A SEMANTIC-DRIVEN CLINICAL EXAMINATION PLATFORM

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Musculoskeletal disorders are widely spread throughout the world-wide population inducing patients' pain and limitation of movement. Nowadays, the large amount of multimodal data, available from acquisition and modeling, is difficult to exploit effectively. Therefore, to help and guide orthopedists during clinical examination, we designed a medical-based ontology of the musculoskeletal system. Existing ontologies are not developed for specific application purposes and are not appropriate for anatomy functional simulation. We hence created this ontology in order to fulfill this lack of functional knowledge. Our model is dedicated to a clinical examination platform and is navigable by machine-based systems.

INTRODUCTION

Musculoskeletal disorders [6,20] are the most notorious and common causes of severe long-term pain and physical disability, affecting hundreds of millions of people across the world. Therefore, it is clinically important to define methods to detect and visualize musculoskeletal afflictions. An advanced understanding of these complaints, through research and in-depth examination (e.g. diagnosis, pre-surgical planning, morphological analysis), is absolutely necessary in order to improve prevention and treatment.

The use of 3D techniques is important for orthopedists wanting to simulate, visualize and navigate through articulations. It can help to define a accurate diagnosis or it can serve to determine the best adapted surgical procedure to the situation. Human joint motion analysis is also a prerequisite for various pathological conditions detection and objective evaluation for surgical therapies (cartilage and ligaments deficiencies) as well as non-surgical treatments. The goal of this work is to visualize and simulate musculoskeletal anatomy and disorders through different data acquisition modalities. The subject's anatomy is capture with a static MRI (Magnetic Resonance Imaging) protocol and the three-dimensional models of individualized anatomical articulations are reconstructed from segmented clinical MRI datasets [5]. Then kinematics data (dynamic MRI, motion capture [21]) are used to track the joint's trajectories and material properties (e.g. elasticity) of soft tissues are measured for the biomechanical simulation [3].

Although a large amount of multimodal data is available from acquisition and modeling, it is difficult to exploit it effectively. For that reason, we developed an interactive clinical examination platform where the system can centralize and manage these multimodal data inputs. To fuse the data and to help and guide the orthopedists during clinical examination, high-level tools are increasingly necessary. In order to extract from the dataset the structural (morphological), functional (physical, mechanical properties, etc.) and topological (geometric features) information of the different elements, we use a knowledge specification. In this context, a medical ontology is effective by structuring and storing the different elements in terms of anatomical concepts, by describing the relationships between the elements and by providing a quick access to the functional parameters. The aim is to provide orthopedists with an interactive visualization framework for individualized musculoskeletal examination.

In the next section, we will first describe our methodology and the semantic structure of our medical-based ontology. We will then present our main results on using the clinical platform in correlation with this ontology.

METHOD

1. Background

In the biomedical domain with the evolution of research, the amount of information and data to be handled is growing so fast (mainly due to acquisition improvement), that it is difficult to manage the content efficiently. To support the sharing and reuse of formally represented knowledge among systems (e.g., process, procedure) and agents (i.e., people acting in a particular domain), it is useful to define the common vocabulary in which shared knowledge is represented [7]. In this context, ontologies are robust architectures to design knowledge representation of concepts and the relations among them in a formal language [2]. Therefore, ontology is becoming increasingly recognized as an essential tool for medical informatics [11] and even more so for bioinformatics.

The use of ontologies in medicine is mainly focused on the representation and organization of medical terminologies (e.g., GALEN Model [4], SNOMED CT [19], Medical Entities Dictionary [10], ICD-9 [8], ICD-10 [9], NCI Metathesaurus [12]). Some are also concerned with the representation of classes and relationships necessary for the symbolic modeling of the human body structure in a form that is understandable to humans and is also navigable by machine-based systems [17,18]. They do not cover all the medicine but contain a high level of completeness and consistency in particular domains. In anatomy, the most renowned is the Foundational Model of Anatomy (FMA) representing the structural organization of the human body from macromolecular to macroscopic levels. This model serves as a reference domain ontology for the discipline of anatomy [16].

