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INTERVENTIONAL MR SYSTEMS

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Abstract

This research paper is aimed at explaining the technology of interventional magnetic resonance imaging or iMRI. The technique has been described in detail followed by different varieties and examples of iMRI applications. In the next section, the advancements in this field have been discussed with special reference to magnetic resonance or MR compatible instruments and ongoing research on augmented reality (AR). However, the target being real time imaging all during a surgical operation, there still appear to be several challenges. The most critical challenges in using this technique have thus been discussed followed by a conclusion.

Keywords: Interventional MR, iMRI, intraoperative MRI, MRI, Magnetic Resonance,

Operating Room, imaging

Introduction

Magnetic resonance or MR techniques are extensively used in the medical world for imaging purpose. Magnetic resonance imaging or MRI is reliable, precise and detailed. Also, advanced MRI implementation can culminate at three dimensional or 3D view of a patient's tissue system. Previous to the development of interventional MRI or iMRI, most of the existing medical imaging technologies were primarily used for the purpose of diagnostic processes. But MRI proves to be more reliable than even the most advanced technologies like computerised tomography or CT scan (Blanco Sequeiros et al 2005). Therefore, experts are now considering expanded intraoperative usage of MR technologies, and iMRI has become a prime area of research in this field.

In this paper, iMRI is defined and classified in a detailed manner. Next, safety considerations are discussed. After that, important advancements in the field of iMRI are discussed. Contextually, challenges in the way of optimizing iMRI are detailed. The paper ends in a concise conclusion. The overall discussions in this paper are focussed on iMRI and the technology of magnetic resonance is elaborated wherever deemed necessary.

Definition and Classification

Initially, magnetic resonance imaging or MRI was utilised to find out and

examine greater intricacies of tissue structure. The primary aim was to understand patient morphology with the help of case specific details in furtherance with increase in scientific knowledge. Through the 1990s, research in magnetic resonance instrumentation targeted at finding out new methods to acquire detailed images more rapidly at higher resolutions to harness greater intricacy in understand patient condition and tissue abnormalities. The basic principle of the function of a conventional MRI device is shown in Figure – 1. (Coyne 2013; Brown and Semelke1999)

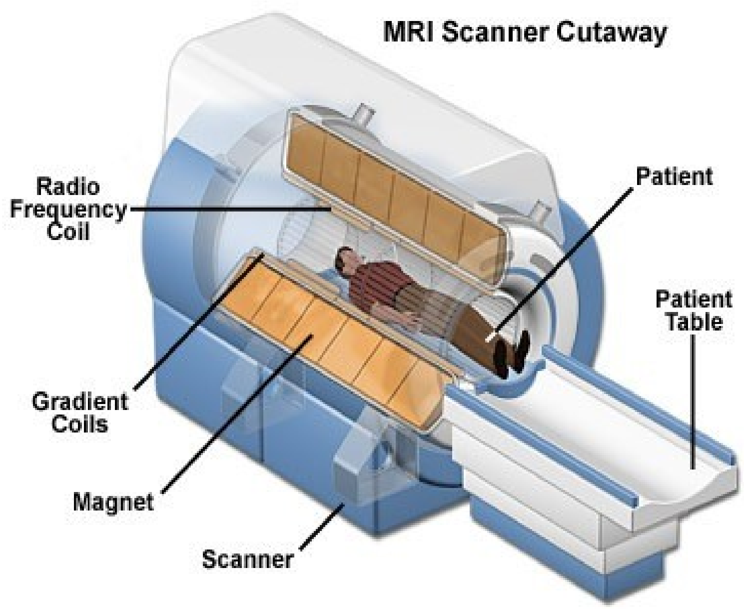


Figure – 1: Basic function of a conventional MRI system (Coyne 2013)

So conventional MRI and Interventional MRI (may also be referred to as

intraoperative MRI) or iMRI are completely different techniques although the basic technology behind them is the same. MRI is used in a largely stationary environment to meet diagnostic aims. But iMRI aims at not only examining but also treating the abnormal tissues diagnosed or discovered during an operative procedure. Furthermore, iMRI can both guide and improve the treatment process, including procedures in an operation room (OR). (Blanco Sequeiros et al 2005; Lufkin, Gronemeyer, and Seibel 1997)

Hushek et al (2008) state that iMRI applications have facilitated development of various improved ancillary devices and techniques that have enriched medical technology and biophysics holistically. For example, continuous research in the field of iMRI led to the invention of advanced pulse sequencing to establish a rapid imaging system with the help of an MR scanner. Furthermore, iMRI research led to the development of rail mounted patient transfer system (PTS) as well (Hushek et al 2008).

