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COMPUTER APPLICATIONS

COLLABORADI: a rule-based diagnostic imaging prescription system to help the general practitioner to choose the most appropriate radiological imaging procedures

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Abstract Significant advances in medical imaging have been made in the past decades, enabling physicians to reach high precision in diagnosing patients' diseases by means of sophisticated imaging tools. However, the use of sophisticated tools is limited by the high costs and, in some cases, by the utilization of ionizing radiation, which have both great impact on the economy of a nation and on citizens' health, respectively. Guidelines have been published among countries to provide physicians with structured rules to be followed to suggest the correct imaging technique, suiting better the diagnostic question and avoiding inappropriate imaging requests. The COLLABORADI is a research project that addressed the phenomenon of inappropriate imaging prescriptions in Sicily (Italy) and proposed the design and implementation of a clinical decision support system to help physicians to set up the most appropriate diagnostic route for their patients. The aim of this paper is to describe the characteristics of the COLLABORADI software and its potential impact in diminishing inappropriate imaging.

Keywords Clinical guidelines · Diagnostic Imaging · Rule-based system · Support decision system

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Introduction

There are widespread concerns that the costs of health care all over the world are rising at unsustainable rates. Prior studies have demonstrated that 30% of resources spent on health care in Western countries do not improve the health of patients [1]. One of the major reasons of the rising costs is the increasing use of radiology imaging procedures, particularly advanced imaging techniques such as computed tomography (CT) scans and magnetic resonance imaging (MRI).

Most authorities agree that cutting down on inappropriate use of diagnostic procedures could improve quality, save costs and protect patients from undue risks and inconveniences. Therefore guidelines, diagnostic algorithms and appropriateness criteria have been established [2–4]. In 2004, the Italian National Agency for Regional Health Services introduced "Guidelines for diagnostic imaging" in congruence to the guidelines applied by other member states of the European Union and Canada, focusing attention on three key issues: investigation appropriateness, radiation protection and expenditure containment. However, guidelines are not always straightforward and easy to follow; therefore, incorporation of appropriateness criteria into clinical practice is low, mainly reflecting the lack of formal training [5, 6].

Table 1 DIRGs for salivary obstruction

(b) NECK (for cervical spine see Section c [SPINE])				
Clinical problem	Investigation	Recommendation	Comment	Dose
	US sialogram	Indicated (C)		0 I
Salivary obstruction	XR	Not indicated routinely (C)	Except in calculus in floor of mouth, where XR may be all that is required	I

The high percentage of radiological examinations, not meeting appropriateness criteria, suggests a need for decision support to help primary care physicians improve the management of patients, by choosing the correct diagnostic imaging procedure, which is most appropriate [7].

COLLABORADI is an Italian EU-funded research project coding the Italian diagnostic imaging (DI) guidelines into evidence-based rules. It is a clinical decision support for general practitioners (GP) providing a method for incorporation of the Italian DI guidelines into computerized ordering and electronic health record systems. Furthermore, the software may be easily implemented according to the further modifications of such guidelines, which may evolve eventually according to technological advances.

The paper aims to preliminarily illustrate COLLABORADI, an electronic software coding data for the diagnostic imaging referral guidelines (DIRGs). To the best of our knowledge, COLLABORADI is the first decision support introduced in Italy and, in our opinion, it could be a useful example for the management of other health-care systems.

National and international guidelines for clinical imaging: an overview

In the past 20 years, many efforts have been made to promote the adoption of national and international guidelines for clinical imaging, principally to support the GP in selecting and justifying radiological procedures. The use of radiological examinations has been regulated by the introduction of guidelines, all valid among the European Union (EU) countries [8]. The Royal College of Radiologists (RCR) in 1989 was the first European association to publish imaging referral guidelines [9]. Furthermore, clinical decision support systems (CDSS) [10] have been implemented to give real-time feedback to providers ordering imaging tests, including information on test appropriateness for specific indications. The Italian DIRGs are the results of the initiative sponsored by the Italian National Agency for Regional Healthcare (AGENAS), aimed to establish appropriate guidelines for all health professionals entitled to refer patients for imaging [11]. The authors focused their attention on three main aspects: (a) examination appropriateness, (b) radiological protection and (c) reduction of public spending.

