The Journey of MRI Guided Interventions and Focused Ultrasound
A Tribute to Professor Ferenc A. Jolesz
21 May 1946 – 31 December 2014

I am very honored to have been asked by EUFUS to present this tribute to my close friend, Professor Ferenc Jolesz, (see Fig. 1) who was very instrumental in all the subjects that were considered in the recent EUFUS Meeting in Barcelona. I am privileged to have taken part in the the journey that Ferenc and I experienced together in the development of Image Guided Therapy and Focused Ultrasound.

Ferenc – or as he was called in the USA – Frank, was born on May 21, 1946 in Budapest to holocaust survivors. And here in Fig. 2 we have a picture of him at age 2 ½.

Budapest is a beautiful city – and I always enjoyed going there with Ferenc, although now I wish I had done this more often. (See Fig 3, courtesy of Google Maps) Because of its beauty I understand why he felt so close to it all the time the famous Chain Bridge is shown by day and by night in Fig. 4. It sits across the Danube River with Buda on the west and Pest on the east bank. In Fig. 5 is the magnificent Buda Castle, which was the residence of the Hungarian Kings.

Ferenc had an interesting career in Budapest. He graduated summa cum laude in Medicine from Semmelweis University (Fig 6.) in 1971. But instead of practicing medicine, he served as a research fellow in Biomedical Engineering and Computer Science at the Kalman Kando College of Electrical Engineering in Budapest (Fig.7). He then completed a residency at the Budapest Institute of Neurosurgery (Fig. 8).

He, his wife Anna and their two daughters moved to Boston in 1979, where he initially worked as a research fellow in the Department of Neurology at Massachussets General Hospital (Fig 9). This was followed by a Research Fellowship in physiology at Harvard Medical School. He joined the Radiology Department of the Brigham and Women's Hospital (BWH) in 1982, first as a resident, then as a clinical fellow in neuroradiology.

He made a pretty swift progression at BWH:

- 1982: Clinical Fellow, Dept. of Neuroradiology, BWH
- 1982-1985: Resident, Diagnostic Radiology, Dept. of Radiology, BWH
- 1985: Staff Neuroradiologist, Brigham and Women's Hospital
- 1985-1989: Assistant Professor of Radiology
- 1987-1988: Director, Neuro MR Imaging Section, BWH
- 1988-2014: Director, Division of MRI, BWH
- 1989-1996: Associate Professor of Radiology
- 1996-1998: Professor of Radiology
- 1998-2014: B. Leonard Holman Professor of Radiology
- 2000-2009: Vice-Chairman of Research, Dept. of Radiology, BWH
- 1993-2014: Director, Image-Guided Therapy Program. BWH
- 2001-2014: Director, Advanced Imaging Center, Harvard Medical School, NeuroDiscovery Center

He thus progressed from a Professor, to a Professor with a Chair, and then became the Vice Chair responsible for research. But most important, and the direction of his energies and thoughts, was his responsibilities for Image Guided Therapy and Advanced Imaging – primarily to enable IGT – Image Guided Therapy. This became the key to our relationship.

He had fantastic colleagues at BWH (see Fig 11), and constant important visitors from all over the world. A key colleague was Clare Tempany (Fig. 12) who now has the key role in continuing his legacy to this day.

Nonetheless Frank stayed close with his family including his wife, Anna who is also an MD, and with his daughters, Marta and Klara. (see Fig. 13 courtesy Anna Jolesz)

And in Fig 14 you can see two of his colleagues and collaborators. On the left you see Nobuhiko Hata – Noby as he is called, currently a Professor at Harvard and working on Image Guided Therapy using image guidance for surgical navigation using robotics
And on the right you see Professor Ron Kikinis, who ran the Surgical Planning Lab at BWH – SPL as it was called.

We saw Ferenc often at the table, and he did love a great meal with his Hungarian friends.. (Fig. 15) We also,had the good fortune to share more than one meal with Ferenc and Anna in Budapest.(Fig 16)

In Fig 17 you see him with one of his closest friends, Prof. Imre Repa, MD, who was one of the first people to use FUS in Hungary, and who, I am sure can tell you much more about Ferenc.

Now, back to Image Guided Therapy and Focused Ultrasound and my personal odyssey with Ferenc: how was I lucky enough to get involved with Ferenc and Image Guided Therapy?

In 1967 I joined the Imaging Group at GE's R&D Center in Schenectady, and in 1975 I moved from the R&D Center to GE Medical Systems (GEMS) in Milwaukee to help start the CT business. I was in CT till 1981 when I started the MR program at GEMS and I did that for about 8 years. This is when I first met Ferenc. Then when my boss, Joe Williams, asked me to look for the "Next Big Thing," I became intrigued by the thought of using imaging and particularly MRI to help in surgery and other forms of therapy delivery. But I started by trying to understand the roles of those medical imaging modalities that GE was not in. Primarily among these was laparoscopy, which was started by Georg Kelling who performed the first experimental laparoscopy in Berlin in 1901. He used a cystoscope to peer into the abdomen of a dog after first insufflating it with air (see Fig 18).

By the late 80's the most exciting use of laparoscopy was to perform a laparoscopic cholescystectomy – the first of which was performed by Professor Dr. Med Erich Mühe on September 12, 1985. (See Fig 19).

It took me almost a month to be able to pronounce "laparoscopic cholescystectomy" without stumbling!

However, the problem with laparoscopy is that it only is able to view the surface and is unable to "get inside". I became very intrigued with the whole idea looking inside and using imaging, specifically MRI, to provide the planning, guidance, monitoring and control capabilities to surgery. This would assist in the transition to minimally invasive procedures which were becoming important in the late 80's and early 90's. To my mind, instant visual control is important to make sure that any surgical procedure is carried out appropriately; no one would advocate doing open surgery with a surgeon who could not see what he was doing; the same should be true of minimally invasive procedures.

