Journal of Network and Computer Applications 117 (2018) 17–29

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

A clinical decision support system to increase appropriateness of diagnostic imaging prescriptions

Domenico Calcaterra[a], Giuseppe Di Modica[a], Orazio Tomarchio[a,*], Placido Romeo[b]

[a] Department of Electrical, Electronic and Computer Engineering, University of Catania, Viale A. Doria, 6, 95125 Catania, Italy
[b] Radiology Department, Taormina Hospital, ASP Messina, C.da Sirina, 98039 Taormina, Italy

ARTICLE INFO

Keywords:
Clinical decision support systems
Diagnostic imaging
Rule-based systems
Clinical guidelines

ABSTRACT

The use of diagnostic imaging procedures has significantly risen in the last decade. However, several studies estimate that a substantial number of requests for diagnostic imaging are inappropriate, leading to unnecessary exposure to radiation, increased wait times, and ineffective use of health care resources. Although many radiology societies from all over the world have published imaging referral guidelines which general practitioners should follow when ordering imaging examinations, the uptake by practitioners is still far from being considered realized nor are the guidelines well integrated in the clinical workflows.

In this paper we present a Clinical Decision Support System (CDSS) that provides physicians with real-time guidance to prescribe patients appropriate diagnostic imaging tests. The CDDS embeds the imaging referral guidelines in the form of coded rules that help the physicians in their prescription work. It also provides tools that promote the collaboration among physicians and radiologists in the diagnostic process. The work has been carried out in a recently ended research project which investigated the phenomenon of inappropriate imaging prescribing in Sicily, Italy. Results from a field experimentation show a high potential impact of the CDSS in reducing inappropriate imaging.

1. Introduction

Medical expenses which all governments have to bear in order to grant their citizens access to diagnostic imaging services have a great impact on the overall public health care expenditure. In most cases, the general practitioner (GP) is in charge of the prescription of imaging investigations, thus defining the most appropriate diagnostic route for specific clinical questions posed by patients.

Although a diagnostic imaging (DI) process is aimed to shed light on the GP's suspected diagnosis after visiting or interviewing a patient, it is not uncommon that the prescribed examination turns to be "inappropriate", i.e., it provides no new information at all for the initially suspected diagnosis to be either supported or contradicted.

Inappropriate DI examinations lead to: a) a waste in economic resources, b) a growth in the average waiting times for accessing DI services, c) a useless and harmful to health exposition to radiations. In order to tackle these drawbacks, many governments have come up with specific DI guidelines, which provide the GP with useful information for the selection of the most appropriate examination according to the patient's specific clinical case. Such guidelines have been crafted by panels of medical experts, and are the outcome of numerous scientific experiments and best practices in the DI field (European Commission, 2014; European Commission, 2000; Royal College of Radiologists, 2012; Société Française de Radiologie, 2005; AGENAS, 2004).

This paper is an extension of the work presented in (Calcaterra et al., 2016; Placido et al., 2017) as part of the COLLABORADI project, an Italian EU-funded research project whose main objective was to code the Italian DI guidelines into "rules", and implement an electronic service for the GP to easily get advices on the most appropriate DI examination to prescribe in response to specific clinical questions. The proposed instrument does not deprive the GP of their role in the prescription process. The GP still has the final say in the matter.

A complementary albeit not minor goal of the COLLABORADI project is the definition of a collaboration platform (hence the project's name COLLABORA-tive DI-agnosis) on which physicians (GP and radiologists) may virtually meet and cooperate. Thus, a bi-directional communication channel is set up through which know-how, best practices and scientific advices may be shared and used as scientific grounds for medical decisions to be taken. However, this aspect falls outside the scope of this paper, therefore it will not be discussed in

* Corresponding author.
E-mail addresses: Domenico.Calcaterra@dieei.unict.it (D. Calcaterra), Giuseppe.DiModica@dieei.unict.it (G. Di Modica), Orazio.Tomarchio@dieei.unict.it (O. Tomarchio), promeo@sirm.org (P. Romeo).

https://doi.org/10.1016/j.jnca.2018.05.011
Received 31 December 2017; Received in revised form 31 March 2018; Accepted 9 May 2018
Available online 17 May 2018
1084-8045/

detail. Instead, focus is put on a) the definition of a data structure for the coding of the Diagnostic Imaging Referral Guidelines (DIRGs) into an electronic format and b) the implementation of a software that leverages on a rule engine in order to derive the most appropriate DI exam which best responds to a clinical question. The rule approach gives the system a high degree of maintainability. In fact, even though modifications are carried out on medical guidelines according to technological advances and new scientific findings, they may be easily accommodated by just updating the rules, without affecting the software framework at all.

The paper structure is organised as follows. In Section 2 a survey of literature is reported. Section 3 analyses the DI guidelines. Section 4 introduces the data model for the DI guidelines and their coding into machine understandable rules. In Section 5 the work carried out in the COLLABORADI project is described: in particular, we present the design and implementation of a clinical decision support system (CDSS) for the prescription of DI examinations, and report practical examples of the system behaviour. Section 6 discusses the findings from the conducted experiments. Concluding remarks are reported in Section 7. Finally Appendix A describes the system behaviour from the user's point of view, reporting the screenshots of the system throughout an entire usage session.

