Magnetic Anchoring and Guidance Systems (MAGS)

Current state of MAGS technology and its future role in Minimally Invasive Surgery

Prof. Jeffrey Cadeddu
UT Southwestern Medical Center
Dallas, TX (USA)

jeffrey.cadeddu@utsouthwestern.edu

Dr. Jeffrey Gahan
Assistant Instructor
UT Southwestern Medical Center
Dallas, TX (USA)

jeffrey.gahan@utsouthwestern.edu

Urologic surgery continues to be one of the most dynamic surgical subspecialties in medicine. As a field, it has consistently embraced new and developing technologies and has implemented these into clinical care. This is especially true within the realm of minimally invasive surgery.

Due to recent advances in technology, even traditional laparoscopy is becoming less invasive and the concept of what constitutes minimally invasive surgery continues to be redefined. Most recently, laparo-endoscopic single site surgery (LESS) and natural orifice surgery (NOTES) have increased in popularity with the idea that cosmesis and trocar morbidity can be improved with smaller or even absent abdominal incisions.

However, these increasingly minimally invasive approaches can be fraught with difficulties. The technical demands due to loss of triangulation, increased instrument collisions, and complicated camera angles have limited these operations from becoming mainstream. Further, because of the shared extracorporeal working space, the surgeon and camera operator often experience a loss of ergonomic functionality.

For these reasons, LESS/NOTES are often considered difficult (i.e. frustrating) procedures even in the hands of the most experienced surgeons. Several adaptations have been made to alleviate these problems. Articulating instruments that bow out were introduced to re-create the triangulation that is seen with conventional laparoscopy. While this solved the problem of instrument triangulation, a new set of problems was introduced. Surgeons now had to adapt to a crossed working environment where the right hand controlled the instrument on the left side of the display. This led to an increased learning curve due to the deviation from the standard laparoscopic instruments. Flexible cameras and the da Vinci platform both helped to remedy some of these problems, but each have their own limitations. While flexible cameras reduce the number of external collisions, decreases in optical clarity as well as unfamiliar working angles are experienced.

The da Vinci platform has decreased the learning curve needed to perform LESS for two reasons. First, triangulation is improved with the robotic instruments as these incorporate the "bowing out" concept. Second, the surgeon's hands are uncrossed at the console so that the right hand now controls the instrument on the right side of the display. However, the robotic arms still cross inside the patient, and new operative techniques must to be mastered to avoid internal collisions. Importantly, the problem of external instrument collisions also remains.

Magnetic anchoring

One technology that has proven to circumvent many of the problems with LESS is magnetic anchoring and guidance systems (MAGS). This technology works something like the classic ship in a bottle where a small incision is made in the abdominal wall (or orifice in case of NOTES) through which surgical instruments are inserted, expanded and deployed. Theoretically, these devices do not occupy space outside the body, but are accessible to the surgeon for use. To be effective, these instruments must be steered and anchored to the abdominal wall in a non-traumatic manner while having adjustable working angles and locations.

MAGS accomplishes this with the use of external hand held magnets that couple to the internal devices. This allows one or more laparoscopic instruments to be removed from the working port (and therefore external space) and returns the surgeon to a more comfortable ergonomic environment. A further advantage of MAGS is the restoration of off-axis working angles. With this technology, the surgeon does not have to look down the barrel of the laparoscopic instruments and the blind spots experienced with conventional LESS are avoided.

Although MAGS technology has eliminated several problems associated with LESS/NOTES, several issues specific to this technology have arisen. The first involves anchoring the instruments to the abdominal wall. Magnetic forces diminish logarithmically with increasing distance, and the weight of the internal device-magnet complex creates a force opposing magnetic coupling. To anchor the internal devices required identifying magnets that were both strong enough to couple across the abdominal wall, while at the same time small enough to not hinder intracorporeal operating space.

Therefore, two pieces of equipment had to be optimised – the external magnet and the internal device-magnet complex. Neodymium-iron-boron (NeFeB) magnets were selected as permanent magnets strong enough to couple at physiologic distances. Further, these magnets have been shown to not cause skin or abdominal wall necrosis at four hours of coupling in a pig model.[1] A schematic representation is shown depicting both the external magnet and internal device-magnet complex. An external view of the hand-held magnets is also shown in a pig model (Figure 1).

Another concern is the obese patient and how MAGS would perform across large coupling distances. Our group has shown that at a range of 8 cm, the magnets are strong enough to maintain their coupling strength, which includes the abdominal wall thickness of all but the most obese patients.[2] However, some limitations remain. Any additional forces to the magnets can also cause decoupling and may be a constraint when using these magnets with retraction or dissection instruments.

Intraperitoneal camera

Perhaps the most promising initial application of the MAGS concept is the intraperitoneal camera. Early in its development, MAGS cameras provided poor images compared to the current digital laparoscopes. Lighting was also originally a problem as the light source was placed around the incisional trocar and shadowing became an issue. This was remedied by improving the optics of the camera itself and integrating the light source into the camera.