About the same time, in 1989, Ferenc gave a famous lecture at GE Medical Systems, and interestingly enough, it was the first time that the CEO of Medical Systems, John Trani, actually sat through a scientific lecture. Ferenc's pointed out that currently, unlike radiology which used computers and advanced software techniques, surgery was still using the same surgical tools that were used by the Egyptians 5000 years ago (see Slide 20). And the whole process depended on the hand-eye coordination of the surgeon.

Ferenc's point was that it was time for a change!

My imaging background helped me understand the potential importance of imaging in patient management. There were four key places where imaging was important in this process: Screening, Diagnosis, Staging and Therapy. The appropriate imaging could provide improved visualization for minimal access therapy procedures and in this way broaden the role of Interventional Radiology. This was especially so as there were a lot of new therapies beginning to be used in the late 80's and early 90's:

- chemoablation techniques
- brachytherapy
- interstitial laser therapy
- RF ablation
- Cryosurgery, and hopefully soon
- Focused Ultrasound

These approaches were both percutaneous and non-incisional. So imaging had a fourfold role in therapy:

1. Planning: better planning and training to reduce procedure time,
2. Guiding: Improved visualization to increase the potential range for Minimally Invasive Surgery,
3. Monitoring: Watch what you are doing it while you are doing it, and
4. Controlling: It is particularly important to be able to control the new therapies such as the thermal therapies, brachytherapy and chemoablation.

Ferenc was particularly instrumental in convincing me that the "Next Big Thing" was to use MR to guide, monitor and control therapy. MR provided superior image guidance and with the right MR system it would also provide the ability to monitor and control what was happening in real time

So the "Next Big Thing" was Image Guided Therapy and I soon became responsible for for it at GE. Figure 21 shows my favorite slide that I used in all my talks about Image Guided Therapy.. In figuring out how to do this, I was constantly consulting and "colluding" with Ferenc.

At about that time, in the late 1989/90 period, Peter Jakab and Ferenc came up with a unique concept to perform lithotripsy within an MR system.

Lithotripsy at that time was very primitive and was done without on-line monitoring of any sort. Peter had the concept to place an array of wires inside a donut shaped waterbag within the MR system around the patient and parallel to the bore of the MR system. One then sent sharp electrical pulses into the wires, which, since they were inside a static magnetic field, would vibrate (just like the gradient coils vibrate during any MR imaging acquisition.) If the wires were pulsed with the correct phasing, a shock wave would be created and focused on the target of interest. Except for the facts that this system used a shock wave and the application was lithotripsy, it is obvious that this is an ancestor of our current focused ultrasound system. This concept became United States Patent 5131392, filed on February 13, 1990 and published on July 21, 1992. See Fig 22.

About the same time, in 1988- 89. Trifon Laskaris and his colleagues at GE's Research and Development Center were developing a novel magnet for an un-named Government Agency which they described as a pair of hula hoops! They were using Niobium-Tin which is superconducting at 10 degrees Kelvin instead of Niobium Titanium which required cooling to 4 degrees Kelvin. The question was whether we could make a magnet using this concept. The first step was to create a feasibility system which eventually was named the IGMIT magnet. The basic concept is shown in Fig 23, with a model shown in Fig 24.

This program was not financed by GE, so to get it done we needed to use OPM (Other People's Money). We were fortunate that through the GE Medical Sales Team in Toronto and its leader, Joe Sardi, we received funding from the Ontario Government in order to build a simple head-only magnet that could be used to perform neurosurgery. The condition was that we had to build two systems, a prototype to be built and installed at Sunnybrook and a final system for neurosurgery at Toronto Western Hospital.

The prototype was built for installation at Sunnybrook Hospital in Toronto, although it was not as beautiful as the model. In Figs 25 and 26 IGMIT system is shown before the covers were put on, and after. And in Figs 27 and 28 are shown how the system was used and some images that were constructed. This was done with the collaboration of the Sunnybroook team headed by Mike Bronskill and his students, as well as Walter Kucharczyk, who was Professor of Medical Imaging at the University of Toronto.

However this configuration turned out to be extremely difficult and expensive to build. In the end we decided on a simpler configuration for the second system to be installed at Western Hospital. This was to take a standard 0.2T biplanar magnet that was built by the GE subsidiary, Yokagawa Medical Systems and turn it 90 degrees (see Fig 29). It was sited in a fully equipped neurosurgical operating room at the Toronto Western Hospital. Although the 46-cm gap was not spacious enough for larger patients or surgeons, it did allow surgery to proceed with rapid imaging for guidance and monitoring as well as controlling the progress of the surgery. There is an excellent article on this and the topic of Interventional Magnets by Scott Hinks, Michael Bronskill, Bruce D. Collick, R. Mark Henkelman, Walter Kucharczyk, and Mark Bernstein, who were the key members of the GE, Sunnybrook and Western teams[1].

However, this did give us the experience and the impetus to create what was called the Signa SP MR System, and also called the MRT (for MR Therapy). But it was usually called the "Double Donut" from its appearance as you can see from Fig 30. It took a while to design and build this system, initially mostly done at the GE Research and Development Center, but in the end it was completed. The key was that this system enabled the doctor to see what he or she was doing inside the patient while they were doing it.

There were some very unique features to the system, as shown in Figs. 30 and 31. It was a 0.5T system which allowed flexible patient entry and positioning, with the patient table entering either axially or transversely. It also allowed the patient to be examined while sitting which enabled the radiologist to see any spinal issues that were not evident with the patient lying down.

This created a lot of excitement, and we made a real splash within GE, even being featured on the cover of GE's 1994 Annual Report! (Fig 32). Ferenc's enthusiasm was very instrumental in creating this excitement. In Fig. 33 you can see him talking to John Trani, the CEO of GE Medical Systems about the Signa SP. The first system was delivered to BWH in March 1994 (Fig. 34) and in Fig 35 is a picture of the team from GE's Research Center, GE Medical Systems and BWH that worked together on that first system.

And while this intraoperative system did not in itself create the revolution in healthcare that we had hoped for, it definitely led to the creation of MR guided Focused Ultrasound which today is creating a revolution in healthcare.