2. Related work

In the past twenty years individual initiatives have been launched by many national governments to promote the adoption of diagnostic imaging guidelines in the concerned clinical contexts. Many European Member States have adopted national imaging referral guidelines for clinical imaging principally to support the referring practitioner in selecting and justifying radiological procedures. Also, the majority of member states have put legal requirements on those guidelines that include radiation doses (European Commission, 2014). The Royal College of Radiologists (RCR) in 1989 was the first European association to publish imaging referral guidelines titled “Making the best use of a department of clinical radiology” (Royal College of Radiologists, 2012). Based on a later RCR's publication, in 2000 the European Commission issued the “Referral Guidelines for Imaging” (European Commission, 2000), with the intent of providing guidelines to help practitioners to make the best use of a department of clinical radiology. The Italian Society of Medical Radiology (SIRM) has been promoting national guidelines as well (AGENAS, 2004) (SIRM, 2014). A brief analysis of such guidelines is provided in Section 3.

In the aim of defining national guidelines for the appropriate use of imaging technologies, in 1993 the American College of Radiology (ACR) formally proposed the “ACR Appropriateness Criteria” (Cascade, 2000). The criteria are meant to be evidence-based guidelines to assist referring physicians and other health care providers in making the most appropriate imaging or treatment decision for a specific clinical condition.

In order to be *appropriate*, a requested diagnostic imaging examination must be able to answer, to the best of knowledge, to a clinical question. This actually quite complicated concept is the focus of the current thinking on health management systems and, in particular, on the Italian one (Martino et al., 2010). Performing inappropriate examinations primarily involves ethical issues, because it strongly impacts on the availability of sophisticated machinery creating the unfortunate phenomenon of *waiting lists* and reducing the number of examinations for those who have a real need (Sardanelli et al., 2005); but it also involves economic issues since it wastes resources that could be more efficiently allocated (Van Breuseghem and Geusens, 2006).

To give an economic dimension of the phenomenon of inappropriate prescriptions, which according to the recent literature (Cristofaro et al., 2012; Rao et al., 2002; Levy et al., 2006) has an incidence greater than 40%, within the COLLABORADI project we analysed the datum of Sicily as a region. In this region during the year 2013, within the diagnostic imaging and nuclear medicine, the following outpatient services have been performed (cumulatively): more than 2 million examinations, for a total cost of about € 150 million. A 10% improvement of the **appropriateness** in performing DI examinations might represent a saving for the Sicilian Regional Sanitary System of almost € 15 million. For the reasons outlined above, in all ministerial and regional health departments' planning documents the improvement of appropriateness is a prominent goal to reach; however, there is no indication on the instruments through which such a goal should be attained.

In addition, most of DI examinations involve ionising radiation exposure, and this determines a risk of non-negligible costs in terms of health for patients, which would further increase the National Sanitary System's expense (Triantopoulou et al., 2005). In Italy there is also the risk of administrative sanctions for GPs and radiologists who do not follow the principles of justification and optimization. While the US is witnessing a widespread adoption of CDSS in the imaging prescription, there is no such an initiative in any of the European Community states. There are some experiences, such as the one described in (Marshall et al., 2011), aimed at improving through an e-learning platform the skill of medical students in the choice of the most appropriate DI examination.

Within this context, the COLLABORADI project aims to create a software system that collaboratively helps the GP to formulate the most appropriate DI examination to answer to a clinical question, taking into account a) the most up-to-date DIRGs (SIRM, 2014) and b) some priority classes defined in the RAO guidelines which are regional guidelines already in force in Sicily. To the best of our knowledge, the COLLABORADI project is the first in Europe to deliver an electronic service which provides clinical support to the DI prescription process. Also, it brings some innovative aspects in the management of a prescription route, as it emphasises the role of an expert radiologist in the path of appropriateness evaluation, and introduces the figure of a controller who is responsible for activating the reimbursement of benefits only if the DI prescription is deemed appropriate.

An approach similar to the one followed by the COLLABORADI project was proposed by ESR iGuide (Summary of the proceedings of the international forum 2016, 2017). A comparative analysis between the COLLABORADI platform and the ESR iGuide is reported in Section 5.3.

In the rest of the paper we discuss the architecture and the implementation details of the CDSS developed within the COLLABORADI project, as well as the experiments performed to prove the viability of the approach.

3. Review of the Italian DIRGs

The Diagnostic Imaging Referral Guidelines (DIRGs) (AGENAS, 2004) are the result of the initiative sponsored by the Italian National Agency for Regional Healthcare (AGENAS), aimed at establishing appropriate guidelines for all health professionals entitled to refer patients for imaging. Editors focused their attention on three main aspects: a) exam justification (or the so-called “exam appropriateness”), b) radiological protection and c) reduction of public spending. A useful investigation is one in which the result - be it positive or negative - will alter management or add confidence to the clinician's diagnosis. A significant number of radiological investigations do not fulfil these aims and may lead to both a wasteful use of radiology and an unnecessarily increased patient irradiation. The DIRGs are broken down into thirteen sections:

a) HEAD, b) NECK, c) SPINE, d) MUSCULOSKELETAL SYSTEM, e) CARDIOVASCULAR SYSTEM, f) THORACIC SYSTEM, g) GASTROINTESTINAL SYSTEM, h) UROLOGICAL, ADRENAL AND GENITOURINARY SYSTEMS, i) OBSTETRICS AND GYNECOLOGY, j) BREAST DISEASE, k) TRAUMA, l) CANCER, m) PAEDIATRICS.

Each set of guidelines is composed of five columns. The first column sets the clinical situation for requesting an examination; the second lists