From a Foundational to a Functional Model of Anatomy; A multiple systems ontology model of the lower limb

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Introduction

Since the early development of the (modern) human anatomy, five centuries ago, Art and Anatomy have been closely associated. Ones of the first anatomists were well known artists (Vesalius, Leonardo da Vinci…). However, the 21st century anatomic representation of the body has taken another direction by using three dimensional (3D) representation and modeling. Although these representations, art or 3D, are beautiful relations between different systems (i.e., neurology, myology, angiology, etc.), they are not the most suitable support for students to understand functional relationships between the various anatomical systems . From a functional point of view it is difficult to visualize links between these different systems, and thus the potential implications of a particular problem from one system (e.g., *arterial clog by atherosclerosis*) on the musculoskeletal system (e.g. *which muscles are going to be impaired due to the clog present in their vascular supply tree?*). In order to tackle this problem, all relations between different components of the neuro-musculoskeletal system must be fully described. Then a visualization tool of the body needs to be built to represent these functional relations.

Materials and methods

Most of the anatomical terms are available from the Foundational Model of Anatomy (FMA) [1]. Unfortunately, the FMA ontology is a lacking information regarding the connections between the different structures within the same system (e.g., *which spinal nerve provides the nerve (terminal branch) to adductor hallucis*?), and between the different systems (e.g., *which muscles are innervated by L4 spinal root?*). This work focused on building these missing functional relationships and connections.

In order to achieve these goals, trained anatomists' described this information and the relationships in based on their teaching and dissection experiences. Associations between osteology, arthrology, myology, neurology and blood supply components of the lower limb were defined. These primary definitions were performed within crude Excel sheets. Since the later sheets are not practically suitable, the next step of the work focused on creating a visualization tool that allows the representation of all the information and connections in an efficient manner. The ApiNATOMY toolkit was used to integrate all these multi-systems information [2].

One of the challenges was to transform the 3D components of bones into a planar model, which is more convenient for schematic representation. Each bone of the lower limb was divided into different parts. These parts were further subdivided into different areas (an example of this division is showed on Fig.1.). For neural and vascular system all elements were defined along a "child–parent" tree-like schemes.