One of the key issues that we had in using the MRT was to find appropriate tools that could work inside a magnet. Most surgical tools were magnetic and could not be used inside a magnetic field. In Fig. 30 you can see hanging on the right side of the double donut a cryosurgery system built by Galil Medical. Other potential tools were lasers as well as RF and we were on the constant lookout for new appropriate devices that would enable us to deliver therapy in a minimally invasive way, while monitoring the delivery of the therapy using MR temperature imaging.

In the summer of 1990, Ferenc called me to tell me that GE had bought a medical laser company. I said that I was very surprised because I knew nothing about it. It turned out that GE had purchased the majority share in Tungsram, a light bulb company in Budapest, Hungary, earlier in that year. Apparently, Tungsram had a small medical laser project within a subsidiary company of Tungsram. I was very interested and contacted a number of people within the GE's Lighting Business, but it took a few months to verify that indeed there was a laser project within Tungsram. It was clear to me that medical lasers would not be a business focus for GE Lighting and I suggested that we visit the company and see what they were doing before this project was spun off or sold. So we organized a trip to Budapest, for four of us, myself, Ferenc, Dr. Dan Castro (Fig 36), a surgeon who was doing ENT laser surgery at the University of California Los Angeles, and Bill Lotshaw, (Fig 37) a laser physicist from GE's Research and Development Center.

On our way to Budapest, we stopped at Graz in Austria where the European Laser Association was holding a very large meeting, an important part of which was devoted to the use of lasers in medicine. Lasers had been used primarily for cosmetic purposes in the past but now the first interstitial uses were surfacing. At this meeting we were joined, by Dr. Tividar Lippényi, (Fig 38) the Managing Director of Tungsram Laser Technology Ltd, the company within Tungsram (Fig 39) that we were to visit the next week in Budapest.

The Hungarians had established Tungsram Laser Technology Ltd, in order to facilitate the transfer of knowledge and technology from Israel to the Soviet Union in the field of lasers in the late '80s. Russia had broken off relations with Israel, and there was no official way for them to talk. So, as the Hungarians told us, the Russians would sit in one room and the Israelis in another room and the Hungarians would act as go-betweens, going from one room to the other. In order to develop some expertise in understand the questions and the responses, Tungsram initiated these laser programs including the medical laser project.

Lippényi met us in Graz on Friday November 9, 1990, before our planned meeting a few days later in Budapest, because he was very excited about an idea he had for the use of lasers in surgery. He wanted to use lasers to create a hologram of the tumor, using data from CT and MR images. The hologram of the tumor would be superimposed directly on the tumor – this he felt, would be the best possible way to destroy the tumor.

We agreed with him that if you could do this it could work. However we pointed out to him that there was a very big barrier: the tumor is inside the patient's body and there was no way that we could put a hologram inside the body without destroying the coherence of the light necessary to create the hologram. It was then that Lippényi made a remark I shall always remember. He told us not to worry about this; it was only a "technical" problem. He said that the University of Budapest, where Gabor (Fig 40) had invented holography, had very smart people and they would solve this problem.

We thanked him for the idea and said we would discuss this further when we got to Budapest the next Monday. The four of us then went for a walk along the Mur River, which flows through Graz. Then Bill Lotshaw said that even though we were laughing at Lippényi's idea now, he believed that in two hundred years we would be able to put a hologram inside the body. This comment triggered a memory in my mind of a friend at the University of Toronto, Kenny Norwich, who was interested in acoustic holography in the 60's, and I said that I knew how to do that now – we would use acoustic waves instead of light waves to create the hologram.

Incidentally, it did not take 200 years, but really only 24 years until an Israeli company, RealView imaging (http://realviewimaging.com/) created the Holoscope which is capable of putting a real hologram (not just augmented reality) inside the body (Fig 41)

We all became very excited by this idea as we discussed its feasibility. Ferenc realized within a day that we did not have to make a hologram, but that we could scan with a focused ultrasound beam through the tumor. Although we continued with the visit to Tungsram in Budapest on Monday November 12, and then London on November 13, where we visited Dr. Steve Bown, the leading laser surgeon in England, our mind was on this idea. Our excitement mounted until we returned to the USA, where we discovered that focused ultrasound was a technique developed fifty years before by Lynn and by the Fry brothers. In addition, Leksell and his collaborators attempted unsuccessfully to develop this technique for brain surgery before he created the gamma knife. However, our original thought was to do this within an MR system, so this became the beginning of MR guided Focused Ultrasound.

We spent 1991 fleshing out the idea. We built five units at GE's CRD, (using OPM) to be put into standard MR systems. The first unit went to Brigham about three years later, followed by systems at Mayo Clinic, Stanford, MD Anderson, and St. Luc in Montreal, Quebec. These were used to ablate benign breast disease as an initial application. The system was very simple: There was a single transducer which guided the focused ultrasound to the spot in the breast that was determined by the MR imaging procedure. MR imaging also served to monitor the temperature change at the focus point and to control the ablation. These initial experiments were quite successful. See the example in Fig.42).

However, GE decided in 1996 that they were no longer going to perform therapy delivery, but only do imaging of the therapy delivery. This was because of a serious accident that occurred in Spain when a radiation therapy system was miscalibrated and resulted in a number of deaths. I was told by the CEO of GE that I had to find a way to move this program out of GE but that I had to do this in a way that would not disappoint and antagonize Brigham, Mayo, Stanford, MD Anderson and St. Luc, all of whom were key GE customers with significant influence.

Trying to get this done took about two years, and was very disappointing but one day at the end of 1997 I received a phone call from Jack Campo, one of the GE lawyers who was negotiating the purchase by GE of the ultrasound imaging company Diasonics Vingmed from Elbit Medical. He told me that the company was interested in therapeutic ultrasound and were planning to work on it, but that GE was not going to buy that portion of the company. I suggested that we sell our program to Elbit Medical, and this happened and became the progenitor of InSightec. At that time also GE purchased a number of Israeli companies from Elbit and I was fortunate to be asked to become the Director of GE Medical in Israel, so I was able to watch the incredible development and growth of InSightec under the direction of Kobi Vortman and his team (see Fig 43).

