Computational Ontologies in Orthopaedic Surgery

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Published online: 22 May 2010
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Abstract

Background Information Technology (IT) plays an important role in storing and collating the vast amounts of healthcare data. However, analyzing and integrating this data to extract useful information is difficult due to the heterogeneous, siloed, disparate, and unstructured nature of the data.

Where are we now? Attempts to standardize data reporting by establishing reporting standards, checklists and guidelines have not been optimal [3, 11, 19]. Moreover, efforts to integrate data through the use of registries, data sharing networks, vocabularies and data standards have also yielded limited results. These efforts, when applied to orthopaedics, where theoretical knowledge is scattered over subspecialties, make it a cognitively challenging and tedious process.

Where do we need to go? Implementing data standardization is an important step towards homogenizing the data so that it can be integrated. Once integrated, the next step would be data analysis for information extraction. This

information would be useful in answering important questions, especially in orthopaedic clinical practice and research, and could even help optimize methodologies in the education field.

How do we get there? With the ability to describe concepts in a standardized manner and define existing interrelationships, ontologies are a potential solution. They assist in standardizing and integrating data and also impart strong inferential capabilities at a granular level. When applied to orthopaedics, they can standardize data collection, link data sources, generate knowledge based on the assumptions present in the interlinked data, thus answering important questions regarding orthopaedic clinical practice, research and education [22, 28, 30].

Introduction

Healthcare routinely faces many challenges related to delivery, management and quality of care as well as outcomes [4]. Further, training the next generation of healthcare providers and supporting healthcare research are additional responsibilities. Healthcare IT implementation is not only seen as a solution to the challenges but also a means to support and enhance training and research. The healthcare community follows a reductionist approach, in the sense that they try to understand the nature of complex issues by reducing them to the interactions of their simpler or fundamental parts. The decentralized nature of the healthcare community, together with this reductionist approach, leads to the conclusion the data are disparate, diverse and heterogeneous, and thus difficult to access and aggregate. Ironically, data that are collected are seldom used to their potential. Unstructured, disparate, and unstandardized data pose a huge challenge to healthcare providers and

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

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researchers alike as knowledge translation becomes a time-consuming, tedious and cognitively challenging process.

The data in orthopaedics are no exception, and thus difficult to convert into useful knowledge, whether in clinical practice, education or research. Data collection in the form of clinical databases and registries has existed for years in orthopaedic practice. Despite the potential usefulness of such data in monitoring trends, quality, outcomes and cost of care, it is difficult to translate these data to useful information for a number of reasons, including the lack of (1) data standards which provide a rigorous description for data representation, defining terms and ensuring compatibility across different clinical studies; (2) interoperability—the ability of two or more computers systems to exchange information; and (3) granularity of data—the quality with which the data fields are divided to provide flexibility in terms of data processing. Clinical decision-making that benefits from a combination of care, laboratory, and outcomes data face the same issues. In education, an in-depth and continued investigation into orthopaedics has resulted in the generation of massive amounts of largely unstructured and disparate information and knowledge. Given our limited cognitive ability and shortage of time, effective education and training demands a more structured approach. Finally, a lack of interoperable standards in design, implementation, analysis and reporting of basic or clinical or outcomes research substantially influences knowledge translation from tier 1 to tier 3.

Computational ontologies with their semantically interrelated, controlled and standard terms are a possible solution to the challenges and issues outlined earlier. Semantic interrelation refers to defining the meaning of the terminology and showing how they are interrelated. This not only serves the purpose of integrating siloed islands of orthopaedic data but also facilitates their granular analysis and interpretation.

In this article we describe the application of (1) ontologies in general; and (2) ontologies in orthopaedics specifically, especially in the areas of (a) clinical, (b) research and (c) medical education and training. We also describe the future of linked data and the concept and application of the Semantic Web.

Ontologies—Definition and Application

Ontologies are a means of describing concepts, things or entities in the world, while defining the relationships that exist between them [14]. They can be developed to represent meanings of terms as applied to a particular domain, that is, to be domain-specific.

For example, the NeuroLex [13, 15] ontology classifies neuroscience concepts into hierarchies and defines

interrelationships among them. It is denoted in the following manner: the class “neuron” is a sub-class of the class “cell” and defines relations between them such as “neuron is a cell”. This ontology has 20,000 concepts (including both classes and synonyms) that include anatomical terms, techniques, organism names, gross anatomy, and cells of the nervous system, subcellular structures, diseases, functions and techniques. Such hierarchies and relationships not only help to effectively search databases but also help organize and understand the returned information. Thus, it helps improve the communication of data between neuroscientists, so that the data can be found more easily and provide more powerful means of integrating data to the distributed resources.

