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Original Article

Towards ontology-based decision support systems for complex ultrasound diagnosis in obstetrics and gynecology

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ABSTRACT

Introduction. – We have developed a new knowledge base intelligent system for obstetrics and gynecology ultrasound imaging, based on an ontology and a reference image collection. This study evaluates the new system to support accurate annotations of ultrasound images. We have used the early ultrasound diagnosis of ectopic pregnancies as a model clinical issue.
Material and methods. – The ectopic pregnancy ontology was derived from medical texts (4260 ultrasound reports of ectopic pregnancy from a specialist center in the UK and 2795 Pubmed abstracts indexed with the MeSH term "Pregnancy, Ectopic") and the reference image collection was built on a selection from 106 publications. We conducted a retrospective analysis of the signs in 35 scans of ectopic pregnancy by six observers using the new system.
Results. – The resulting ectopic pregnancy ontology consisted of 1395 terms, and 80 images were collected for the reference collection. The observers used the knowledge base intelligent system to provide a total of 1486 sign annotations. The precision, recall and F-measure for the annotations were 0.83, 0.62 and 0.71, respectively. The global proportion of agreement was 40.35% 95% CI [38.64–42.05].
Discussion. – The ontology-based intelligent system provides accurate annotations of ultrasound images and suggests that it may benefit non-expert operators. The precision rate is appropriate for accurate input of a computer-based clinical decision support and could be used to support medical imaging diagnosis of complex conditions in obstetrics and gynecology.

Introduction

Expert systems are computer systems that emulate the decision-making ability of a human expert. The first expert systems were created in the 1970s [1]. Modern expert systems are computer programs designed to support the human decision-making and have been developed in almost every field of medicine [2]. In general, Computer-based decision support system (CDSS) can be defined as "software[s] designed to directly aid in clinical decision making in which characteristics of individual patients are matched to a computerized knowledge base for the purpose of generating patient-specific assessments or recommendations that are then presented to clinicians for consideration" [3]. In Obstetrics, they were mainly used to assist in the management of labor [4]. Early research suggested that expert systems could validate results, provide a textual interpretation and archive all results to database for audit, research and medicolegal purposes [5]. However, their clinical use in obstetrics and gynecology has been limited. We have developed a reliable and scalable CDSS and tested it on early pregnancy ultrasound. More specifically, our system involves Semantic Web technologies and a novel ontology that is a computational model representing the knowledge of ectopic pregnancy ultrasound imaging. This model enables computer reasoning based on imaging concepts (echographic signs, types of ectopic pregnancy, echographic views, ultrasound modes).

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In developed countries, ectopic pregnancy common disorder, that occurs in 1–2% of pregnancies. The estimated mortality rate from ectopic pregnancy is 17/100,000 ectopic pregnancies [6], and it is accountable for up to 10% of pregnancy-related deaths [7]. It is defined by the implantation of gestational sac outside the endometrial cavity [6,8] and the most common site for ectopic to implant (around 95% of all ectopics) is the fallopian tubes (tubal ectopics). About 5% implant within the uterine wall (myometrium), but outside the endometrial cavity. The non-tubal locations of ectopic pregnancy are much more difficult to diagnose than the usual tubal location, and they are associated with higher morbidity and mortality rates [9]. Transvaginal ultrasound scanning has been demonstrated to be superior to transabdominal scanning [9]. Moreover, based on the recent improvements in imaging quality and expertise, it is now conceivable that skilled operators reach a definite diagnosis by the first ultrasound examination [10]. However, the early pregnancy scans are performed by a heterogeneous group of staff with different levels of training and expertise to manage patients at risk of ectopic pregnancy (e.g., emergency physicians, sonographers, radiologists, doctors in training) [6,11]. In practice, three consultations or more are needed to diagnose 50% of the patients at risk of ectopic pregnancy [12]. In this context, developing a CDSS for ectopic pregnancy is relevant, the first requirement of such a system being to enable precise annotations of ultrasound images of ectopic pregnancy.

The aim of this study is to present an overview of the design of our knowledge base intelligent system including a novel ontology and to evaluate this system for the annotation of ultrasound images of ectopic pregnancy.