Classification

In this subsection, a concise classification of iMRI systems is given. Most of the explanations have been derived from Hushek et al (2008) and Lewin (1999).

(1) Superconducting 0.5T system: This was a low field strength application suitable inside an OR environment. The system can be used for MR guided surgical procedures. This kind of configuration can allow radiologists to directly access the imaging volume while interventional procedures are carried out. Surgeons are also provided with a standard approach up to the patient while near real time intraoperative imaging continues without moving the patient. (Hushek et al 2008)

(2) Compact iMRI system: This is an integrated MR system which works with surgical navigation instruments in neurosurgical OR without needing any extensive instrumentation changes. (Hushek et al 2008)

(3) 0.2T vertical gap system: This system is based on a low field conventional 0.2T permanent magnet system utilising horizontal gap. This kind of system can be rotated by

90o to give the gap a vertical configuration. (Hushek et al 2008; Schulz et al 2004)

(4) Horizontal gap systems: This system utilises shared resources for both diagnostic andoperative procedures. In this system, there is a flexible OR table which can also be utilised for imaging purposes as well. (Hushek et al 2008)

(5) Cylindrical bore systems: In this system in general, 1.5T cylindrical magnets are deployed in a flexible operative and imaging setting. These systems are organised as a “multiroom suite” (Hushek et al 2008) with additional rooms to provide for diagnostic imaging, magnet storage, additional OR space, etc.

(6) 1.5T MR/Angio suite system design (Hushek et al 2008): This is a medium to high strength iMRI system which is actually an improved bore magnet arrangement. It has multimodality configurations which can facilitate safe PTS even for patients having highly complicated cardiac conditions.

(7) 1.5 XMR suite system design: Sometimes, using X-rays for imaging purposes is an imperative. This kind of cases arises when the patient might not be exposed before strong magnetic fields. For example, if a patient has metallic implants in his/her body then he/she might not be exposed to a magnetic field. In such scenarios, portable X-ray machines must be used in combination with MR techniques. XMR suite systems help in achieving this. These suites mostly have multi-room configuration facilitated by rapid patient transfer systems. (Bock and Wacker 2008; Hushek et al 2008)

(8) 3.0T system designs: These are fairly high intensity magnetic field MR instrumentation.

A prominent example is the IntraOpSigna HD 3T MRI system designed by GE Healthcare. The machine applies magnetic fields up to 3T to obtain high definition and detailed images of the patient even in an OR environment. The machine has been

suitably designed to allow patient access and is equipped with surgical instruments that are not affected by magnetic field. (Hushek et al 2008; Lewin 1999)

(9) XMR suite application: Hushek et al (2008) state that cardiovascular applications of iMRI have substantial potential. However, they mainly suffer from hazards of radiation. In order to overcome this challenge, highly integrated MR instrumentations are being designed to use portable X-ray imaging machines in the OR environment. This class of designs has mostly been used on animal specimens in experimental setting and need

more clinical trials.

Safety Considerations

There are two important physical phenomena that may create considerable

problems while conducting iMRI. Firstly, there is the effect of heating of the sharp metallic instruments that are used for surgical interventions. This is also known as the antenna effect. According to Dempsey, Condon, and Hadley (2001), antenna effect may lead to the rise of temperature of terminal points of sharp instruments. Even inside the weaker magnetic field of an iMRI environment, temperatures of sharp surgical instruments (especially at terminal edges) may rise up to 63.5o Celsius. This is enough to burn a delicate internal tissue of the body.

Secondly, biophysicists and scientists are battling to mitigate the harmful

influences of the resonance effect too. Due to this effect, metallic loops (for example, a coiled catheter wire or guide wire) might be deflected when moved inside a magnetic field.

In the case of iMRI, the magnetic field caste across the patient's body may also cause similar defections of surgical instruments during an operative procedure.

Researchers like Dempsey, Condon, and Hadley (2001) point out that resonance effect causes unwanted heating too. Moreover, resonance effect may lead to instrumental malfunction. For example, an ECG machine may malfunction due to the resonance effect caused by RF waves.

Due to both the antenna and resonance effects, precise and sharp instruments may encounter the problem of heating while an iMRI procedure is being carried out. According to Blanco Sequeiros et al (2005), the hazard of radio frequency or RF generated heating of the terminal edges of instruments such as guide-wires and needles should be taken into account in order to avoid any damage of the affected tissue. An iMRI procedure can be further complicated if deflection of the sensitive surgical instruments occur. Moreover, materials with high magnetic susceptibility must not be introduced near an operating MR scanner even by accident. Furthermore, electrical appliances in the MR environment must placed with utmost care so that interference

problems may not take place. (Park et al 2010)

Advancements

The idea of iMRI originated during the late 1980s and early 1990s, when medical professionals were looking for more sophisticated devices for intraoperative monitoring of surgical processes. Experts like Elgort and Duerk (2005) have summarised various improvements in the evolutionary course of iMRI since the 1990s.