The DIRGs comprises 13 sections, listed as follows: (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) pediatrics. Table 1 shows a guideline sample from the DIRGs.

The recommendations are designated as follows: (a) the investigation most likely contributing to clinical diagnosis and management; (b) specialized investigation (frequently complex, time-consuming or resource-intensive investigations, usually only requested by medical doctors who have the relevant clinical expertise to evaluate the clinical findings and act on the imaging results); (c) not indicated initially (includes situations where experience shows that the clinical problem usually resolves with time, and where deferring the study is suggested); (d) not indicated routinely (non-routine studies to be carried out if a physician provides cogent reasons or if the radiologist feels the examination represents an appropriate way of furthering the diagnosis and management of the patient); (e) not indicated (examinations that will usually not contribute to the management of the patient). The use of radiological investigations is closely related to radiation risks, considering that even small radiation exposure can be dangerous. The estimate of the total risk of stochastic effects (cancer, leukemia, hereditary effects) resulting from exposure to radiation is performed using the effective dose, which is measured in sievert (Sv). Table 2 shows the typical effective doses of ionizing radiation from common imaging procedures.

COLLABORADI: design and implementation

The approach followed by the COLLABORADI system's designers was to build a software decision support system that, by leveraging on DIRG guidelines coded as "rules", could be used by the general practitioners (GP) to get advices on the most appropriate DI examination to prescribe in response to specific clinical questions. The proposed tool does not substitute the physician in the prescription process;

Table 2 Effective dose classification

Class	Typical effective dose (mSv)	Examples
0	0	US, MRI
I	<1	CXR, limb XR, pelvis XR, cervical spine XR
II	1–5	XR, IVU, lumbar spine XR, NM (e.g., skeletal scintigram), CT head and neck
III	5–10	CT chest and abdomen, NM (e.g., cardiac)
IV	>10	Some NM studies (e.g., PET)

rather, when adequately stimulated by the GP, it provides them with hints on the most appropriate diagnostic workup. The final decision is of course left to the GP.

The COLLABORADI project focuses on the design and implementation of: a data structure to model the main concepts of the DIRGs; a set of formal rules to capture and