The existence of multiple terms representing the same concept often leads to ambiguities and especially poses a problem when one wants to query multiple resources. For example, the terms “neuron” and “nerve cell” refer to the same thing, having the same underlying meaning, however because of the two different names a computer is unable to recognize the similarity. Thus when one queries a database for “neuron”, information associated with “nerve cell” is not retrieved. With the help of ontologies, one can then specify that both terms mean the same thing and a computer search would then retrieve information relevant to both terms. Thus ontologies play a role in standardizing the data, meaningfully connecting it and making it machine-readable. In an ontology, the concepts or things are represented as sets (or classes) along with properties (or attributes) and relationships of each class member. Relationships describe the way in which the classes or concepts can be related to each other. For example, relationships such as “is_a”, “part_of” are defined between class members of a cell ontology such as “neuron is_a cell” or “central nervous system is part_of nervous system”. Defining such relationships facilitates merging of data from different sources, since the sources are linked and querying one data source would retrieve information from all the linked sources. This aggregation can be used to determine facts that are not directly represented in any one source and facilitate interoperability across multiple databases. By representing information in a standard format, it is possible for others to use the data for their own purpose and thus sharing and reuse of data is made possible [14].

For example, the ontology of the musculoskeletal system of the lower limbs allows remote diagnosis of its pathologies [8] (Fig. 1).

Folksonomies, vocabularies (a collection of words for a particular concept), and data standards have all been used to standardize data, however ontologies are now preferred for a number of reasons [9, 10]. Folksonomies are defined as indexes or categories [31], which are actually uncontrolled vocabularies with a tag and set of resources associated to those tags. They are used in applications such

Fig. 1 The general architecture of the ontology of the musculoskeletal system of the lower limbs is shown.

as social networks to enhance search capabilities. However, folksonomies have certain drawbacks such as uncertainty in the meaning of and differences between terms, varying levels of specificity, lack of guidance on syntax and slight variations of spelling and phrasing [23, 31], polysemy and granularity [10]. Thus ontologies are chosen over folksonomies as they provide a domain vocabulary and define the semantic structure that relates to the different terms of that vocabulary [9]. Ontologies are in fact controlled vocabularies with advantages such as standardization of data elements and enabling inferencing of data at the granular level. They not only provide a unified vocabulary of terms to describe the concepts but also relate the concepts together into hierarchies and networks which provide the basis for inference and automated reasoning.

Formal representations of data—that is, representing data in a structured format thus ensuring it will be processed in a consistent way, allowing both humans and computers to understand it, is achieved by making implied concepts and knowledge explicit through the application of ontologies. Standardization of data elements for collecting and reporting of data is one of the key benefits of use of ontologies, which contributes to improved communication of research results, standardized reporting of articles for streamlined meta-analysis, and improved quality of meta-analysis.

Applications of Ontologies in Orthopaedics

Clinical Applications

Application of ontologies to the clinical practice ranges from building computational ontology for hospital scenarios, musculoskeletal system of the lower limbs, clinical practice guidelines and computer-aided decision systems, to name a few. These applications, their use, and benefits are explained in detail in the following paragraphs.

In hospitals, one of the main problems that hinders decision making is the sharing and reusing of data among software programs used in the process. This is due to the different platforms used to capture data which may not be able to share data among themselves, the different formats in which the data are captured, and the lack of a unique identifier to link the data. Thus due to this incompatibility between the software programs, making informed decisions is a problem. OntHos-ontology [2] is a collection of terms and their definitions, which are applicable for modeling scenarios of hospital logistics. This supports communication between programs and provides an efficient representation of the data. Interoperability between systems is also one of the benefits because the concepts are presented, compared, and discussed by researchers with different ideas.