The current MAGS camera used by our group is a tethered 1.5 x 7 cm cylinder which contains an independent lens, a light source and a permanent magnet centered on the long axis. This camera achieves a 30-degree down angle with light provided by an LED array surrounding the lens and produces images rivaling the current 5 mm digital laparoscopes (Figure 2). The current prototype studied by our group has improved lighting and resolution compared to many previous designs.[3] Perhaps the most telling example of the functionality of this MAGS camera is the successful completion of both a MAGS-assisted LESS nephrectomy and appendectomy in human subjects.[4]

In addition to the MAGS camera, other instruments have been combined with MAGS technology including dissectors, cautery elements and retractors. Dominguez et al reported a series of 40 LESS cholecystectomies utilising a magnetic grasper/retractor they termed the "neodymium magnetic forceps."[5] This device consists of an internal magnet attached to an alligator grasper and is used for gallbladder retraction. This device couples to an external magnet and works when the paired external magnet is moved along the skin surface.

Through this, the gallbladder can be manipulated to facilitate dissection. The authors noted that the use of the magnetic forceps allowed them to achieve retraction angles (and therefore triangulation) during LESS surgery that would have been difficult, if not impossible, without another trocar. As the internal devices become more advanced and contribute more significantly to the operation, further instruments could be removed from the single port site thereby facilitating triangulation and decreasing instrument collisions.

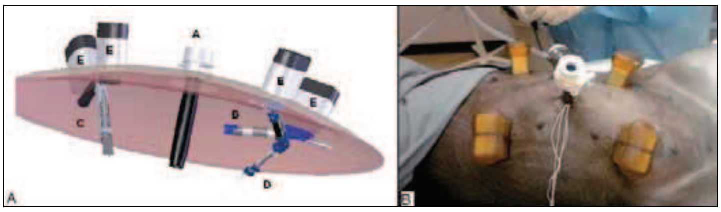

Figure 1: A: schematic representation of a magnetic anchoring and guidance system platform (MAGS). A- Conventional trocar B- MAGS camera C- retractor D- cautery element E- external magnets. B: External neodymium-iron-boron (NeFeB) hand held magnets (orange) used in a pig model.

MAGS technology represents an evolving technology that allows the key tenets of laparoscopic surgery to be maintained during LESS, namely triangulation. Theoretically, this should improve surgeon comfort and reduce workload. Our group recently compared MAGS-assisted LESS to conventional LESS looking at surgeon satisfaction. Unpublished work by our group using a Likert scale (impression of task difficulty) showed a statistically significant decrease in number of external and internal collisions, as well as improved ergonomics for MAGS-assisted LESS compared to conventional LESS. Within this study, an assessment of workload showed MAGS-assisted LESS resulted in a significant decrease in effort for surgeon and camera driver alike.

Admittedly, the current benefit that LESS confers to many patients is nominal when compared to the increased difficulty and ergonomic workload experienced by the surgeon. MAGS, however, may help to reconcile this difference. For example, we now accept a single camera as the standard for laparoscopic surgery. With this technology, multiple cameras could be deployed into the abdomen allowing the surgeon to switch between the two, giving multiple viewing perspectives and possibly eliminating the camera operator.

MAGS also has the ability to be integrated with already established technologies. A yet unexplored aspect would be combining a MAGS camera with the da Vinci platform. This would allow the bulky camera arm to be removed from the equation in single site robotic surgery, and permit an increase in the range of motion of the working arms without collisions.

Challenges

Although promising, as evidenced by previous work, challenges remain. The cameras have improved, but still require wires to pass through the incisional trocar. This has been noted to be a hindrance in their usage, again due to competing external working space. Ideally, wireless cameras and perhaps wireless instruments could be employed to maximise this technology. Further, the magnets themselves may need improvement in terms of coupling strength.

Currently, only permanent magnets have been studied, but electro-magnets may be useful as they provide stronger coupling forces with adjustable field strengths. Lastly, the internal working elements to date are rudimentary, mostly involving simply graspers and retractors. These devices may represent the area in most need of improvement if MAGS technology is to progress.

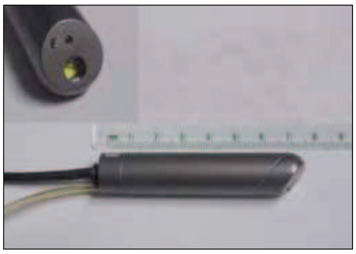

Figure 2: MAGS 30-degree down angle camera with LED light source.

To fully realise the potential of MAGS technology, improvements in multiple areas are needed; however, this will likely require a shift in the current paradigm towards one of purposeful design. Meaning, instead of adapting current technologies to suit MAGS usage, new instruments would be engineered specifically with the application of MAGS technology in mind. Perhaps with the development of novel MAGS equipment and devices, the current barriers to LESS/NOTES can be overcome and surgeons can continue to push the boundaries of minimally invasive surgery, only now without the frustration.

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