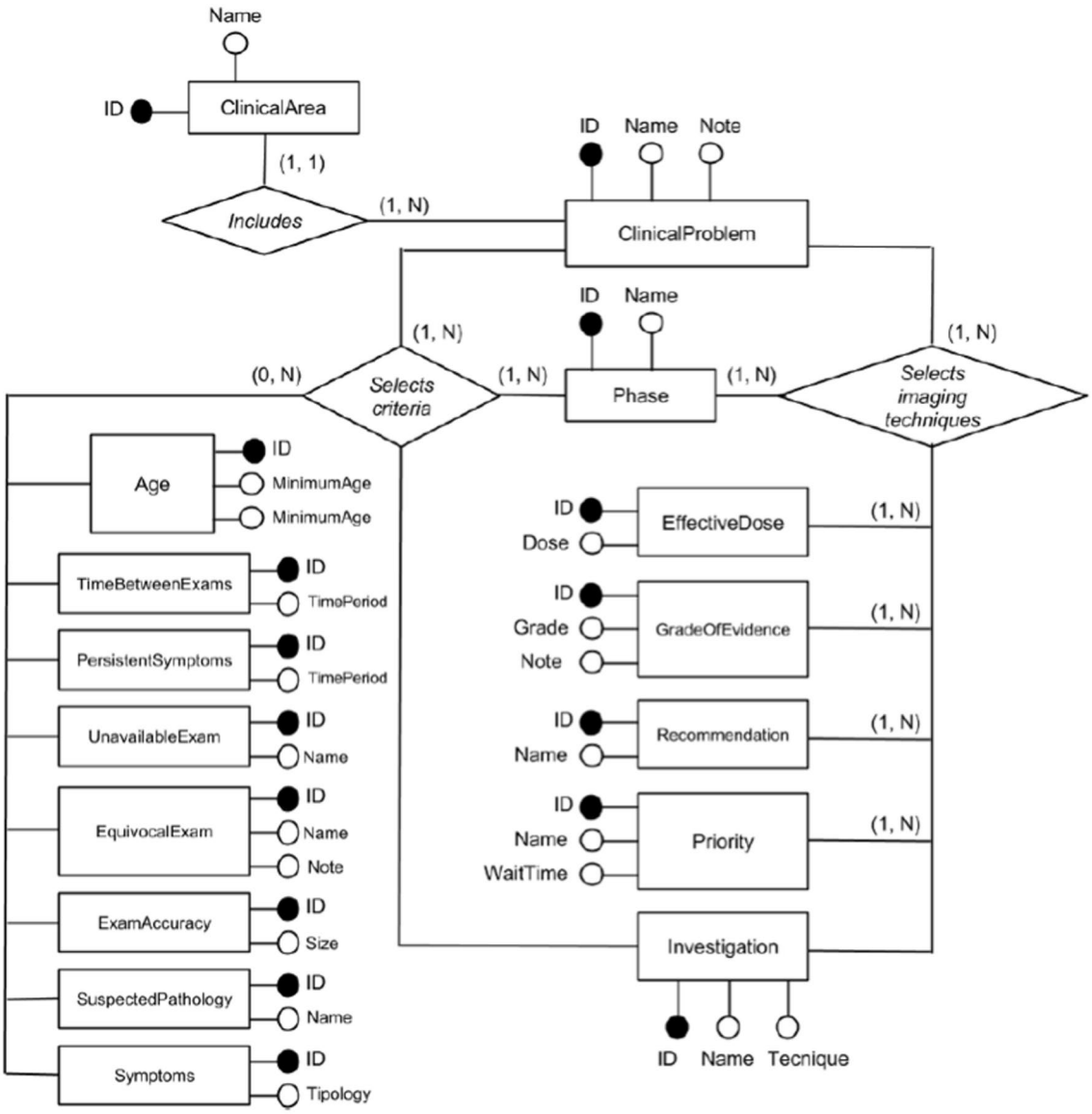


Fig. 1 The DIRG data model in the E–R form

model the guidelines contained in the DIRGs; a Web application that leverages on the implemented rules to guide physicians in the DI prescription. The DIRGs data model is summarized in Fig. 1.

As mentioned before, the DIRGs are divided into 13 sections, each containing clinical cases for which a specific imaging investigation is provided. Every investigation comes with its recommendation, its grade of evidence and its effective dose. *ClinicalProblem* and *ClinicalArea* represent the medical situation for which radiological examinations are requested for and the medical area to which they belong. The *Phase* defines the scope of the clinical problem under examination (diagnosis, follow-up). Clinical problem/phase pairs allow every possible investigation, along with their recommendation, grade of evidence, effective dose and time priority [12–14].

All of the above information is, respectively, represented by Investigation, Recommendation, GradeOfEvidence, EffectiveDose and Priority entities. The criteria are therefore represented by (a) phase: characterized by the Name attribute, which specifies the clinical problem's stadium of interest; (b) Age, characterized by the MinimumAge and MaximumAge attributes; (c) TimeBetweenExams, characterized by the TimePeriod attribute, which describes the minimum time interval to be followed before the patient can undergo the same examination; (d) PersistentSymptoms, characterized by the TimePeriod attribute, which specifies how long the symptoms have been persisting; (e) UnavailableExam, characterized by the Name attribute that identifies the non-locally available examination.