This modeling is necessary for the development of clinical information systems or hospital simulation models, as this makes comparing results and integrating systems more feasible. It covers aspects from document management to scheduling in the selected scenarios (Fig. 2). The “temporal concept” includes concepts such as dates, fixed and relative time points, time intervals or durations and also abstract terms like “today” or “now”. The “medical concept” contains terms for describing medical knowledge, including those for clinical guidelines to a meta-object-model for the definition of symptoms, diagnosis and therapies. The “employee concept” has terms for abstract concepts for the description of hospital staff like qualifications, roles etc. The “appraisal concept” is for scheduling and planning decisions in hospitals. The “appointment concept” represents concepts for scheduling of treatment and examination tasks, those necessary for an appointment, tasks, times, present persons and resources. The “document concept” is for the form and content of various types of clinical documents like diagnostic findings or patient data. The “organization concept” is introduced to describe a hospital scenario, the underlying organization and its entities like functional units that provide services for examination and treatment, wards, administration, and special entities like, for example, a pharmacy or an orthopaedic service. The “process concept” includes terms that describe processes composed from atomic actions,

Fig. 2 The hierarchy of the ontology for a hospital scenario, the OntHoS-Ontology, is shown.

sequences and alternatives and provides a meta-model with adaptations to specific modeling languages. The “object concept” describes abstract, nonexistent objects, for real objects (rooms, medical and general devices, supplies etc) or persons (patients, hospital staff etc.).

For example, this ontology can be applied to develop flexible and adaptable coordination strategies. Since the treatment of hospital patients requires complex coordination of a large number of organizational (autonomous) entities, special requirements are needed for the interdepartmental synchronization to organize patient appointments and provide medical service for treatment and examination. Departmental capacities are limited by their resources, that is, the rooms, medical devices, and personnel, thus coordination strategies may range from simple queues to complex scheduling that requires shifting of appointments. Moreover, a department may desire a high load but patients prefer shorter waiting periods, thus this ontology can help in such scenarios to achieve a high grade of flexibility.

Another application of this ontology was seen in a policy agent project, where the goal was to develop a scheduling system for centralized operating rooms based on “intelligent” software agents. Centralized operating rooms are used by different medical departments of the hospital, which results in better utilization of devices,

rooms as well as personnel, and provides higher flexibility of planning in case of emergencies. However, the conflicts that arise from planning between resources and staff lead to higher costs. Thus, this ontology plays a role in resolving these conflicts by organizing the scheduling process with minimum human interaction, but also taking care of the individual interests of all participants. Different preference and appraisal concepts, integrated into the ontology, were modeled according to the user preferences which brought about a greater flexibility for deriving preference or utility profiles.

The study of the impact of pathologies of the musculoskeletal system in biomechanics is usually based on models that may be rigid or deformable. Although these models help understand the mechanism of the joint or gait and diagnose the pathologies, they cannot simulate pathologies very well. An extensible ontology—namely the ontology of the musculoskeletal system of the lower limbs (OSMMI) [8]—was recently developed which helped not only in formalizing the studies related to the lower limbs of the human body, but also building an expert system to diagnose the pathologies of the lower limbs and especially gait. It ensured equality in decision, diagnosis and treatment. Use of the ontology allowed a remote diagnosis of the pathologies and helped examine the impact of pathologies on the musculoskeletal system as well as improving the quality of the diagnosis (Fig. 1). It also helped to model new problems based on the gathered knowledge.

Adaptation of the clinical guidelines designed by medical specialty organizations or government agencies is required before they can be used by clinicians at specific institutions. Reasons for delay in adaptations involve the variations of institution settings such as type of practice, location, availability of resources, and difference between patient populations, local policies, and practice patterns. The GuideLine Interchange Format (GLIF) [25, 26] defines the ontology for modeling and executing clinical practice guidelines and a medical ontology to facilitate the mappings from GLIF representation to different electronic patient record systems. A GLIF3 model [28] based on ontology allows sharing of encoded guidelines among institutions and platforms besides making the data available and in a useful and standard format. This helps to provide a common standard care within a health care organization and among different organizations. The common standard has the advantage of providing direct execution of guidelines in response to network-based queries, since it will be stored on a central server on the internet, or serve as a repository of standardized, encoded guidelines.

Expert opinion is invaluable for the diagnosis and treatment of childhood deformities, especially of the lower limbs. A Computer-Aided Decision System (CADs) [8]

formulated on a diagnostic-based ontology, was developed to make the expert opinion implicitly available and experience-based knowledge explicit. It consists of a diagnostic ontology of the musculoskeletal system of the lower limbs, a biomechanics meta-database, a statistical classification based on data mining techniques, the process of extracting patterns of data to convert data into information, and an interactive web-based module for managing the interaction between experts, patients and the CADs. CADs is used to provide and broadcast knowledge of medical experts such as those in medicine, surgery, physiotherapy etc. for the diagnosis as well as treatment of children's deformities, especially of the lower limbs. For example, the Rotational Abnormalities and the clubfoot deformity of the musculoskeletal system of the lower limbs was studied [8] and it was found the quality of the diagnosis and subsequently the treatment improved through an evidence-based diagnostic approach, a conservative treatment, and a followup process. CADs is also extending this study to other children's deformities.