InSightec grew and in 2004 received FDA approval for the treatment of uterine fibroids with the statement by the FDA in their Talk Paper of Oct 22, 2004 that the "FDA expedited review of the device because it offers significant advantages over existing treatments for uterine fibroids."

But Ferenc did not stop there. In 1996 he and Kullervo Hynynen submitted a patent for the delivery of therapeutic agents through the Blood Brain Barrier. This was granted in May of 1998.

BY 2005 the initial brain surgery trials were done at the Brigham (see Fig. 44). Ferenc kept creating more and more capabilities for doing Image Guided Therapy, including the creation of the Advanced Multimodality Image Guided Operating (AMIGO) suite that houses a complete array of advanced imaging equipment and interventional surgical systems for use before, during, and after surgery. He also was instrumental in creating the National Center for Image-Guided Therapy (NCIGT) which is the NIH's central resource for image guided therapy. It is now the Ferenc Jolesz National Center for Image Guided Therapy (Fig 45). He has also been recognized by his colleagues in Hungary (Fig. 46)

One thing I clearly remember is the InSightec Board meeting of November 2014 a month before he passed away, when he really urged the company to forget everything else and concentrate on the brain and opening the BBB.

His passing was a shock to all of us who had been working with him for more than 25 years. But, we cannot say that there will be no-one around to take his place. His legacy continues as we can see in Fig. 47 . . . . .

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Fig. 1. Professor Ferenc Jolesz

Fig 2. Ferenc at age 2 ½ (Courtesy of Anna Jolesz)

Fig 3. Budapest (courtesy Google Maps)

Fig 4. The Chain Bridge across the Danube (by day and by night)

Fig 5. Buda Castle (courtesy Google)

Fig 6. Insignia of the Semmelweiss University

Fig. 7. Kalman Kando College of Electrical Engineering in Budapest

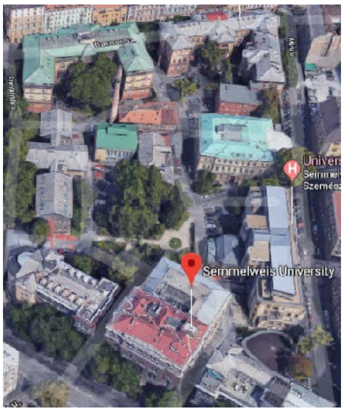


Fig 8. Budapest Institute of Neurosurgery indicated by the red marker

Fig. 9. Massachussetts General Hospital

Fig. 10. Brigham and Women's Hospital (BWH)

Fig 11. Ferenc and some of his colleagues at BWH

Fig 12. Ferenc with Professor Clare Tempany, who is now the Center Director, National Center for Image-Guided Therapy, the Vice Chair of Radiology Research, Brigham & Women's Hospital and the Ferenc Jolesz MD Professor of Radiology, at the Harvard Medical School

Fig 13. Ferenc’s wife, Anna Jolesz MD, together with his daughters, Klara and Marta

Fig 14. Ferenc and Anna, together with Professor Nobuhiko Hata (left) and Professor Ron Kikinis.

Fig 15. Ferenc and Anna with close friends from Hungary

Fig 16. In Hungary with Anna, Morry and Charlotte Blumenfeld

Fig. 17 . Ferenc with Professor Imre Repa

Fig 18. George Kelling and the Cytoscope

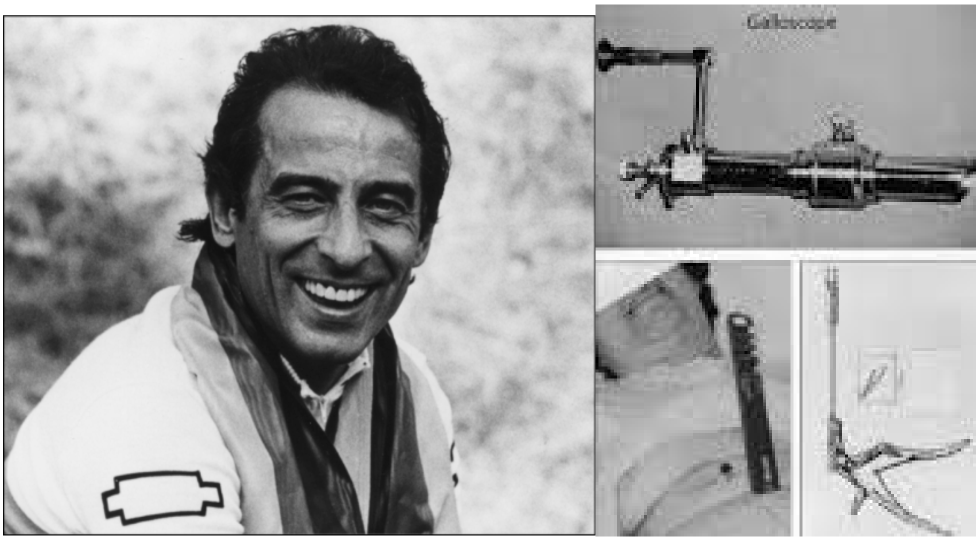


Fig 19. Professor Dr. Med Erich Mühe who performed the first laparoscopic cholescystectomy