Although there are many different techniques for organizing collections of rules into automated experts, the Drools [15] software was chosen. Drools is a business rule management system which also includes a reasoning engine. It was chosen because of its intuitive rule definition mechanism, its Web integration versatility and its continuous development guaranteed by JBoss community. Specifically, the DRL (Drool Rule Language) format was used to define the rules. They are just IF–THEN statements where the antecedent (IF clause) is a combination of criteria-based conditions and the consequent (THEN clause) is the action related to the investigation selection. An example of clinical problem rules defined in the DRL is provided below for illustrative purpose. As reported in the DIRG guidelines for thyroid nodules and enlargement, the set of all useful examinations is composed of color Doppler US, US-guided fine needle aspiration cytology (US-FNAC) and scintigraphy. Color Doppler US is the initially indicated investigation. Figure 2 shows the DRL rules defined for choosing the examination to be performed on the patient. The first rule establishes that a short waiting time color Doppler US is to be recommended when a palpable thyroid nodule of recent onset is suspected. The second rule establishes that a deferrable waiting time color Doppler US is to be considered when either a thyroid inflammation or a thyroid dysfunction or a goiter is suspected. The third rule establishes that scintigraphy should be considered in patients with equivocal ultrasound-guided fine needle aspiration cytology (US-FNAC) findings. Figure 3 illustrates the high-level COLLABORADI application architecture, which is based on the well-known Model–View–Controller (MVC) software design pattern [16], to separate internal representations of information from the ways that information is presented to the user. In this design pattern, the View represents the

Fig. 2 The DRL rules defined for choosing the examination to be performed on the patient

```
rule "Thyroid nodules and enlargement_1"
   when
         SuspectedPathology == "Palpable thyroid nodule of recent onset"
   then
         Investigation = "Color Doppler US";
         Priority = "Short";
end
rule "Thyroid nodules and enlargement_2"
   when
         SuspectedPathology == "Thryroid inflammation ,
         Thyroid dysfunction , goitre"
   then
         Investigation = "Color Doppler US";
         Priority = "Deferrable";
end
rule "Thyroid nodules and enlargement_3"
   when
         EquivocalExam == "US-FNAC"
   then
         Investigation= "Scintigraphy";
end
```

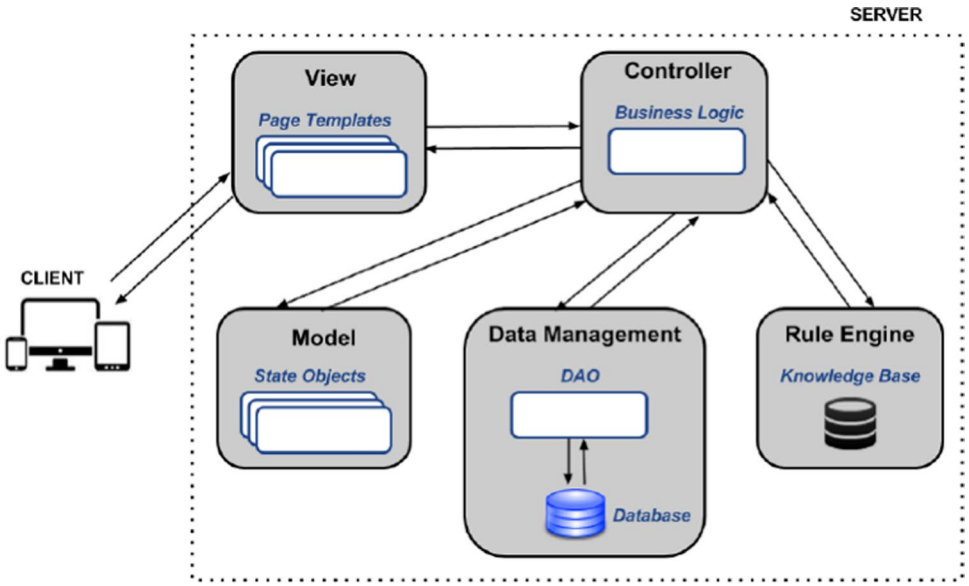


Fig. 3 High level COLLABORADI architecture diagram

presentation of the application, (i.e., all the elements in the user interface such as buttons, display boxes and so forth), whereas the Model represents the underlying, logical structure of data and operations (Business Logic) and does not contain any information about the user interface. The Controller is the component responsible for intercepting and translating user input into actions to be performed by the Business Logic, which in its turn implements the core operations of the applications.

