METRICS, F-59000 Lille, France
[b] CHU Lille, Clinique de Chirurgie et Orthopédie de l'Enfant, F-59000 Lille, France
[c] Univ. Lille, UMR 8026 CERAPS, F-59000 Lille, France
[d] Univ. Lille, Inserm, CHU Lille, U1189 - ONCO-THAI, F-59000 Lille, France
[e] CHU Lille, Médecine Nucléaire et Imagerie Fonctionnelle Salengro, F-59000, France

Abstract

*Although paper-based transmission of medical information might seem outdated, it has proven efficient, and remains structurally safe from massive data leaks. As part of the ICIPEMIR project for improving medical imaging report, we explored the idea of structured data storage within a medical report, by embedding the data themselves in a QR-Code (and no URL-to-the-data). Three different datasets from ICIPEMIR were serialized, then encoded in a QR-Code. We compared 4 compression algorithms to reduce file size before QR-Encoding. YAML was the most concise format (character sparing), and allowed for embedding of a 2633-character serialized file within a QR-Code. The best compression rate was obtained with gzip, with a compression ratio of 2.32 in 15.7ms. Data were easily extracted and decompressed from a digital QR-Code using a simple command line. YAML file was also successfully recovered from the printed QR-Code with both Android and iOS smartphone. Minimal detected size was 3*3cm.*

Keywords:

Health Information Exchange; Data Collection; Data Compression

Introduction

While transmission of medical information and data sharing is a key point for quality patient care, efficient healthcare system and clinical research, protection of medical data remains paramount [1]. Also interoperability (on technical, syntactic and semantic sides) is challenging when dealing with medical data, because of the variety of Electronic Health Record (EHR) software, the absence of widely shared common infrastructure for sharing health data, and the high sensitivity of clinical data [2].

With growing interest in data warehousing and data reuse, focus has been made on the quality of the data, and its processing with important concepts as feature extraction [3].

At one end, it is necessary to research and develop cutting-edge technology, and common infrastructures to improve interoperability and digital medicine [2]. We place our work at the other end, and intend to use the "low-tech" communication channel that is the paper-based transmission, and harness the potential contributions of QR-Codes to the challenge of interoperability.

QR-Code was initially designed for traceability in industrial process and stock management [4]. In the public domain, it is mainly used to guide the user to an embedded URL, and save a time-consuming typing process to the user. QR-Code have few specific uses in health for now, but seems to gaining interest. A PubMed query (http://pubmed.gov) on the "QR-Code" term returned only 247 results, of which 135 were published from 2019 to 2021. Among the few medical usage of QR-Codes, we found mostly informational purpose with an URL to an informational website for patients [5] or healthcare teams [6], and educational purpose by allowing interaction during courses or additional material, with an improvement in engagement from students [7].

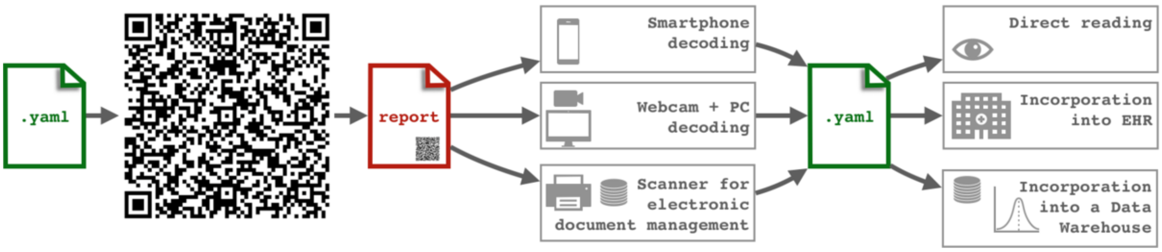

Figure 1. Paper-based transmission of structured medical data: possible workflow

We believe the traditional paper-based transmission is safe and effective for transmitting medical information. We describe in this paper a possible way of transmitting structured data, by embedding the data itself in a QR-Code, printed with the medical report (Figure 1).

Methods

Data sources: the ICIPEMIR Project

We previously set the ICIPEMIR project (Improving the completeness, interoperability and patient explanations of medical imaging reports), as a method to improve medical imaging report [8]. In this workflow, the physician fills-in a form with predefined items for the intended exam, hence creating structured data. From this input data is generated a medical report composed of (1) a text report, (2) a graphical display (based on the result/values), and (3) a QR-Code embedding the data itself (Figure 2).

