Multimodal 3D Data Fusion and Reconstruction for Needle Insertion Guidance in Cryoablation Procedures

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La Medicina Incontra la Realtà Virtuale: Applicazioni in Italia della Realtà Virtuale in Medicina e Chirurgia

Intervention

Registration

CT scan

Patient Specific models

In-silico simulation

Planning

Diagnosis

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Summary

- Problem statement: pathology and therapies
- Ablation procedure: Cryo and RF
- Image guided interventions
- Description of proposed system
  - Intra operative data fusion
- Conclusions and future work
The Anatomy of Kidney Tumors

Kidney tumors are characterized by small size, confined area, and easier percutaneous access.

They are good candidates for ablation procedures.
Access Routes and Constraints

Must preserve bones and nerve structures

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Puncturing surgical action

- Act of penetrating a biological tissue with a needle, e.g. to perform a biopsy or perform ablation techniques.
- The goal is to reach the selected target point with a needle or probe.
- In contrast with "open" approach where inner organs or tissue are exposed
- The lesion is then burned using radiofrequency (RF ablation) or frozen using a cold probe (cryoablation)
Cryo versus RF Ablation

- To avoid dangerous low impedance path in RF procedure, a single needle is placed multiple times to cover the entire region of the ablation (very difficult to verify the correct coverage).
- Cryo Ablation could use multiple needles at the same time (more linear system).
- Cryo ablation could work in presence of big vessels near the tumors (with a lot of caution).
- Easier to check with medical image modality the coverage (the ablated region is a “iceball”).
Cryoablation Characteristics

- **Cryoablation**: performs cycles of freeze and defreeze to kill biological tissue.
- **Cryoprobes**:
  - **Iceball**: the distribution of the temperature inside the ice ball is not uniform but is described by set of isotherms:
    - From -3°/0°C, at the external margin of the iceball
    - The temperature decreases with a gradient along the iceball reaching -140°/-190° near the tip of the probe
    - The isotherms between -20°/-40° cause necrosis of cells.
Cryoablation Procedure

- Cryoablation is usually applied for patient with small tumours with a diameter < 4 cm and in which the tumour is placed in superficial position
- **Forbidden regions (kidneys crioablation)**
  - Ribs XI – XII
  - intercostal nerves, iliohypogastric and ilioinguinal nerves
- **Pre-surgical examination:**
  - CT or MRI images
  - definition of target area and surroundings
Diagnostic Aids

CT image allows to determine the position and dimension of the tumor (red circle) and delineate the position of the forbidden region, such as the ribs (yellow line).

(A) Renal ultrasound showing the lesion (arrow). (B) During cryoablation, the edge of the ice ball is identified as a hypoechoic area (arrow) with posterior acoustic shadow, making difficult the determination of posterior and lateral ice ball edges.

Percutaneous renal cryoablation under computed tomography (CT) guidance. (A) An exophytic renal mass is shown as a contour deformity on noncontrast CT (arrow). (B) One cryoprobe is placed in the tumor, and the ice ball is identified (arrows) as a zone of low attenuation that is easily differentiated from surrounding tissue. This ablation could be precisely monitored and controlled with CT.
Procedure Requirements

- Need accurate pre-operative planning
  - To avoid damage to vessels or healthy tissues
  - Usually the target zone is not visible during surgery (quality of intra-operative images is lower than pre-operative)
  - MRI is the imaging mode with higher quality, but usually less used
  - CT is widespread used, but multiple scans are needed → radiation dose problem
- US is less used due to the poor image quality
- The target moves when breathing
- The position of the target varies in time (pre-operative image != intra-operative anatomy)

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Intra-operative Images

- The target moves when breathing
Image guided surgery: general scheme

- Acquire volumetric data
- Preoperative data processing: extract features: markers, surface, gradients, intensities
- Plan
- Pre-operative
- Intra-operative
  - Place reference frames on tools, camera and optionally on patient
  - Calibrate tools and camera
  - Acquire images
  - Extract features: markers, surface, gradients, intensities
  - Register
  - Navigate

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Materials

- An optical tracker system, manufactured by NaturalPoint
- US system from Ultrasonix.
- RGB+depth camera Microsoft Kinect.
- Needle with markers
Image guided surgery: proposed approach
Pre operative data analysis

- Pre operative data have better image quality → easier to diagnose the lesion
- Usually a CT acquisition with contrast medium is available for the patient
- Easy to evaluate anatomical relationship and critical area for the procedure, and to define the target point and entry region.
Intra operative data: RGBD

- Surface reconstruction
- Markers segmentation
- Initial registration with CT surface (markers + surface CT - surface RGBD)
- Continuous registration to update data (surface RGBD - surface RGBD)

=> Patient monitoring: skin deformation, breathing motion, patient movement.
Intra operative data: Ultrasound

- Real time update of planning data
  - Patient is awake (under local anesthesia) during the surgery \(\rightarrow\) need to track motions of the target region due to breathing and tissue deformation (RGBD+US)
  - Blood flow to the kidney is not blocked during surgery \(\rightarrow\) need to monitor the flow (US?)
  - Needle tip position could be measured and compensated (US+RGBD?)
Tool calibration and tracking

- **US calibration**

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- **Needle calibration**

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Tool calibration and tracking

- Kinect calibration

![Graph showing tool calibration and tracking](image-url)
Image guided surgery: test set-up
Reference frames registration
Data fusion: US-CT-3D models
Data fusion: US-CT-Kinect
Example of navigation procedure
Conclusions and Future Work

- Cryoablation is an effective alternative to kidney partial nephrectomy
- The use of advance multi modal image and sensor integration could improve the accuracy and the precision of this technique.
- Advance navigation system could increase the safety of the procedure and could spread the application cases

Future Work:
- Breathing motion correlation based on RGBD data and motion model estimated from US data (Synergy style)
- Needle deformation estimation from US → tissue deformation model (FEM?)
- Iceball monitoring based on US data (FEM?)
- Animal and clinical trials of the developed navigation system
- Add semi-automatic tasks to the procedure
Thank you!