As depicted in the Fig. 3, the Business Logic is responsible for interpreting the request coming from the client browser, creating or updating the Model, and coordinating the View to be delivered back to the browser. The Data Management is where communication with the database takes place through the Data Access Object. The Rule Engine (implemented by the DROOLS) is the component used in the decision-making process regarding the prescription of appropriate imaging studies. The Knowledge Base

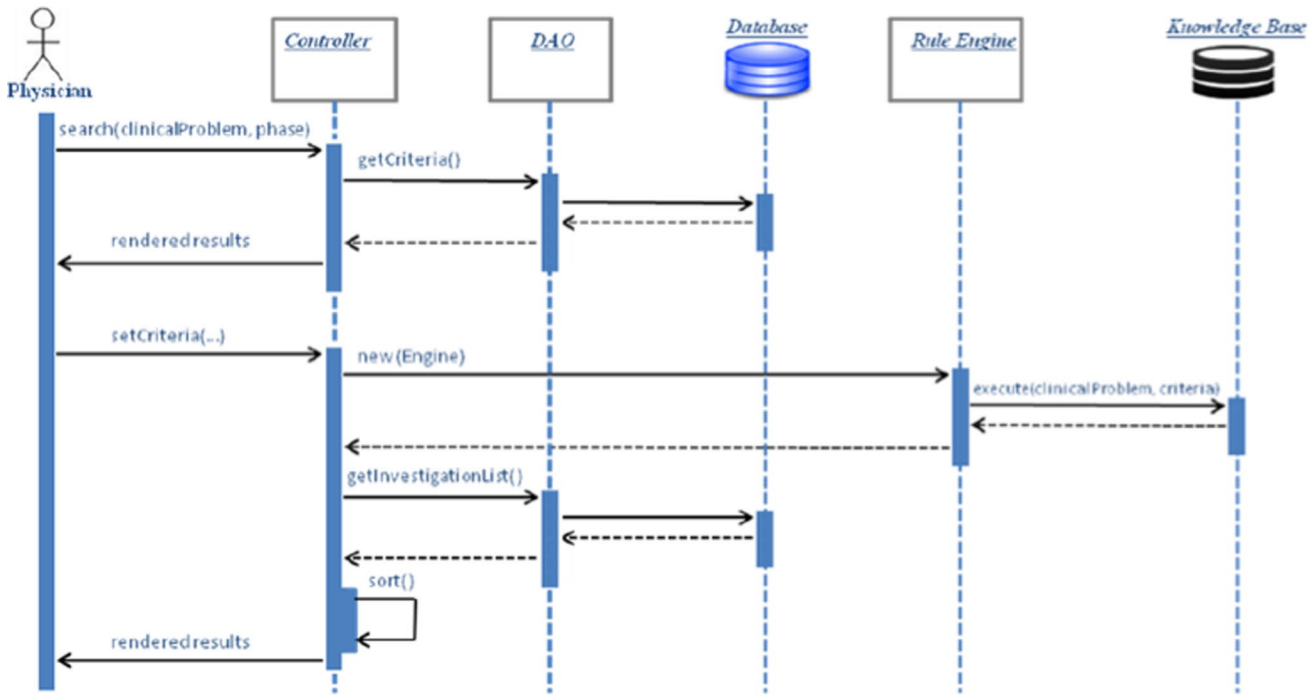


Fig. 4 Search clinical problem view with criteria sequence diagram

represents the whole set of criteria-driven rules defined for all the clinical problems, which the DIRGs cover.

