Towards developing an MRI-based mapping and 3D visualization of erectile nerves

Kharlamov, E; Mitrokhin, V; Pyatnitskiy, I; Vorontsov, O; Aleksandrov, B; Droupy, S
Cavernous nerves (CN) mapping is highly non-trivial

CN are **microscopic** and show **variable locations in different patients**; postoperative sexual potency rates are widely variable following radical prostatectomy;

**several technologies** are being used to study cavernous nerve anatomy and physiology:
- electrical and optical nerve stimulation
- dye-based optical fluorescence and microscopy
- Ultrasound and MRI, etc.

some of these methods have a potential for intraoperative use for identification and preservation of CN.

We consider MRI as one of the best appropriate techniques for accurate and convenient cavernous nerve mapping.

The goals of the study:

• to develop a precise methodology that allows mapping erectile nerves and vessels around the prostate and then down towards the crus of the penis

• to evaluate this methodology in the clinical practice for:
  • preoperative planning
  • 3D virtual patient-specific modeling
  • intrasurgical fused MRI-Ultrasound navigation
  • intrasurgical computer assistance via virtual reality (VR) and augmented reality (AR)

We developed a scanning & mapping methodology with:

- **12 MRI studies with Siemens MRI scanners with 3 healthy volunteers:**
  - Aera48 1.5T, two Coils Body18;
  - Skyra48 3T, Coil Body60;
  - Prisma64 3T, Coils Spine+Body18

- **MRI image segmentation and 3D modelling**
  - Software: Siemens syngo MR E11, Inobitek DICOM viewer PRO (v. 1.14), Matlab, 3D Slicer 4.10.2.

- **Model evaluation with in-vivo electrostimulation and histological staining of cadaver tissue**
Results: the developed methodology includes 3 steps

1) MRI of the human male pelvis and internal part of the penis
   MRI scan protocol:
   • T2_TSE (AX, COR, SAG)
   • T2 mapping (AX)
   • T2_space ZOOMit (AX)
   • T2_space_SPAIR

2) Post-processing in order to locate main structures and map the CN

3) Detailed 3D reconstruction of the manually differentiated nerves

We verified the accuracy of MRI 3D model using:
   • in vivo electrostimulation of 10 patients before robot-assisted radical prostatectomy
   • histological study of cadaver tissue after MRI and 3D modelling
1) Coils are located above and below the patient, thus the maximum density of the scanning elements is in the zone of interest. The optimal location of the scanning elements relative to each other for the effective use of the parallel data acquisition factor (iPAT).

2) The direction of phase coding for sagittal images to eliminate signal loss in the center of FoV and minimize artifacts «flow»

3) Scanning with slicer blocks without «concatenation». Blocks are combined in MPR (multiplanar reconstruction).

4) Selection of scanning parameters (BW, TR and TE for TSE) and other sequences to minimize the movement artifact, structures contrast and chemical shift.

5) Comprehensive preparation of the patient before the MRI to minimize movement of internal organs (Espumisan + Microlax + Buscopan + Loperamide)

6) Using TrueFISP Cine to evaluate the preparation performance before scanning.
3D slicer MRI based (T2 seq) model of CN with the seminal vesicles, prostate and crus of penis regions

CN – cavernous nerves
SV – seminal vesicles
P - prostate
CS – corpus spongiosum
CC - corpus cavernosum
3D slicer MRI based (T2 seq) model of CN fused with T2_space_SPACEIR model (vessels segmentation)

CN – cavernous nerves
SV – seminal vesicles
P - prostates
CS – corpus spongiosum
CC - corpus cavernosum
3D slicer MRI based (T2 seq) model of CN fused with native T2 seq AX and SAG images

CN – cavernous nerves
SV – seminal vesicles
P – prostate
PB – pubic bone
CS – corpus spongiosum
CC - corpus cavernosum
3D slicer MRI based (T2 seq) model of CN with the main surrounding structures

CN – cavernous nerves
SP – sacral plexus
HP – hypogastricus plexus and nerves
ST – sympathetic trunk
SV – seminal vesicles
B - bladder
P – prostate
R - rectum
CS – corpus spongiosum
CC - corpus cavernosum
CN mapping process. MRI T2 SAG image fused with T2_space_SPAIR (bright, fluid liquid content structures). It helps to differentiate nerves and vessels.

CN – cavernous nerves (arrows)
B - bladder
P – prostate
SV– seminal vesicles
Erectile nerves visualization accuracy was assessed and verified using in-vivo electrostimulation and histological staining.

1) As the result of in-vivo electrostimulation the mean percentage of sensitivity and specificity of the methodology was 95% and 85% respectively.

2) As the result of histological staining, sensitivity and specificity was:
   - 91% and 84% for nerves > 0.3 mm
   - 55% and 49% for nerves < 0.3 mm
Comparison between Histology and MRI images

Nerve structures – red arrows and marks
Artery - blue mark
Our results on humans are among the first on MRI visualization of the pelvic plexus and CN with further verification. Comparing to previous works\textsuperscript{1} we demonstrated that our methodology shows high specificity for nerve fibers > 0.3 mm in diameter.

• CN mapping is still a highly non-trivial task
• CN can be precisely mapped with MRI
• Developed methodology facilitates high accuracy segmentation of nerves
• Pre-operative implementation of the developed methodology can optimize the prostatectomy strategy and increase CN preservation efficiency