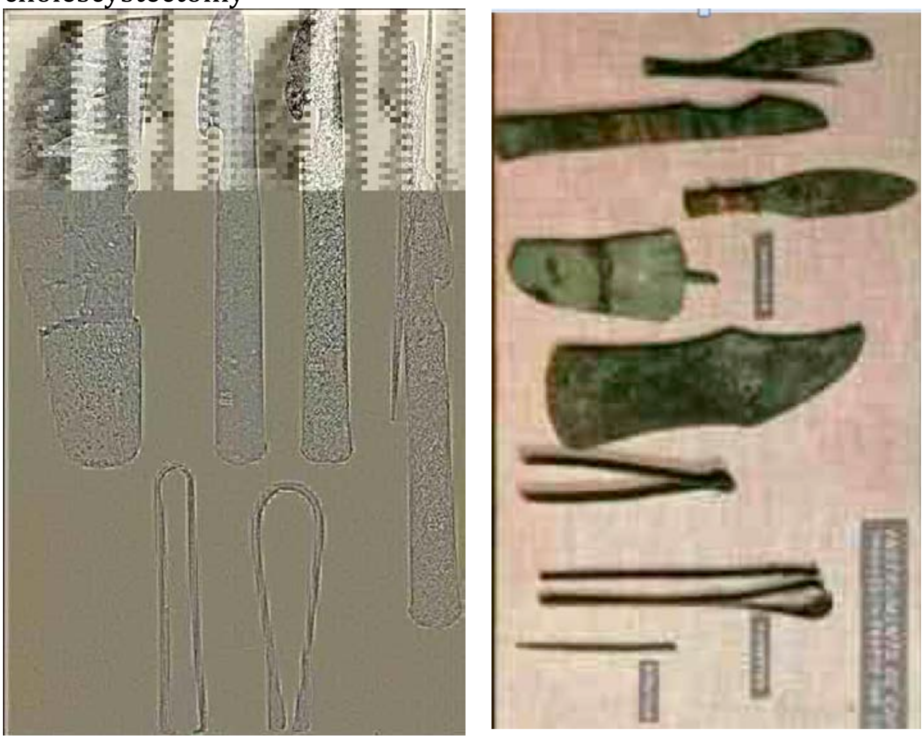


Fig. 20 Early Egyptian surgical Tools

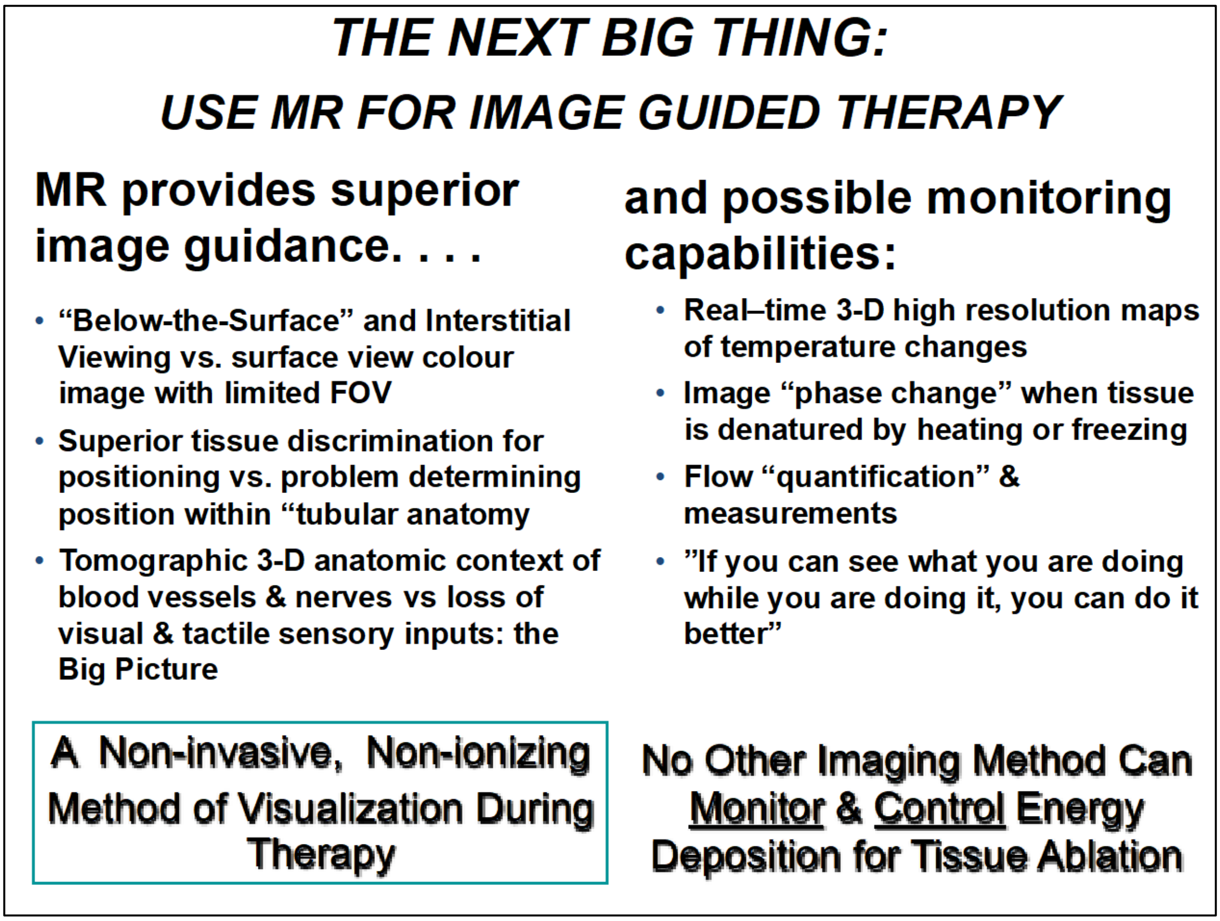
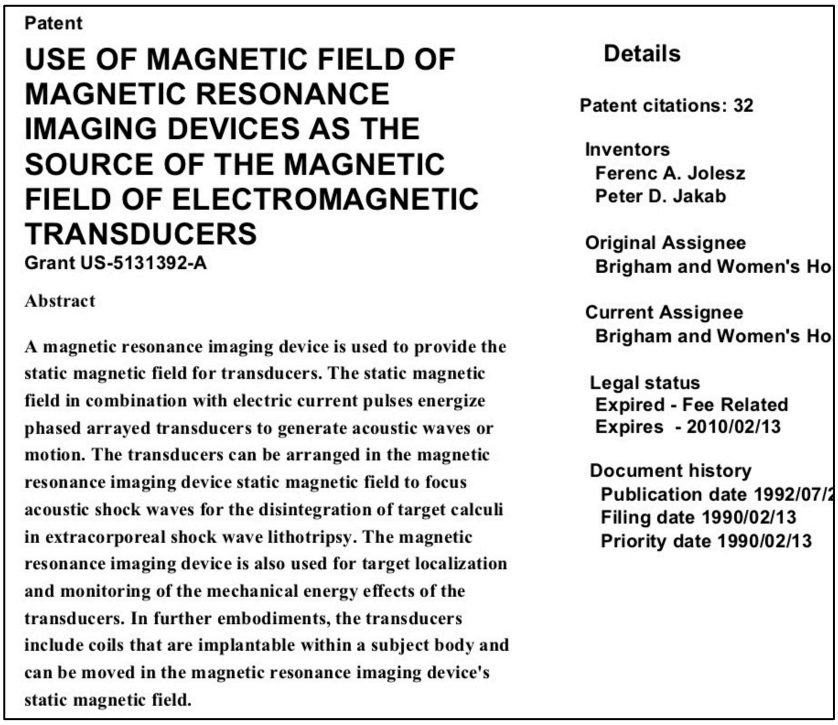


