Magnetic nanoparticle detector for laparoscopic surgery: assessment of detection sensitivity

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PURPOSE

Sentinel lymph node biopsy (SLNB) is a minimally invasive procedure developed to detect and remove sentinel lymph nodes (SLNs) to select treatment regimes in a variety of tumor types. An SLN is one of the first lymph nodes draining from a primary tumor and it therefore has the highest probability of containing metastases. The detected SLNs are surgically removed and pathologically investigated to identify potential metastases. Consequently, when identified during surgery and free of tumor cells, removing all regional lymph nodes becomes obsolete decreasing the burden to the patient. Magnetic SLNB is enabled by injection of superparamagnetic iron oxide nanoparticles (SPIONs) combined with a handheld probe detecting the SPIONs. Additionally, a pre-operative MRI scan can be used for intraoperative guidance and a post-operative MRI scan can be used to confirm that all SLNs were removed. For abdominal tumors, such as prostate cancer, (robot-assisted) laparoscopic surgery is standard care. The main challenge when developing a detector for a laparoscopic procedure is the combination of diameter of the detector (limited by the use of trocars) and sufficient detection depth. A laparoscopic differential magnetometer (LapDiffMag) was developed to enable magnetic laparoscopic SLNB, and assessed on its clinical performance regarding (depth) sensitivity.

METHODS

To detect magnetic nanoparticles, differential magnetometry (DiffMag) was used [1]. This patented nonlinear detection method is SPION-specific and is influenced minimally by surrounding tissue and surgical instruments made of steel. LapDiffMag utilizes excitation coils to activate magnetic nanoparticles and detection coils to acquire the consequent magnetization of the particles. To maintain sufficient depth sensitivity after decreasing the diameter of the detector, the excitation and detection part of the system were separated [2]. Excitation coils were designed large and placed underneath the patient, while the detection coils in the probe are kept small enough to fit through a standard 12 mm trocar (Figure 1: setup). However, with this new setup, the detection coils move through the excitation field, leading to disturbances in SPION detection. This was solved by active compensation, a way to actively cancel-out the excitation field perceived by the detection coils, facilitated by an additional set of compensation coils [2]. To assess performance of the LapDiffMag, we used Magtrace® magnetic nanoparticles (a CE-certified and FDA-approved tracer for SLNB) in the following experiments:

- Identification of minimum iron content detectable by LapDiffMag: various amounts of Magtrace® (2.8, 5.6, 7, 9.8, 14, 28, 42, 56, 84, 112, 252, and 504 µg iron) were positioned directly in front of the probe.
- Assessment of depth sensitivity of LapDiffMag: a sample containing 504 µg iron was measured at various distances to the detection probe in air.

RESULTS

An advantage of LapDiffMag is that it potentially can be used in a regular operating room during laparoscopic surgery, in contrast to other magnetic methods such as an MRI scan or EMG measurement. Strength of the signal detected by the LapDiffMag system is presented on a screen and as a sound with a pitch corresponding to the strength of the signal detected. The minimum detectable amount of iron by LapDiffMag was found to be 9.8 µg, representing the sensitivity of the system. Detection depth of LapDiffMag for a sample containing 504 µg iron was found to be 10 mm.

CONCLUSION

LapDiffMag demonstrated promising first results in terms of iron sensitivity and detection depth. It is a new route for laparoscopic magnetic SLNB that has the potential to facilitate abdominal cancer treatment strategies.

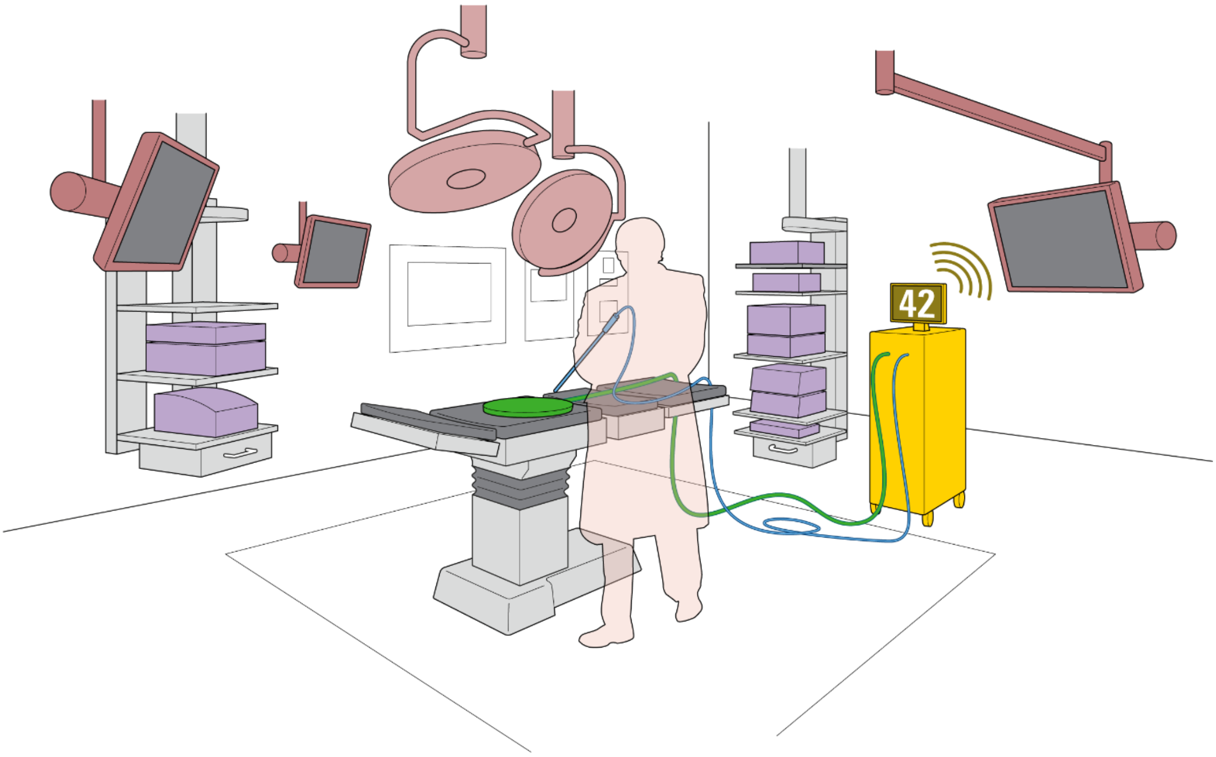

Figure 1 – LapDiffMag situated in an operating room. The excitation coil is shown in green, the detection probe in blue, and the control unit in yellow. The number (42) displayed, and the pitch of the sound represent either the amount of particles close to the probe or the distance between probe and sample.

REFERENCES

[1] Visscher M, Waanders S, Krooshoop H J G, ten Haken B (2014), Selective detection of magnetic nanoparticles in biomedical applications using differential magnetometry, Journal of Magnetism and Magnetic Materials, 365: 31-39.

[2] van de Loosdrecht M M, Waanders S, Krooshoop H J G, ten Haken B (2018), Separation of excitation and detection coils for in vivo detection of superparamagnetic iron oxide nanoparticles, Journal of Magnetism and Magnetic Materials, 493: 165362.