Personalized healthcare is based on computer modeling of an organism's functional behavior, that is, their physiomes. However, integration of the numerous computational services proves to be a hindrance due to the lack of standards and interoperability between resources. A Living Human Digital Library (LHDL) [21] was developed to facilitate data sharing and the computational facilities within the biomechanics community. This was achieved through web and grid technologies supported by semantics. Such integration can thus be applied to different disciplines such as chemistry, clinical and subsystems such as orthopaedics, cardiac etc.

A number of community tools, data repositories and algorithms for medical researchers and clinical works were provided for orthopaedics research and treatment, within LHDL. This framework enables the integration of services to suit specific requirements and thus assists in modeling individual humans of clinical purposes, in this case orthopaedics. The LHDL is mainly involved in biomechanics, interaction and visualization of the patients, collecting data and developing infrastructure to model the human musculoskeletal system. This can help not only predict how mechanical forces are exchanged internally as well as externally but also at any dimensional scale from the whole body to the protein level. When new data and algorithms are available, the infrastructure can be updated and extended, as required, at any level.

Research Applications

Collaborative research is essential in biomedicine as it leads to better access to expertise, equipment, resources,

funds, more prestige, better efficiency and productivity, more focus [20] and enhanced user knowledge [7]. An approach to developing a virtual research environment, called the "Virtual Bone Laboratory" [12], was undertaken and would enable orthopaedic researchers to collaborate remotely. The Collaborative Orthopaedic Research Environment (CORE) developed the Virtual Bone Biology Laboratory which incorporates the basic science disciplines of molecular and tissue biology, engineering and computing. It also includes the medical (prosthetics, pharmacology, trials management) and clinical disciplines which mainly include the musculoskeletal applications in orthopaedics and rheumatology. It prepares the processes and test methods which are required for the development of new technologies for the management of information and the construction of technologies on the nanometric scale. The higher surgical trainees (HSTs) are qualified surgeons who are undergoing training to be consultants. However, they are not computer specialists and they usually move posts twelve times during their training, while maintaining an e-portfolio of their work. The CORE assists HSTs in the coordination and running of the "Virtual Bone Laboratory" experiments and also in the design, collection, review, analysis, reporting of results and dissemination of trials and experiments as well as maintenance of their e-portfolios. Thus, the orthopaedic surgeons (including HSTs) can collate and analyze trial results, organize internal project discussions and reviews, produce technical reports and papers and also teaching and training materials.

Knowledge-based tools use artificial intelligence techniques in problem-solving processes to support human decision-making, learning, and action. Those present in medical applications are difficult to integrate with clinical records and are most often not reused, thus posing problems in integrating and analyzing disparate data present in medical applications. The GALEN (Generalized Architecture for Languages, Encyclopedias and Nomenclatures in medicine) High Level Ontology [30] developed terminology servers and data entry systems based on a Common Reference model for medical terminology. Since it is practically impossible to build a perfect model for medical nomenclature, a generalized model was developed that could fit closely enough with the medical terminology to enable intuitive user interaction, especially for clinical data entry or classification and retrieval of medical concepts, also support the reuse of information to integrate medical records, decision support and other clinical systems and thus support collaboration between different groups. This facilitated the linking of patient care data and the abstractions required for statistical, management and research objectives.

For example, this ontology was used in a project to create a planning system for cardiology patients, which

supported interactive care planning. Individualized care plans could be created, providing assistance in evaluating the treatment options as well as scheduling clinical activities all taking into account the patient preferences and values. In another example, this ontology was used to represent segments of coding systems, focusing on orthopaedic surgery, urology, cardiovascular and respiratory sections, in building clinical systems in a commercial collaboration [29].

Personalized healthcare is based on computer modeling. However, integration of the numerous computational services proves to be a hindrance. A Living Human Digital Library [18] was developed to ease sharing of data and the computational facilities within the biomechanics community. This was done by using web and grid technologies, supported by semantics. Such integration can be applied to different disciplines such as chemistry, clinical, and sub-systems such as cardiac and orthopaedics.