Improved MR scanner

Initially, only 0.2T to 0.5T magnetic fields could be used for the purpose of iMRI.
But by the middle of 2010s, advanced short bored open scanners have been developed which can caste more homogeneous magnetic fields with strengths ranging from 0.7T to 1.5T. These scanners are manoeuvrable and more precise. (Elgort and Duerk 2005)

However, powerful scanners with strength up to 3T have also been achieved for the purpose of iMRI. IntraOpSigna HD 3T MRI system designed by GE Healthcare can be regarded as a prominent example (Hushek et al 2008).

Interventional pulse sequencing and adaptive imaging

For diagnostic purposes, even only a single image of a tissue area can be sufficient. This image can be constructed with the help of different frames and imaging pulses to give rise to a three dimensional (3D) impression. However, iMRI is far more complicated. (Gedroyc 2000; Blanco Sequeiros et al 2005)

In iMRI, two pre and post operative images of the affected tissue area are critically important. And in the course of the operative process or surgery, images must be taken in smaller time intervals. For the purpose of surgical navigation, even real time imaging is necessary. Fast frequency imaging techniques like SSFP (Steady State Free Precession), FIESTA (Fast Imaging Employing Steady State Acquisition), etc. have now been introduced in the sphere of MR imaging that can immensely help in obtaining at least near real time images. (Elgort and Duerk 2005)

Furthermore, new techniques of setting adaptive image parameters have revolutionised the process of imaging plane adjustments. Software applications for custom image reconstruction along with catheter driven MR imaging have proved to be highly assistive in this regard. (Wacker et al 2004)

MR compatible instruments, tracking and visualization

Several manufacturers like Sophysa, TopSpin Medical, Inc., etc. have developed MR compatible instruments that can be used to handle even the most risky patients.

These instruments are precise and usable even inside high magnetic field environments. Moreover, the instruments can be tracked with much ease due to higher patterns of contrast. For details, see Figure – 2 and Figure – 3. (Sophysa 2013; Kolka 2008)

Figure – 2: MR compatible universal shunting valve. These shunts can be used to facilitate blood

circulation or flow of cerebrospinal fluid as the case may be. (Sophysa 2013)

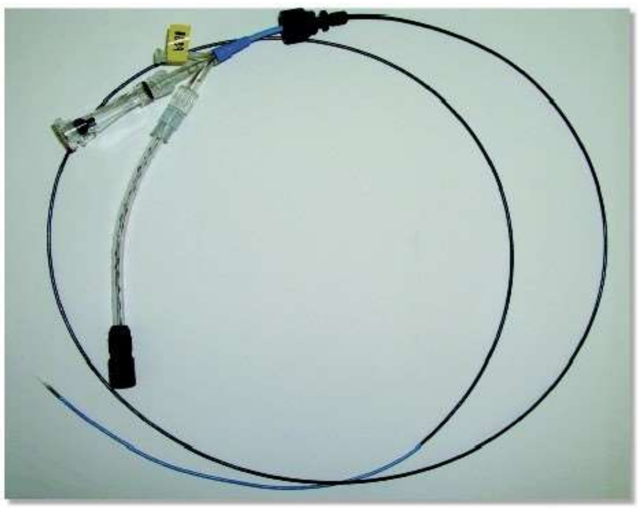


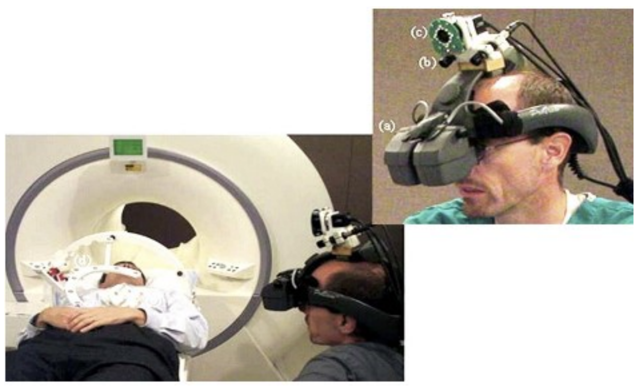
Figure – 3: MR compatible catheter from TopSpin Medical, Inc. (Kolka 2008)

Catheters are the most critical instruments whose movements are to be monitored in the course of an intraoperative MR imaging event as the surgical processes progress. For optimal catheter visualisation, Elgort and Duerk (2005) have pointed out that there are two most benefiting methods. Firstly, tuned resonant circuits which are

"capacitively coupled to separate channels of the MR scanner's receiver hardware" (Elgort and Duerk 2005, p. 1090) can be used which creates different colours for the catheter tip and catheter length. Secondly, tuned resonant circuits having inductive coupling with the "external transmit/receive RF coils" (Elgort and Duerk 2005) can be used which provides better visualisation by amplifying the signals gathered from the catheter based coil.