One of the key points of this project is to determine mandatory items for each type of medical imaging report, in the form of a dataset (JSON Schema for "instructions of use", and YAML for "dataset for one occurrence"). For each imaging exam, this requires a dedicated bibliographic review, screening of guidelines, and expert validation [8]. We are currently working on different medical imaging exam, to determine their mandatory items.

In this paper, we use datasets of 3 imaging exams, determined in our previous work. Files from ICIPEMIR project are available online at https://github.com/arthurldp/medical_imaging_report.

Structured datasets, and serialization format

These datasets were serialized using the YAML format, which is a JSON superset, and is both human-friendly and character-sparing. Unlike simpler formats such as "comma separated values", YAML allows for complex cardinality that can occur in medical data such as one-to-many (Figure 3).

We compared the size of different serialization formats (YAML, XML, JSON) for our three datasets, using the Unix built-in word count utility.

```yaml
%YAML 1.2
---
example_dataset:
  patient_name: Doe
  patient_birth: 1901-01-01
  fever: false
  lithiasis:
    lateralisation: [Left, Right, Left]
    size: [7, 5, 6]
```

Figure 3. Example of YAML dataset, with a one-to-many cardinality

QR-Encoding

QR-Codes were generated from YAML files using the open-source Unix Libqrencode library (Table 3). Error correction level was set to low (7% of data bytes can be restored), and output format was PNG.

Compression algorithms

We selected 4 different open-source compression algorithm/library (xz, zip, gzip and bzip2), and compared them on time of execution and compression ratio. The average time of processing was calculated for the whole sequence (Compression-Encoding-Decoding-Decompression) on 10 iterations. Compression ratio was calculated as (uncompressed size) / (compressed size).

Detection and decoding

We tested QR-Code decoding on the larger YAML file. Digital QR-Code decoding was obtained with Zbar library (Table 3). The QR-Code was also printed in decreasing size, from 15*15cm to 1*1cm. Two models of smartphone were used, one Android-based smartphone (Fairphone 3+) and one iOs-based smartphone (iPhone 8). Since Android native camera did not support QR-Codes scanning, we used one of the many free QR-Code Scanning application available.

Legal analysis

We asked researchers from a team specialized in health law to conduct a legal analysis of our solution with respect to French and European regulation.

Results

Structured datasets, and serialization format

For each of the three datasets, YAML serialization format required less characters (including spaces), than XML (respectively 2.45, 2.21 and 1.74 times more) or JSON format (respectively 1.27, 1.70 and 1.73 times more; Table 1).

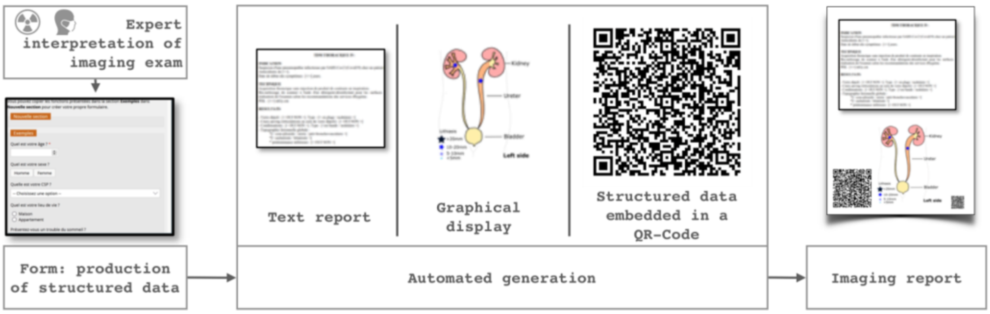

Figure 2. ICIPEMIR workflow for automated production of imaging report.

Table 1. Dataset character count depending on serialization format.