Ontology integration has been limited so far to the creation of mere mappings between one terminology-based ontology and another without bringing significant scientific advancement. To achieve the necessary improvements, developers should start from a validated framework or a reference ontology (i.e. it provides the scientifically tested framework) to design extended ontologies developed for specific application purposes [15]. Following this direction, our proposed ontology is based on the FMA, since we are dealing with the human anatomy. However, as a canonical representation, the FMA provides no functional knowledge about the properties of the anatomical entities and it is not dedicated and appropriate for anatomy functional simulation. Hence our goal is to provide a generic ontology of anatomical concepts (using the terms and the structure of the FMA as a benchmark) that can supply functional parameters in order to describe their behavior and characteristics. Our ontology is strictly limited to the musculoskeletal system and can be further individualized.

2. Semantic structure

Our first intent with this ontology is to incorporate all concepts that relate to the structure of the musculoskeletal system figuring in the literature or in anatomical discourse. To design this model, we used Protégé3.1.1 [14], a free open source ontology editor and knowledge-base framework.

With Protégé, the concepts are structured in classes which are organized in a hierarchy that is a directed, acyclic graph (i.e., the lower in the hierarchy, the more precise the concept). Classes correspond to specific anatomical components (e.g., Muscle, Cartilage, Bone, etc.) and contain entities (instances) representing the concrete parts of the body (e.g., Left rectus femoris, Right pubofemoral ligament, etc.). Fig. 1 shows the *QuadricepsFemoris* frame with its instances in the Protégé graphical user interface.

Instances are associated with a set of attributes defining its properties and relationships with other entities (instances). These relations are called *anatomical links.* For example, the left adductor magnus *has a tendon* named the left proximal tendon of the adductor magnus which *is attached to* the left ramus of ischium. In this way, all entities are connected together and provide information about their particular role in the global system.

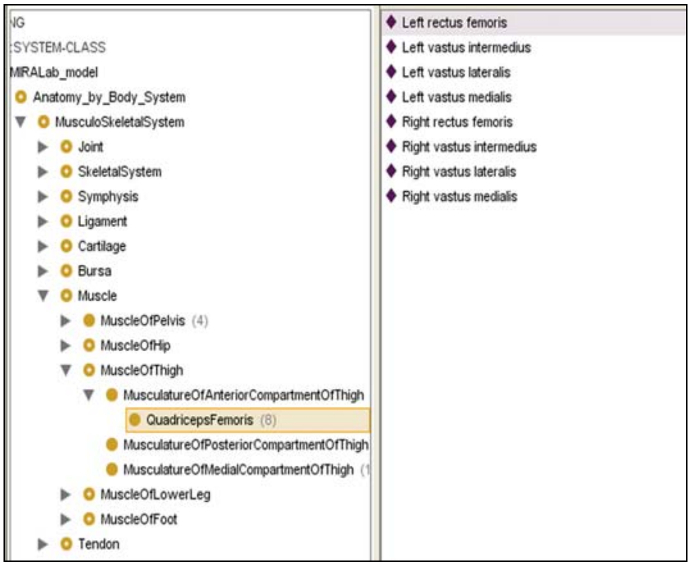
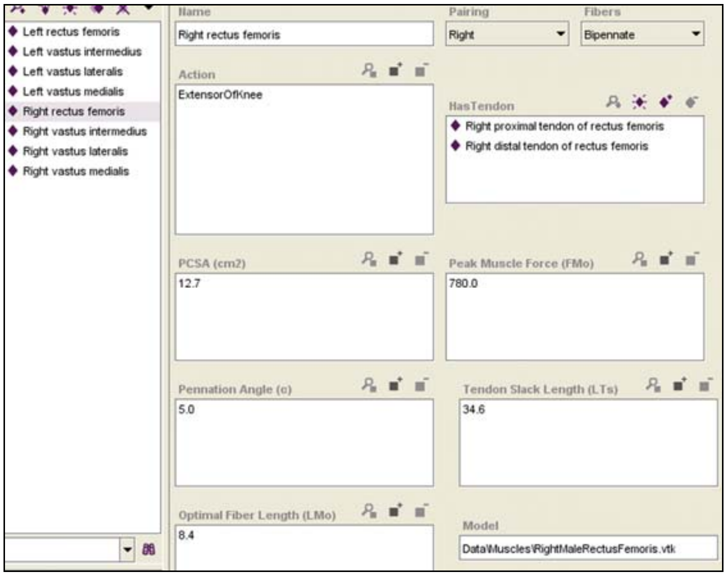


Fig. 1:
The frame of the concept QuadricepsFemoris (highlighted in the left hand pane) with its instances (right hand pane).