Material and methods

Design of the knowledge base system

Our knowledge base for ectopic pregnancy imaging semiology consisted of a dedicated ontology and a collection of images annotated with this ontology. The Semantic Web introduces a new form of intelligent system called application ontology [13] which can represent the concepts and relations that are relevant to represent obstetrics and gynecology ultrasound semiology. The ontology includes the appropriate vocabulary, i.e. the terms for the description of the considered ultrasound semiology. This model is both human readable and computable, thus supporting the automated algorithms on which the CDSS relies. Our ontology using state of the art best practices for designing the ontology [14,15], provided coverage of the terms and the concepts that are used for medical reasoning in this domain, i.e. imaging signs, anatomical locations and technical elements. The collection of reference ultrasound images illustrates the concepts of the ontology. An overview of the knowledge base design is presented in Fig. 1, the detailed design of the knowledge base is presented in a medical informatics journal [16].

We leveraged natural language processing (NLP) techniques to extract and to select medical terms from a collection of medical texts from two sources: the medical literature (*PubMed* abstracts) and a set of de-identified reports of ultrasound examinations from a specialist center in the UK. We searched *PubMed* for all medical publications indexed with the MeSH term "Pregnancy, Ectopic" from January 2000 to December 2014 and associated with an abstract, resulting in a collection of 2795 abstracts. Additionally, we extracted 4260 ultrasound reports form the early pregnancy clinic database at the university college London hospital (UCLH), restricted to ectopic pregnancy cases from October 2006 to April 2014. The lexico-syntactic analysis of these texts resulted in the extraction of 40,237 single/multi-word terms.

A computational form of knowledge was developed from these extracted terms: using previously described methods [17,18], including the reusing of parts of existing terminologies for medical imaging [19] and human anatomy [20], the concepts representing the domain were selected and were validated by two experts. The relations/links between them were then defined. Finally, the structure of the resulting ontology, i.e. terms, concepts and links between them, was represented in a standard language for ontologies (OWL) and was formally validated.

In addition to the development of the ontology, we extracted from the literature a collection of ultrasound images of ectopic pregnancies illustrating the ultrasonographic signs present in the ontology. We restricted the 2795 above-mentioned citations to the articles in English, indexed with the MeSH term "Ultrasonography"

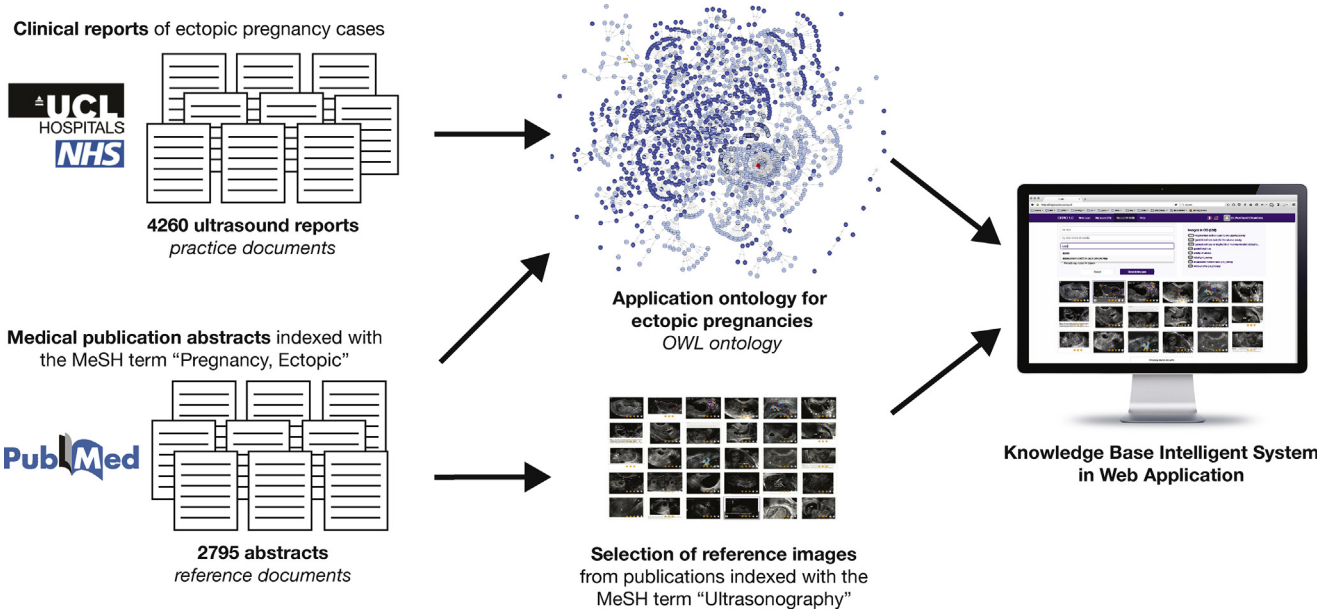

Fig. 1. Design overview of the knowledge base intelligent system for ectopic pregnancy: ontology design and reference image collection.