Dataset	Format	Line count	Word count	Character count
Urolithiasis	YAML	77	245	2633
	XML	140	180	6438
	JSON	200	310	3356
Renal scan	YAML	50	180	1976
	XML	88	139	4367
	JSON	124	219	3356
Cystography	YAML	46	121	1401
	XML	56	76	2432
	JSON	80	145	2417

*Figure 4. Example of QR-Code embedding raw YAML file (without compression) for urolithiasis. 173*173 squares.*

QR-Encoding

Maximum character storage capacity of a QR-Code is set at 4,296 for alphanumeric values (with an error correction level set to "low")[4]. In our situation, alphanumeric format did not allow for data serialization, because of square brackets, underscores, and lower-case. Therefore we had to use binary format (e.g. ISO 8859-1), leading to a maximum character storage of 2,953 [4]. QR-Codes were easily generated for each dataset with a simple command line (Table 3).

Compression algorithms

Compression-Encoding-Decoding-Decompression process was fast and efficient. The best performance was obtained with gzip, with a 2.32 compression ratio in 15.7 ms. Also, the QR-Code obtained was accordingly smaller than the one produced from raw file (Table 2, Figure 4, and Figure 5).

Table 2. Comparison of compression algorithms, on YAML file for urolithiasis.

Compression	File Size (bytes)	Compression ratio	Time (ms)	Qrcode side (squares)
None (raw)	2,633	NA	31.6	173
xz	1,196	2.20	21.1	117
zip	1,279	2.06	21.7	121
gzip	1,137	2.32	15.7	113
bzip2	1,167	2.26	18.8	113

Detection and decoding

Digital decoding of the QR-Code was successful for any QR-Code and any compression format using a one-line command line (See example for gzip compression in Table 3).

Table 3. Unix command lines

Action	Command line
Compression & QR-Encode	`gzip input.yaml -k9 -c | qrencode -8 -o qrcode.png`
QR-Decode & Decompression	`zbarimg --raw --quiet --oneshot -Sbinary qrcode.png | zcat > output.yaml`

*Figure 5. Example of QR-Code embedding gzip-compressed YAML file for urolothiasis.113*113 squares.*

As for manual decoding, the larger QR-Code (urolithiasis, 2,633 characters including spaces) was successfully decoded using both type of smartphones, with native camera on the iOS device, and using any free app for QR-Code scanning with the Android device (Figure 4). When we decreased the printed size of the QR-Code, it was still decoded from a 15*15cm version down to a 3*3cm version. Decoding was impossible for a 2*2cm printed QR-Code of 2,633 characters.

The QR-Code embedding the compressed YAML could be detected but could not be decoded by the smartphones, because of the lack of built-in decompression algorithm (Figure 5).

Legal analysis

The transmission of medical information must comply with certain legal requirements, relating to professional secrecy and the protection of personal data. At the European level, technologies related to telemedicine and the transmission of information between healthcare professionals are not subject to a harmonized framework [9], but must take into account the 2011/24/EU Directive on cross-border healthcare, the Directives on information and telecommunications (Directive 2000/31/EC on electronic commerce and Directive 2002/58/EC or e-Privacy) [10], and the EU Regulation 2016/679 on the protection of personal data. In our case, there is no electronic transmission, which simplifies the legal framework related to this method of medical information. The sensitive data concerned by the QR code can be transmitted to another professional on the legal basis of consent, as allowed by Article 9 of the GDPR.

At national level, the implementation of telemedicine in the broad sense, and therefore the transmission of data from one medical practitioner to another, may be subject to various provisions. In France, for the treatment of a patient, physicians or medical teams who collaborate in the diagnosis or treatment of a patient are obliged to keep each other informed [11]. With the patient's consent, or on his or her initiative, the health professional transmits to the other professionals whom the patient intends to consult during his or her care the documents useful for the continuity of care [12]. Continuity of care is a duty of the medical practitioner [13].

Discussion

Our approach consists in "re-materializing" the transfer of information, in particular from medical imaging reports, by inscribing this information directly in a QR-code printed on the same paper sheet as the medical report itself (Figure 2). The first objective was to determine a serialization format, that was character sparing, and human-friendly, so it would be readable in its raw form by any physician, and possibly by the patient. YAML format was optimal for this purpose, and allowed one-to-many cardinality, which is often mandatory in medical data. The second objective was to fit all the data in the QR-Code, and we realized the actual character limit was lower than the "4,000 character" limit usually associated with the QR-Code in people's mind. When using characters from ISO 8859-1, the maximum storage dropped to 2,953 [4]. This constraint led us to consider the use of compression algorithm to lower the size of the data file, and therefore the size of the QR-Code. On the four compression algorithms tested, gzip obtained the higher compression ratio, lowering the file size from 2,633 to 1,137 bytes.