Some instances contain specific attributes referring to functional (e.g., material properties, peak forces, etc.) or kinematical (e.g., joint center, joint axis, etc.) parameters so as to define the functional properties of the entity. This aspect constitutes the most valuable part of our ontology. Indeed, we are dealing with complex data processes which can be automated to reduce manual operations. By storing these parameters at a high level, we can access them very quickly. For example, the instance *Right rectus femoris* includes mechanical and physical properties (Fig. 2). The corresponding values are used to simulate the muscle biomechanics.

Our ontology proposes another significant contribution: all entities are linked to a 3D mesh. As we cannot directly store the 3D model in the ontology (the volume of data is too large), we use a pointer towards the model's file path to represent the relationship between the instance and its 3D mesh (the *Model* attribute in fig. 2). With this method, our application can automatically associate the concept to its concrete representation. Since we distinguish the left and the right part of the body (the instance contains this specification), all entities are clearly identified.

Finally, for our model to be more flexible, the end-user can browse the ontology in two ways. He/she can either navigate through the concepts by major body divisions (e.g., component of trunk, component of thigh, etc.) or by musculoskeletal system's components (e.g., Tendon, Muscle, etc.).



- Left rectus femoris
- Left vastus intermedius
- Left vastus lateralis
- Left vastus medialis
- Right rectus femoris
- Right vastus intermedius
- Right vastus lateralis
- Right vastus medialis

Name: Right rectus femoris
Pairing: Right
Fibers: Bipennate
Action: ExtensorOfKnee
HasTendon: Right proximal tendon of rectus femoris; Right distal tendon of rectus femoris
PCSA (cm2): 12.7
Peak Muscle Force (FMo): 780.0
Pennation Angle (c): 5.0
Tendon Slack Length (LTs): 34.6
Optimal Fiber Length (LMo): 8.4
Model: Data\Muscles\RightMaleRectusFemoris.vtk

Fig. 2:
Attributes associated to the instance Right rectus femoris. The Model attribute (bottom left pane), refers to the model's file path.

3. Implementation

Our ontology is designed with Protégé. This framework offers a wide range of plugins to export the ontology in different formats. We finally chose to convert our model into an XML file because this markup language is standard, portable and simple. It also provides tools to process the dataset and make queries (e.g., XQuery, XPath).

To connect the generated XML file with our clinical examination platform, we used Berkeley DB XML [1], an embedded XML database with XQuery-based access to documents stored in containers and indexed based on their content. This solution allows us to read the XML file via a C++ API in order to visualize our medical ontology directly in our application and to create queries.

RESULTS

Our system integrates conventional diagnostic support (MRI), visualization and simulation tools and the ontology constitutes the interface between the application and the medical interpretation of data. Concretely, since the ontology can be accessed during the clinical examination, it can help the orthopedist to associate the results with the medical terminologies in a comprehensive way. Fig. 3 shows the graphical user interface of our clinical platform; the ontology is available in the right hand window.

For the visualization, the ontology offers many advantages. By querying its elements and relationships, the platform can retrieve structural, functional and topological information from the dataset which can then be processed to manage graphical contents. The following descriptions illustrate some interactions: When using the platform, the orthopedist can browse the ontology's classes and dynamically load the 3D models he/she needs to analyze (i.e., the user clicks on the instance from the ontology browser and the corresponding model is loaded). The user also has many tools at his/her disposal to help him/her navigate through the articulations. For example, he/she can select an organ on the viewer and the system will display its properties or he/she can choose between various display modes according to the muscle's functional dissection (e.g., flexor of hip, extensor of thigh, etc.). The ontology provides the respective muscle's action.