Evidence-based medicine relies heavily on systematic reviews and meta-analyses (SR-MA). However, poor reporting of clinical trials impairs the ability to perform high quality meta-analyses and consequently delays the translation of clinical research findings to clinical practice. Despite their importance, the SR-MA process is slow, taking an average of two and half years to traverse from a Randomized Controlled Trial (RCT) to a SR-MA. There are instances when SR-MA has been known to take longer than nine years [32]. In addition to lack of enough appropriate publications to conduct a SR-MA, it is effort intensive and detail-oriented which makes it a tedious and time consuming task [27].

One study demonstrated the use of an ontology, containing tags related to Randomized Controlled Trials (RCTs), to tag the quantitative aspects of HIV RCTs [6]. By tagging all articles using the ontology, all information required for SR-MA is readily available for subsequent extraction of information needed to perform the meta-analysis, thus making the process relatively simpler and faster. Consequently, extracting studies related to a particular topic is also easy as they are already categorized using tags from the ontology. As a result, the productivity and quality of the meta-analysis process increases and makes it stream-lined. The results of this study demonstrate that a scientific article tagged using an ontology can improve the speed of SR-MA by facilitating simultaneous extraction of qualitative and quantitative information from constituent research articles. This method not only enables semiautomation of the meta-analysis process but also facilitates conduct of a meta-analysis in real time. This approach has the capability to improve overall quality of reporting of RCTs in neurosurgery, ultimately streamlining the translation of clinical research findings to improvement in patient care. This approach can be further extended to

orthopaedic surgery, to streamline meta-analysis in this field and thus assist in formulating clinical practice guidelines.

Medical Education and Training

The field of neuromuscular biomechanics uses knowledge from several subdomains such as orthopaedics, mathematics, electronics, mechanics, computer science, computer graphics and statistics. Several resources are pooled over these subdomains, such as for the implementation of new simulations methods where knowledge from orthopaedics, tissues mechanics is used by the software developer. By and large, this knowledge is stored as books, journals or documents with no link between the sub domains. Implementing an ontology will be most advantageous as it will be able to handle model specific data as well as represent knowledge in a reusable way with model and experiment information. This will help increase collaboration and sharing of knowledge between people in different subdomains [22].

An ontology was implemented in one such scenario [22] where the aim was to enable it to handle model-specific data, simulation setup, results and conclusions. The ontology was implemented using a main database to store all the common knowledge from all the subdomains along with information from the experiment database, their results and the documentation from software tools. When a model or result file was loaded into the system, information was extracted from the file and then combined with the knowledge from other domains. Also, the information could be extended into the file with the references to other resources. Thus, with the ontology containing both the model and simulation result, more information could be seen and shared, that is knowledge from one experiment could be incorporated into the knowledge-base and reused in another experiment.

The Virtual Orthopaedic University (VOU) is an initiative to provide clinicians with an infrastructure to manage most of the administrative, research, and educational workload of the university within the digital domain [35]. Traditional infrastructures have issues such as implementation and with providing access to information to users. The associated cultural and pedagogical aspects are also a major concern. With the use of an ontology, sharing and reuse of knowledge is enabled and helps to establish new types of interactions with the users [35]. The Virtual Orthopaedic University provides assistance to use computer-assisted surgical tools with dedicated interactive media, linking web-based training to resources and clinical data collection from ongoing trials in orthopaedics. The underlying ontology is implemented to enable sharing and

reuse of knowledge and to establish new types of interactions with the users.

The VOU, by the use of the ontology, offers a personalized set of learning material and guidelines to promote effective learning. For example, with this system in place at a local hospital, it provided an infrastructure for clinicians to use computer-aided surgical tools along with interactive media, thus linking the educational environment of web-based training to resources to clinical data collection from the ongoing trials in orthopaedics [35]. Also, this virtual infrastructure helped to manage the administrative, research and educational work of the university. It also ensured the availability of up-to-date educational material, which benefited surgeons by providing greater access to information without any hindrances, as those associated with traditional infrastructures.

