Nervous System Exploration Using Tractography To Enhance Pelvic Surgery

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Pelvic surgery raises the challenge of preservation of nerves that handle urinary, genital and digestive functions, especially in situations where these structures may be modified by tumors or malformations. Recent works on 3D nerve visualization, that rely on cadavers dissections [1, 3] or intra-operative use of probes detecting myelin-binding fluorophores [5], do not provide pre- or post-operative analysis of the pelvic nervous anatomy. Magnetic resonance neurography as in [12] requires a slice by slice manual segmentation of the nerves. Diffusion MRI, associated with tractography algorithms, is currently the only technique allowing for in-vivo exploration of the nervous network [2] with no need for manual nerve segmentation. In contrast to brain imaging that motivated a lot of work, only few studies focus on peripheral nerves visualization [9, 10, 14]. In this paper, we propose a method for pelvic tractography analysis based on patient-specific organ segmentation. It is demonstrated with promising results on a healthy adult subject.

1 Anatomy of the Pelvic Nervous Network

The pelvis region is a complex 3D structure gathering urinary, genital and digestive systems (see e.g. [8]). These systems are both irrigated and innervated by an intricate network of vessels and nerves, enclosed by a tight bony and muscular cage (Fig. 1). Somatic functions of pelvic organs are ensured by a ramified nervous network, originating from the spine and issuing from L4-L5 vertebral canals and S1-S4 sacral holes. Autonomous functions are ensured by the presacral sympathetic/parasympathetic networks originating from neural crest migration. Being directly involved in both conscious and unconscious motricity and sensitivity of organs and skin, the main nerve bundles to be preserved during surgical operations are the sacral plexus, pudendal plexus, pudendal nerve, and inferior hypogastric plexus.

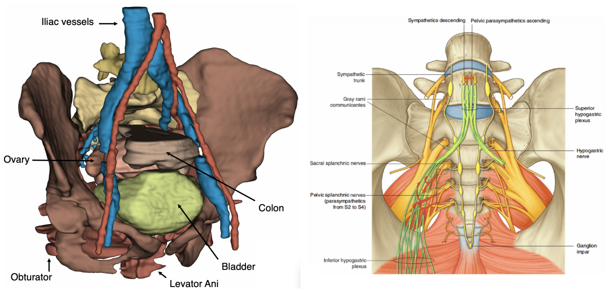

Figure 1: *Left: Pelvis 3D model for an adult healthy female subject. Right: Pelvic somatic and autonomous nerves [8].*

2 Methods

The complexity of the nervous network anatomy makes it difficult both to observe using standard CT and MRI sequences, and to analyze, thus limiting the de-

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velopment of nerve preservation techniques in pelvic surgery. The proposed method relies on a combination of anatomical and diffusion MRI sequences, segmentation of anatomical structures, and recognition of the nerves from tractography based on their spatial arrangement.

2.1 Data Preparation

The data used to illustrate the method are MRI images of an adult healthy female subject. A volumetric T2w image (with a voxel size of $0.625 \times 1 \times 0.625\, mm^3$) was used for the organ segmentation. A DWI image was acquired with 50 directions, $b = 1000$, voxel size of $2.5 \times 2.5 \times 3.5\, mm^3$, and a tractogram was computed using a diffusion tensor based algorithm, with the software MRTrix3 [13]. To avoid inherent limitations of ROI based pelvic tractography (e.g. lack of reliable seeds positioning due to noise issues) [10] limiting tractograms accuracy, we selected seeds sparsely in a whole-body mask. The parameters were set as follows: seeds condition $FA > 0.15$, termination condition $FA < 0.01$, fibers length $= 50 - 800mm$. The final whole-body tractogram was composed by one million fibers.

2.2 Organ Segmentation

Pelvic organs segmentation (Fig. 1) was manually performed by an expert surgeon on the T2w image within the 3DSlicer [11] environment. The segmented regions were: pelvic bones (hips and sacrum) and muscles (piriformis, coccygeal, obturator and levator ani), bladder with the ureters, genital system (vagina, uterus and ovaries), colon and rectum, iliac vein and arteries. In order to provide additional spatial references to the tractography segmentation algorithm, specific regions of interest for nerves (sacral canal, sacral holes and ischial spine) were subsequently identified in the image.

2.3 Tractogram Processing and Nerve Recognition

Due to the huge amount of false positives encountered in whole-body tractograms, we introduce a filtering algorithm that exploits spatial relations between nerve bundles and segmented anatomical structures. The core of the contribution is the recognition of each nerve bundle based on directional, path, connectivity and orientation information. For instance, S4 is described as "crossing **SacralHoleS4** *and* crossing **SacrumCanal**". Similar descriptions have been developed for all nerve bundles of interest. Translating these descriptions, expressed in natural language, into operational algorithms requires modeling each spatial relation. An approach based on simple relations between bounding boxes of organs, as proposed in [15] for brain white matter, is not sufficiently accurate given the complexity of the pelvic structures. Therefore, we propose to rely on the previous segmentation, and on fuzzy definitions of spatial relations [4], similarly to [6, 7]. For instance, a directional relation with respect to a given structure is modeled as a cone originating from this structure and oriented in the desired direction, and a fiber in this cone satisfies the directional relation to the structure. A recognized bundle is then a set of fibers satisfying the description.

3 Results

Sacral Plexus (from L5 to S4), Pudendal Plexus (P) and Inferior Hypogastric Plexus (IHP) are represented in Fig. 2 along with relevant structures. Optimal concordant anatomical results were obtained for the sacral plexus, including sacral root S4. The pudendal nerve, originating from the pudendal plexus, was not viewed in its entirety until the pubic junction. The inferior hypogastric plexus is a thin but rich nervous network which was not completely represented either. The use of higher resolution diffusion images could further improve the results.

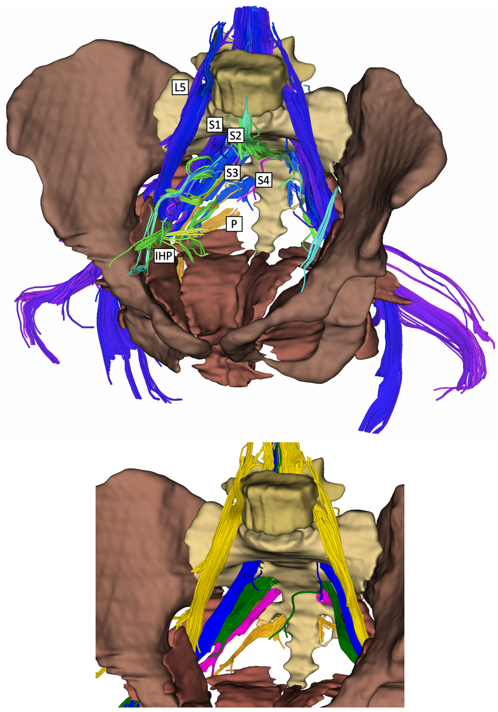

Figure 2: *Top: Sacral (Blue), Pudendal (Orange) and Hypogastric (Green) plexuses obtained with the proposed method. Bottom: Sacral Plexus detail.*

4 Conclusion

This preliminary study demonstrates the feasibility to visualize both somatic and autonomous pelvic nervous network using in-vivo tractography techniques. We are currently evaluating applications for surgical planning and post-operative follow-up in pediatric cases of pelvic malformations and tumors.

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