Fig 21. My favorite slide on becoming responsible for Image Guided therapy at GE


Patent

USE OF MAGNETIC FIELD OF MAGNETIC RESONANCE IMAGING DEVICES AS THE SOURCE OF THE MAGNETIC FIELD OF ELECTROMAGNETIC TRANSDUCERS

Grant US-5131392-A

Abstract

A magnetic resonance imaging device is used to provide the static magnetic field for transducers. The static magnetic field in combination with electric current pulses energize phased arrayed transducers to generate acoustic waves or motion. The transducers can be arranged in the magnetic resonance imaging device static magnetic field to focus acoustic shock waves for the disintegration of target calculi in extracorporeal shock wave lithotripsy. The magnetic resonance imaging device is also used for target localization and monitoring of the mechanical energy effects of the transducers. In further embodiments, the transducers include coils that are implantable within a subject body and can be moved in the magnetic resonance imaging device's static magnetic field.

Details

Patent citations: 32

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Expired - Fee Related
Expires - 2010/02/13

Document history
Publication date 1992/07/2
Filing date 1990/02/13
Priority date 1990/02/13

Fig. 22 Original Patent by Ferenc and Peter Jakab to do lithotripsy in the MRI system

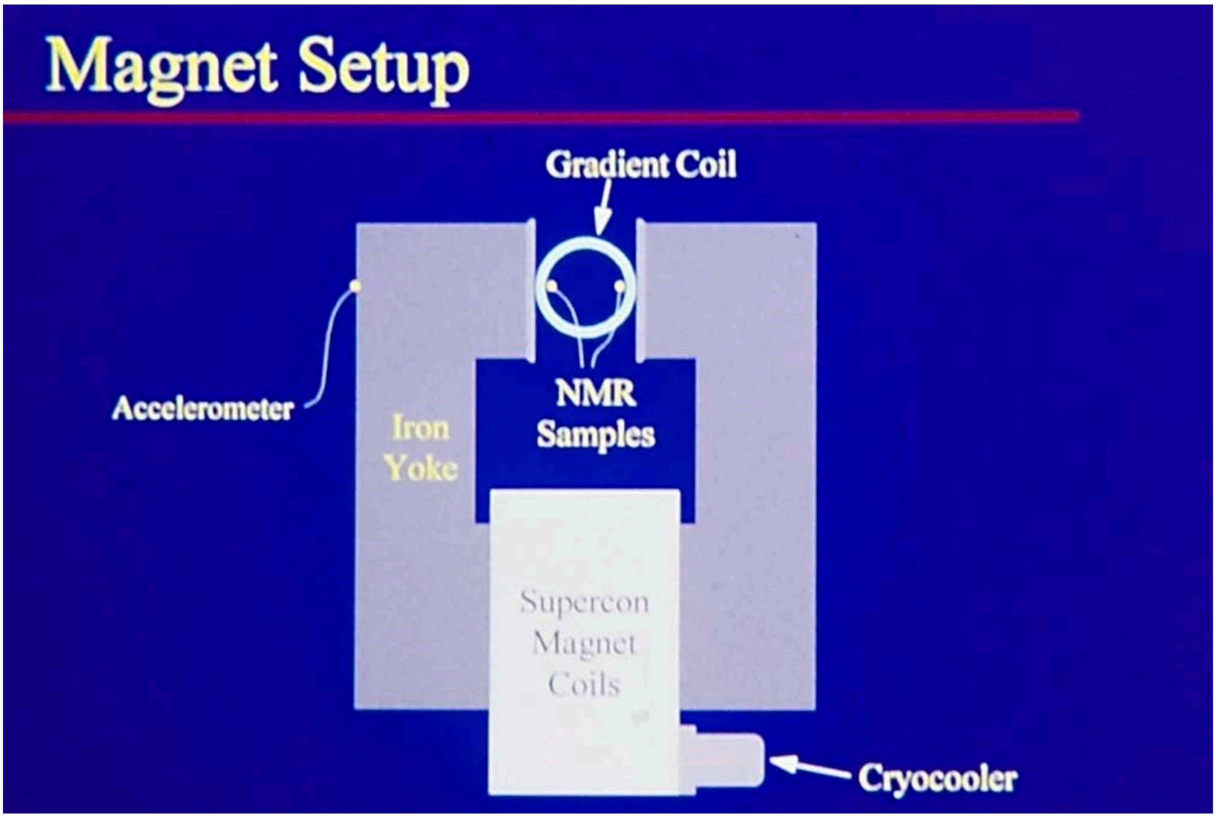

Fig 23. Setup for the Feasibility System (the IGMIT Magnet)