Augmented reality introduced in surgical system

Augmented Reality or AR technique is still in a state of development and needs reliable clinical trials involving human volunteers. However, it appears to be a very practical and promising imaging technique that can help in image manipulation almost in real time and unprecedented rapidity (see Figure – 4). Surgical systems in the realm of AR will allow preoperative collection of MR images even while the patient has not been placed directly under an MR scanner. This is facilitated outright during the intervention (for example, during a percutaneous procedure) by slotting in image data "along with additional real-time information, directly into the surgical environment through 3D overlays mapped onto the patient and surgical equipment." (Elgort and Duerk 2005)



(d)
Figure – 4: An iMRI application set up with augmented reality or AR capability. Part (a) is a stereoscopic display sys t e m . P a r t (b)(eis) a pair or video cameras. Part (c) is a tracking camera. Part (d) is a cluster of reflective markers. Part (e) is a cluster of both optical and MR markers. (adapted from Elgort and Duerk
2005)

Challenges

According to basic theory regarding the functions of an MRI device, an ideal material that is to be used to manufacture an MR compatible instrument should have magnetic susceptibility comparable to that of a human body. Several plastic materials have such features. Gedroyc (2000) has mentioned substances like Plexiglas and Teflon in this category of MR compatible materials. But the challenge is that when an instrument is manufactures with the help of this kind of plastic, it may not be as precise and stiff as its metallic counterparts. In other words, instruments such as scalpels can be manufactured with a suitable plastic material, but its sharpness and stiffness are generally not up to the requirements of surgical procedures.

Furthermore, although plastic made instruments can be used inside or adjacent to a magnetic field, they are difficult to visualise due to their human-like magnetic susceptibility. Moreover, problems arise during sterilisation as well (Gedroyc 2000).

Biophysicists have tried to manufacture MR compatible and optimally effective

instruments with the help of alloys such as titanium alloy. These instruments were helpful to solve the problems of visibility, durability and sterilisation. However, alloy-built instruments also proved to be insufficiently stiff and sharp in critical surgical procedures.
(Gedroyc 2000)

Manufacturers have been able to bypass a considerable number of constraints to built MR compatible devices and instruments. For example, a cerebrospinal fluid (CSF) shunting valve to be used during spinal surgery can be manufactured with the help of alloys in some portions and plastics in others. But heating may occur even to MR compatible instruments. This effect is correlated with the strength of the magnetic field applied. Imaging sequences used may also induce heating of the instruments. Strong magnetic field iMRI applications with rapid imaging sequences are particularly prone to this problem (Blanco Sequeiros et al 2005).

Slow image updating is another critical issue in iMRI. During surgical operations particularly when considerable invasion is necessary (e.g. a major cardio-vascular surgery), only low magnetic field strength MR imaging scanner is plausible. And when low field strength iMRI instrumentation is used, images are acquired slowly, frame rates can be poor, and low resolution images are obtained. Now even when low resolution images are obtained, general surgical navigations can be carried out. But slow frame rates or imaging pulses may lead to considerable loss of valuable time. According to Blanco
Sequeiros et al (2005), such a situation is rather “frustrating” for the healthcare

providers,

mainly the surgeon.

And if there are strict necessities regarding the quality of an MR image (for example, in tumour resections the quality of post-operative imaging is a crucial factor), then most of the iMRI applications appear to be unreliable. Firstly, inside an OR environment it is generally impossible to apply intense magnetic fields ranging up to 3T. This results into poor quality images. Secondly, without optimum pulse sequencing and implementation of a dedicated software suite, customised reconstruction of MR images to culminate at a 3D
view of the affected tissue is not possible in real time. (Elgort and

Duerk 2005; Lewin 1999)

Conclusion

It cannot be denied that there are many hurdles in implementing iMRI in most of the complicated OR scenarios. Further, advanced iMRI applications appear to be costly. MR compatible instruments are still being developed and instrument performance needs to be optimised. Yet, by the means of continuous hard work and research, medical technologists are coming up with more advanced iMRI applications. These days, at least near real time images of an operative procedure can be obtained with iMRI, and introduction of advanced technologies like AR can drastically improve reliability and usability of this interventional imaging technique.

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