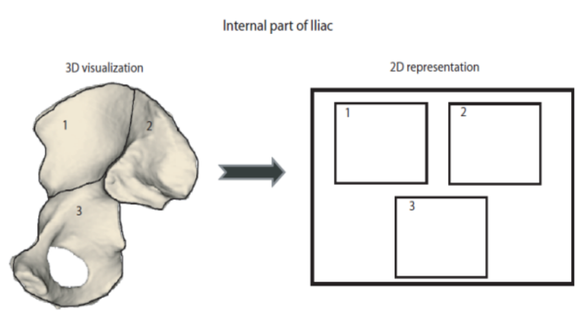
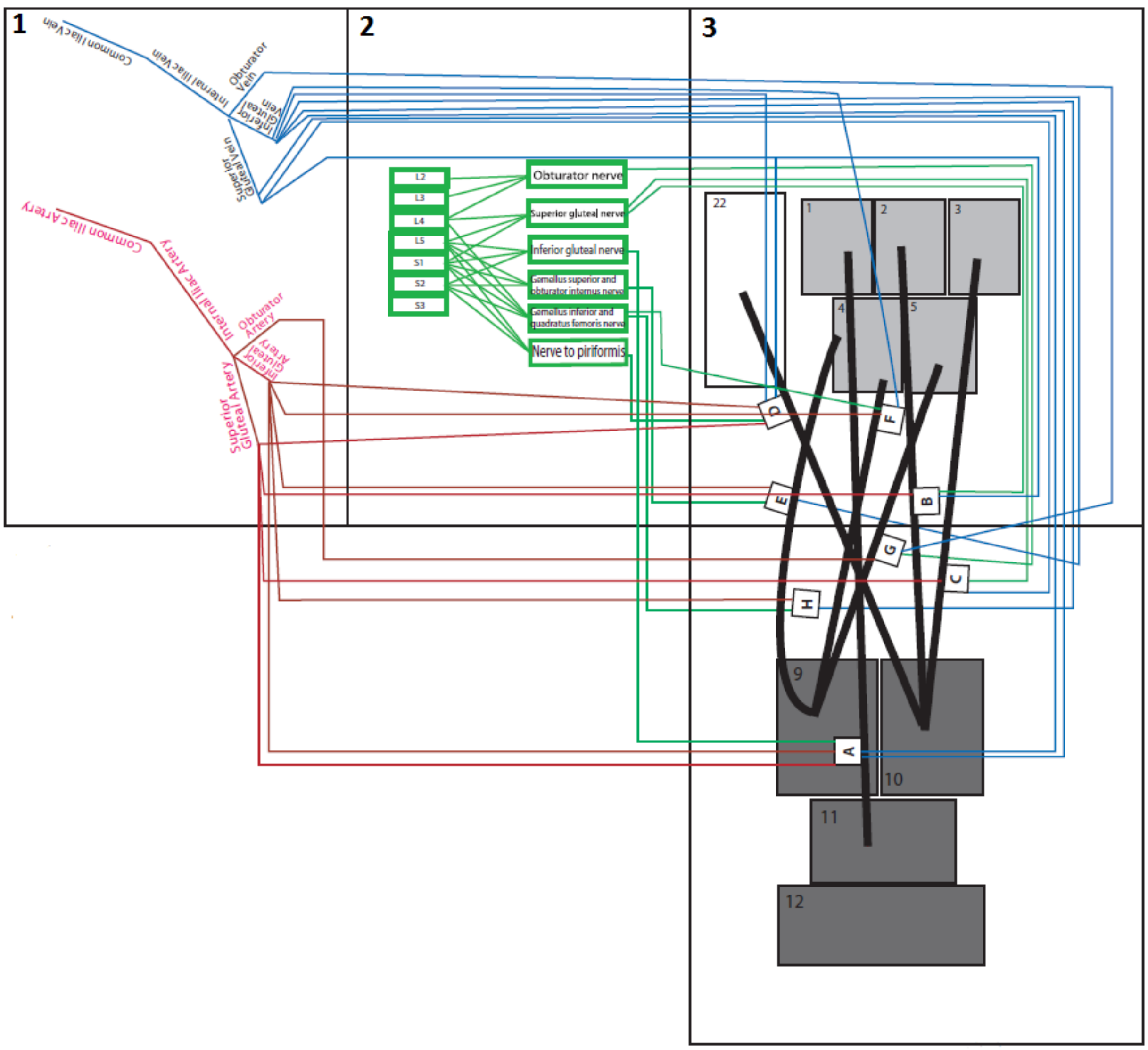


Figure 1: Representation of the division of the internal aspects of the Iliac bone into three regions.

Results and discussion

An example of scheme that has been created is presented in Fig.2. It shows the posterior part of the iliac and femur bones and includes pelvis muscles and their connectivity with vascular and neurological structures. Note that this scheme is automatically generated by the ApiAnatomy tools used for this study from the anatomical relationships above-defined by the anatomists.

Figure 2: Representation of pelvis muscles. In the box on the left (1) the hierarchy of arteries and veins, in the middle box (2) the neural part with connection between spinal roots and nerves (in order to not overload the figure connections with the plexus were not represented). In the box on the right (3) the subdivision of the external part of iliac and posterior part of femur, black lines present the muscles: A=*Gluteus Maximus*, B=*Gluteus Medius*, C=*Gluteus Minimus*, D=*Piriformis*, E=*Gemellus Superior*, F= *Gemellus Inferior*, G=*Obturator Externus*, H=*Quadratus Femoris*. All these structures are then linked with their anatomical and functional connections.



Conclusions

In this paper we presented a new methodology aimed to improve visualization of all functional connectivities between anatomical structures. Great care must be taken so that this simplification of the anatomy's high complexity corresponds to reality. Of course some information about descriptive anatomy will be lost because this work primarily focuses on the functional aspects. On the other hand, the developed ontologies can be easily integrated in a variety of educational or professional tools: for example, an electronic anatomical atlas that would use the ontology to guide a students between the various anatomical and physiological components related to particular functions, e.g., *what are the components required for walking?* Note that the answer not only include joints and muscles, but also the nervous and blood supply and their relationships towards the heart and the central control by the brain. Other applications include guideline support for diagnosis pipeline or annotation support for clinical reporting. Another benefits to such complete functional ontology is that it could be used as a standardization tool between medical professionals.

Acknowledgments

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