The COLLABORADI system in action

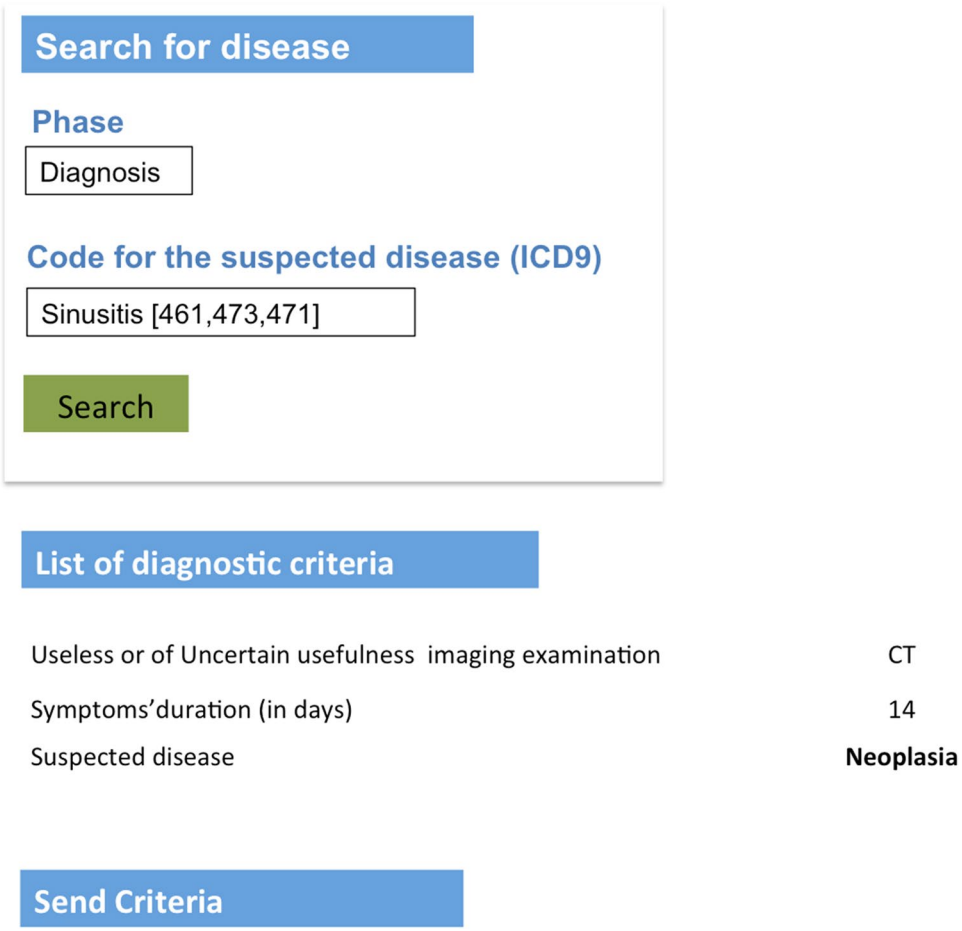
Physicians log on the system through an authentication process based on the username and password. When they first access the platform, they are provided with the "Search clinical problem" view, as shown in Fig. 4.

The interface allows searching the available investigations for a particular clinical problem, whose selection is facilitated by the auto-complete feature that filters all possible matches according to the specified phase. By pressing the "search investigations" button, physicians will be asked to specify one or more criteria, in relation to which an examination will be privileged among the available ones. Figure 5 shows the interface presented to physicians in case of a sinus disease, for which they are required to fill in the fields on criteria: EquivocalExam, PersistentSymptoms and SuspectedPathology.

The PersistentSymptoms field is mandatory and must be manually entered as a numerical value (in days), while the other ones can be selected directly from a dropdown list. For the clinical case under consideration, the criteria are assumed to be specified as follows: EquivocalExam = CT, PersistentSymptoms = 14, SuspectedPathology = malignancy. When physicians press the "Submit criteria" button, the system acquires the criteria, interacts with the rule engine and finally returns an investigation list sorted by medical appropriateness in a descending order. Figure 6 shows the final view for sinus disease resulting from the criteria set out above.

Each investigation includes the information mentioned (i.e., explanatory comment, priority, waiting time, recommendation, grade of evidence, effective dose, use of contrast medium). Finally, physicians are free to order any examination provided by the system, by just pressing the "Prescribe" button.