Fig 24. Model of the IGMIT system

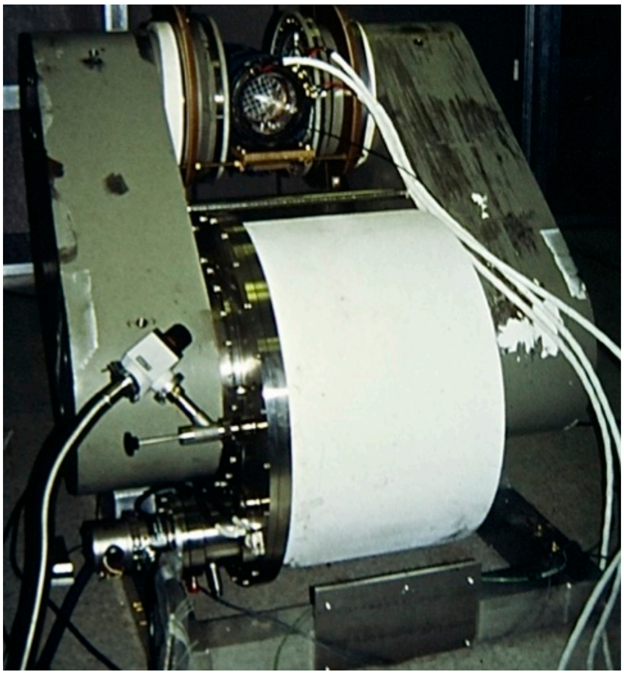

Fig 25. The IGMIT system before the covers were put on

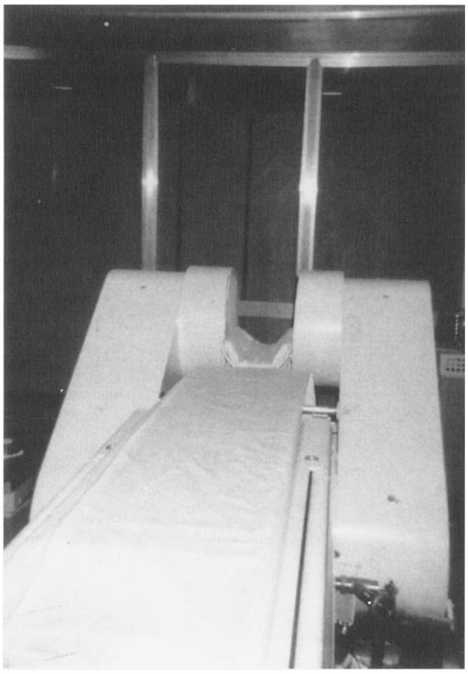

Fig 26. The IGMIT system after the covers were put on

Fig 27. The IGMIT system in use for knee imaging

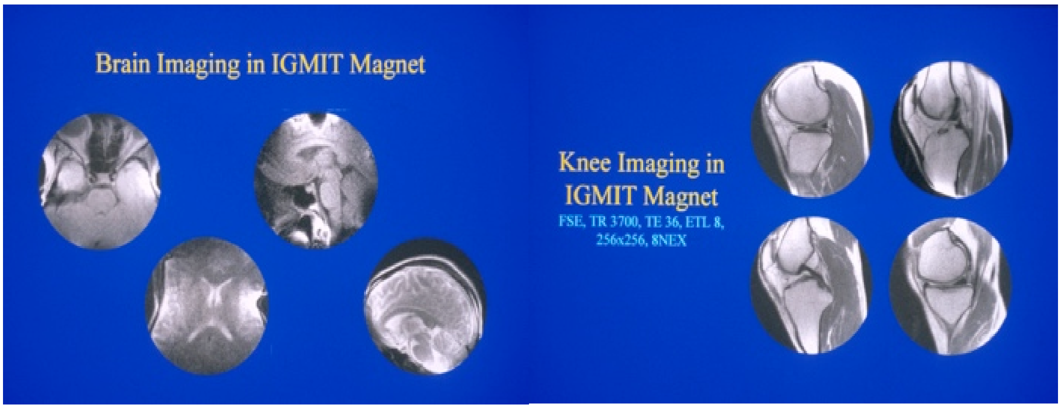

Fig. 28. Brain and Knee imaging with the IGMIT magnet.

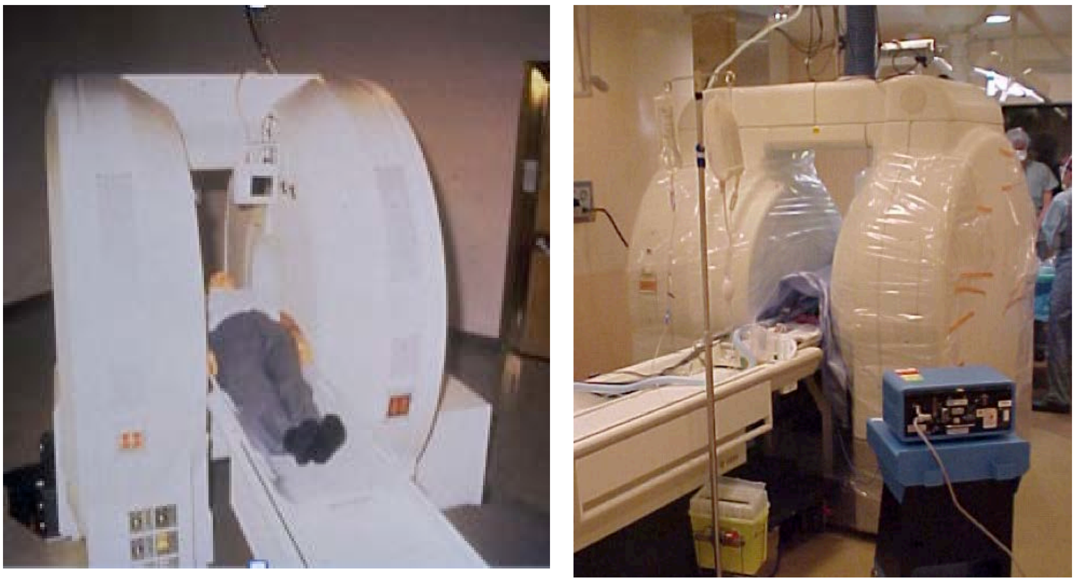

Fig. 29. The Sunnybrook interventional magnet system.