Ontologies have been used, in this example, implicitly to specify educational goals and explicitly to represent different subject matters to be taught in a course. An educational contract is one which brings together the educational syllabus and the learning agreement, a two-way proposal between the clinical tutor and the trainee. With the tutor and the trainee located at two different locations, this contract is usually paper-based. With an online educational contract based on an ontology, the process of creating a contract can be accomplished efficiently. It also provides benefits such as mapping into the personal profile of the individual, and provides multiple perspectives on the educational syllabus such as user category, clinical skills, trauma, elective etc. Thus, knowledge can be shared and reused. The relationships between different user groups, syllabi and clinical skills, in a new learning environment can be maximized and thus support clinical decision making. The ontology also helps in building a sophisticated web-based educational environment that provides efficient ways of navigating, clustering and viewing the educational syllabus. Therefore, by using the ontologies as models to enable the share and reuse of knowledge and to improve the linking in systems, it exploits real-world relationships between the concepts in the learning environment [20].

The Semantic Web and Linked Data

Convergence and integrated use of communication technologies, whose paradigm is the internet, has contributed to creating a new environment of access and promotion of knowledge on a worldwide scale. Linking clinical, research and open data poses a great challenge to clinical researchers due to the several electronic medical records and the numerous databases for distributed web search. The greatest challenge is to make the information available in a

consolidated, continuous, sustainable, and reliable manner. The lack of integration between clinical data affects the quality of health-care since the individual solutions are incapable of sharing and reusing the information among themselves.

In this context, in order to meet the challenge of data integration, it is considered that the structural approach must be replaced by the semantic approach, where information seeking is performed by knowing the meaning of information by focusing on understanding the data and their associations with other data while performing the search. The Semantic Web [1] can assist in understanding the data available on the web as it is about Linked Data so that the person or machine can explore the data. When merging two databases in a large hospital, using existing ontologies can help expand the basis of knowledge through the use of ontological engineering. The search can be customized to help professionals and researchers search the data easily. The future is to combine semantic web technology, with other methods, in the strategies for integrating data, considering the publication of information, intelligent search of information, and exchange of information in an automated and intelligent way. This would substantially increase the use of biomedical data in healthcare and research, to improve the delivery of care services to the users of health system.

Discussion

In this article we describe ontologies and their applications in general as well as those applied to orthopaedics, especially in the areas of clinical, research and medical education and training. Based on the description of the use-cases of the applications of ontologies to the field of orthopaedics, we showed that they can prove to be extremely beneficial as they have the capability to standardize data and draw inferences based on the data, at a granular level. This can be applicable in clinical practice, research and medical education and training [3, 11, 19]. The data can be represented in a machine-readable way [15] which can facilitate interoperability across multiple databases and provide integrated results from different biomedical resources [18] thus enabling sharing and reuse of data [28] and also making the data relevant for longer periods of time. Ontology-driven information systems facilitate improved and faster decision-making by enabling integration of multiple disciplines.

From the orthopaedic perspective, extensive use of ontologies in the areas of clinical practice, research, medical training and education is beneficial. Building computational ontology for hospital scenarios [2], musculoskeletal system of the lower limbs, clinical practice guidelines and computer-aided decision system [8] as well

as applying them in the research areas of biomedicine, health-care and evidence-based medicine along with their use in medical education and training are some of the widespread applications of ontologies which have proven to be advantageous when applied to healthcare.

There have been numerous efforts to implement data standards to improve the quality of reporting, such as QUORUM, CONSORT, STROBE, TREND to name a few [5, 11, 17, 33]. Although the quality of reporting has substantially improved in many areas of biomedical research [11, 16, 24], it is still not standardized or optimal [3, 34], and ontologies are now opted for, especially to standardize data collection and analysis.

Even though ontologies are preferred, the cost and time involved in implementing these standards in the form of ontologies is seen as a barrier by researchers. Also, as resources are scarce and the funding for a project is limited, ontologies fail to be the obvious choice. Therefore, use-case specific ontologies are preferred as opposed to domain and upper level ontologies which do not cost as much and take less time to implement.

Thus, use-case specific ontologies should be used as per the requirement. Once the ontology is implemented and the data standardized, it can be integrated. Once integrated, the next step is to analyze the data to obtain knowledge from the information. This knowledge can then assist in answering important questions, especially in orthopaedic clinical practice and research and even help optimize methodologies in the education field.

Acknowledgments We thank the “Research on Research” team for the templates for writing the introduction and discussion sections of the manuscript as well as templates for Literature matrix, Duke University Health System. (Available at: <http://researchonresearch.org/>. Accessed Dec 12, 2009.)

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