Fig. 5 Entering specific criteria



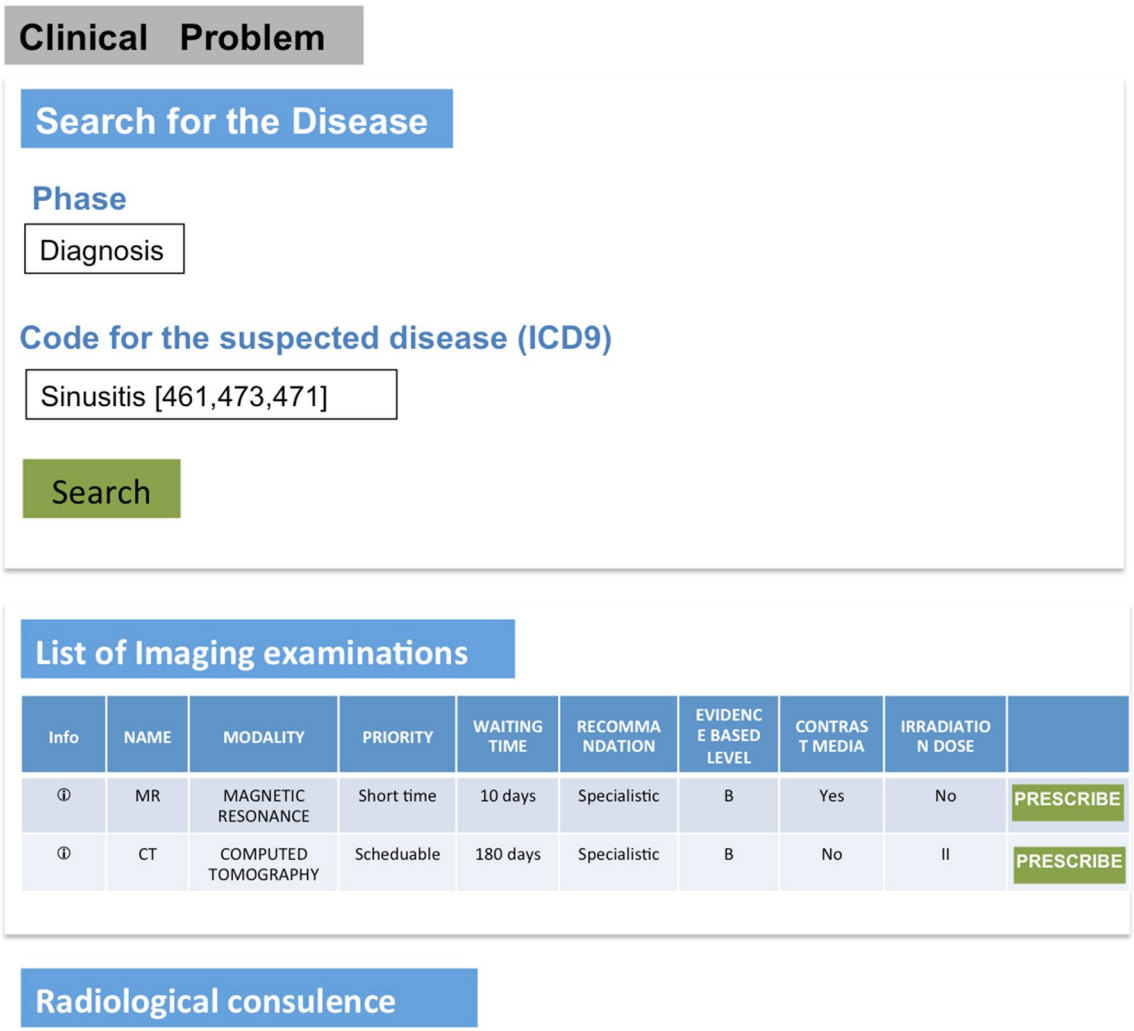


Fig. 6 Results list sorted by clinical appropriateness

Conclusion

Inappropriate imaging impact on the public health implicates a waste of resources which could be addressed differently. It impacts also patients' health due to inappropriate radiological exposure, meaning stochastic cancer risk. The COLLABORADI is an electronic service guiding and supporting physicians in choosing the most appropriate diagnostic imaging for patients' health issues. By doing that, COLLABORADI analyses the phenomenon of inappropriate DI prescriptions and suggests a way to tackle it.

COLLABORADI is now a trial software approved by the ethics committee. It is now in use in the public health system of ASP Messina, involving daily the work of general physicians and specialists.

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Compliance with ethical standards

Conflict of interest The authors involved in the study have declared that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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