Concerning the simulation which requires many parameters to be taken into account (e.g., muscle biomechanics depend on forces and material properties, bones motion relies on joint center definition, etc.), the ontology simplifies the data process. Since the functional and kinematical parameters are stored in the ontology, we have a quick access to them. The data transfer can be automated which reduces manual operations.

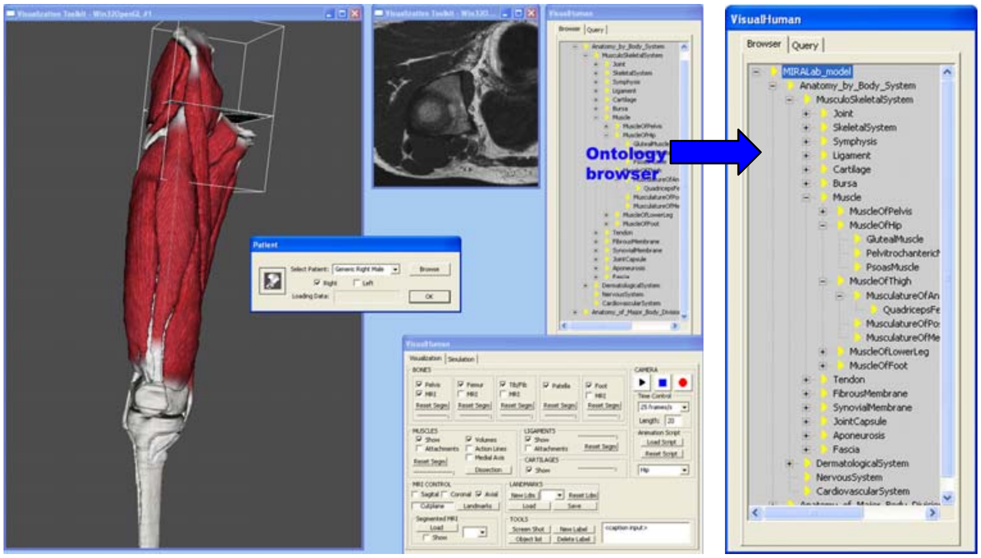


Fig. 3:
The clinical examination platform with the ontology (right hand window and right image), the 3D visualization window (left), the MRI window (middle top), the patient loader (middle window) and the visualization/simulation tools (bottom right window).

Furthermore, the ontology is a support for data fusion and completion. As all the acquisition modalities and measurements will not be systematically available at clinical sites, sparse input datasets can be completed with generic data. Indeed, the ontology stores these generic data and can be therefore used as functional or anatomical reference. However, when a patient's data exists, the ontology can be partly individualized. When accessible, our system will automatically refer to the patient's values, otherwise it will fill the gaps with the generic data. Missing information is estimated from generic values combining redundant multimodal data.

In a real-life scenario, all these aspects can be used to set up a pre-operative planning. Before a hip arthroplasty due to osteoarthritis for example, the orthopedist will first load the patient's hip articulation and the respective cartilages by using the ontology browser. With the help of medical images (MRI), he/she will analyze the shape of the bones and retrieve the necessary anatomical and morphological information from the ontology. He/she will then simulate the joint to analyze the limitation in the range of movement and the stress sustained by the cartilages, while the visualization tools will help him/her navigate in the 3D space.

CONCLUSION

Future work lies ahead to finally deliver an achieved platform taking into account all the acquisition modalities and measurements at disposal. Our expectation is that the ontology will enhance the transfer of these data and simplify their management and processing. Furthermore, handling data at a high level should allow statistical analysis for subject comparisons and longitudinal studies. For instance, it will help identify if functional pathogenesis arise with common anatomical anomalies (e.g., cartilage degeneration, abnormal morphology, etc.) or patient predispositions (e.g., overweight, muscular deficit, etc.).

Our short-term goal is to continue the different acquisitions (mainly motion capture and 3D body scanning) from which functional parameters can be extracted and collected. Relevant parameters will be stored in the ontology for further use. Moreover, we plan to improve our clinical platform by adding automatic diagnostic tools to compute standard morphological measurements (e.g. alpha angle [13], retroversion [13], etc.). The final framework will enable a close examination of patients and supply pre-operative parameters to the orthopedist.

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