Structured datasets were successfully recovered from the QR-Code, either on a digital version of the QR-Code with a simple command line and an open-source library, or with Android-based and iOs-based smartphones. When using compression to reduce the QR-Code size, smartphones could still detect the QR-Code but the data was impossible to recover, because of the lack of built-in decompression algorithm.

One important point of our study is that we used real-life datasets for each medical imaging exam, determined by an academic work, with a bibliographic review for each, and subsequent validation by clinical experts [8]. We used only open-source libraries for compression, QR-Code production or decoding, in this manner, any software engineer, or physician interested in embedding structured data in a medical report, is free to use this concept in his/her own way.

From a legal point of view, it is likely that, although it is not described for the transmission of medical records, this mode of communication will be well accepted, given that the QR code on the paper prescription is the mean chosen to initiate e-prescription throughout the country in 2020.

The key to implementation of this system remains patient information and consent. It is essential that the patient receives clear information, which the health professional must ensure is understood, so that his or her consent is free and informed. Then, as with a traditional paper report, the patient will be able to access the information contained in the QR code and decide to pass it on in all awareness to the professionals he/she will consult.

One of the main ideas of the ICIPEMIR project is to capture and structure the medical information at its origin (upstream), and to keep it "embedded" in the medical report document. Creating a centralized database for every institution performing these exams seems highly challenging, if not hopeless. For this reason, we chose to store this data physically on the paper sheet document, in order to allow for a secondary extraction in electronic health records and data warehouse. Documents would be scanned for the presence of a QR-Code, and the embedded data would be extracted for data reuse (Figure 1). Since the data is to be structured upstream by the radiologist, we believe that the definition of the mandatory fields is a crucial point to hope for a useful reuse of the data, in the same way the "Feature Extraction" is a crucial step of the data-reuse process [3].

Since the QR-Code is limited in character count, we do not believe this concept could be generalized to any type of medical data.

To the best of our knowledge, we found only three papers with raw data embedded in the QR-Code, as opposed to the usual URL-to-the-data content. Lin et al. used printed QR-Code embedding medical information on prescription generated in the hospital destined to surrounding pharmacies computer system. They did not specify a serialization format [14]. Nakayama and Shimokawa successfully embedded a short portion of an electrocardiogram in a QR-Code (from two to four beats, depending on the number of leads), but the presentation did not match the cardiologist expectations [15]. Mao et al. split a file containing medical data, then embedded the split data on successive QR-Codes frames, that were displayed in a streaming video. User would capture the stream with a smartphone to recover the original data from the QR-Codes frames [16]. In our work, the embedded data is meant to be stored in a paper or a pdf file for a digital version (portable document format), and we use a standard format for serialization.

Using a compression algorithm could prevent accidental decoding of the medical data by an undesired person without a specific QR-Code reading app with the proper decompression algorithm. But it would not resist to a malicious individual wishing to collect these data. On the other hand, we believe that any malicious individual having a medical report in their hands, already has access to the information, whether it is on a QR-Code or in a text report.

Through the ICIPEMIR project, we intend to spread the production of "enhanced" medical report, embedding structured data for selected imaging report. We are currently developing a software for medical report production, and a prototype of smartphone app for QR-Code scanning and decompression of the files.

Further works will focus on the adhesion of physician and patients to this method of production for medical imaging report, and feasibility of in-real-life importation of such data by the patient, the physician, and the clinical researcher. If this method of data transmission proves useful, we will consider other types of medical information to transmit on a QR-Code for secondary integration (e.g. laboratory results, medical summary of a patient, list of patient's current medications).

Conclusions

We showed here a proof of concept of paper-based transmission of structured medical data, using QR-Code. Although the application of this concept may not fit to every type of medical data, nor any type of medical report, we believe it could help integration of some medical information accessible to a standardization of its such as medical imaging.

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Address for correspondence

Dr Arthur LAURIOT DIT PREVOST, Clinique de Chirurgie et Orthopédie de l'Enfant, CHU Lille - Hôpital Jeanne de Flandre, Avenue Eugène Avinée, F-59000 Lille, France; E-mail: arthur.lauriotditprevost(at)chru-lille.fr.