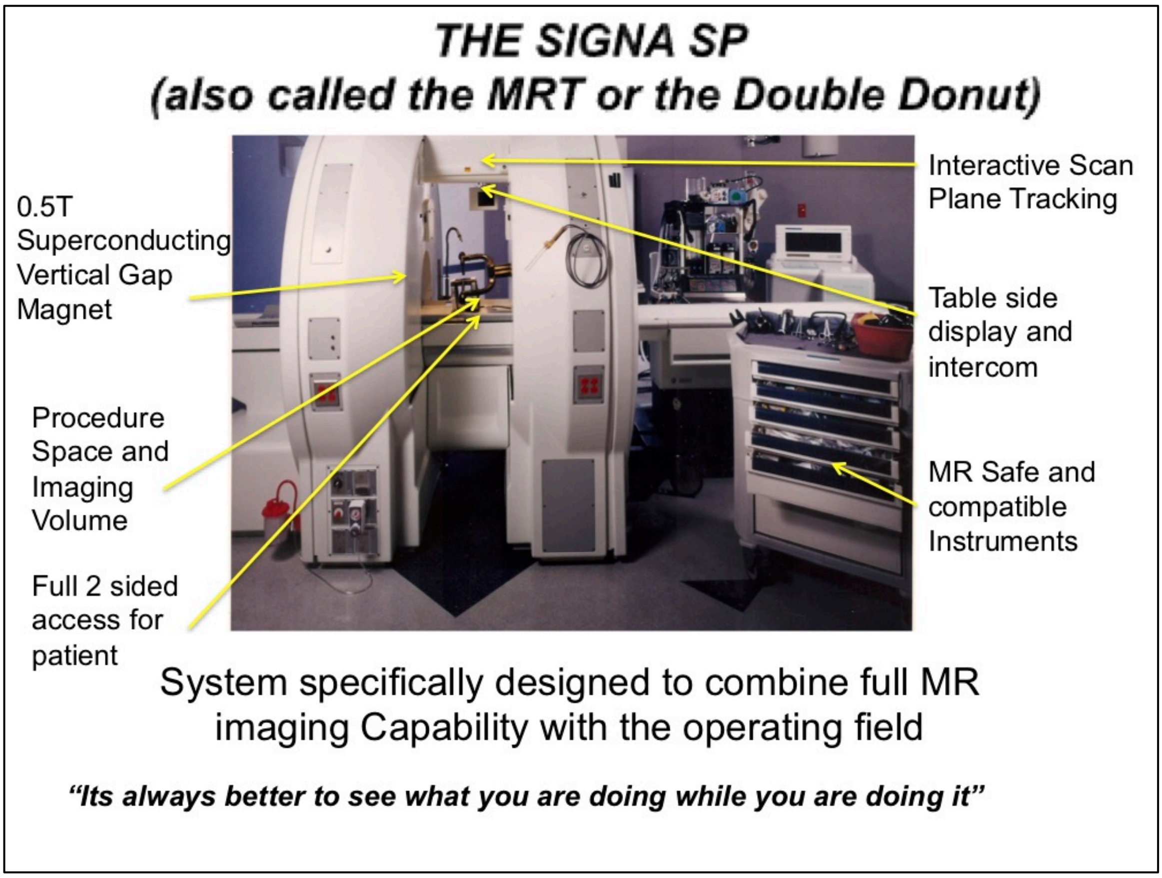

Fig 30. The Signa SP

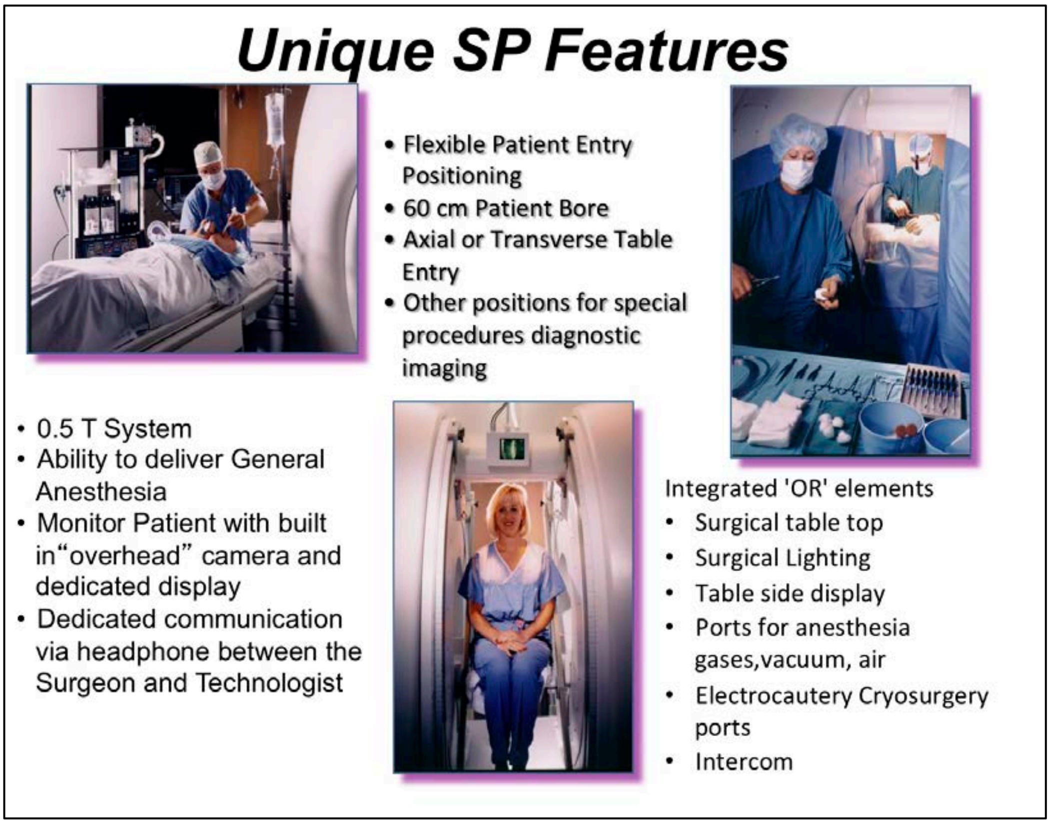

Fig 31. Unique features of the Signa SP

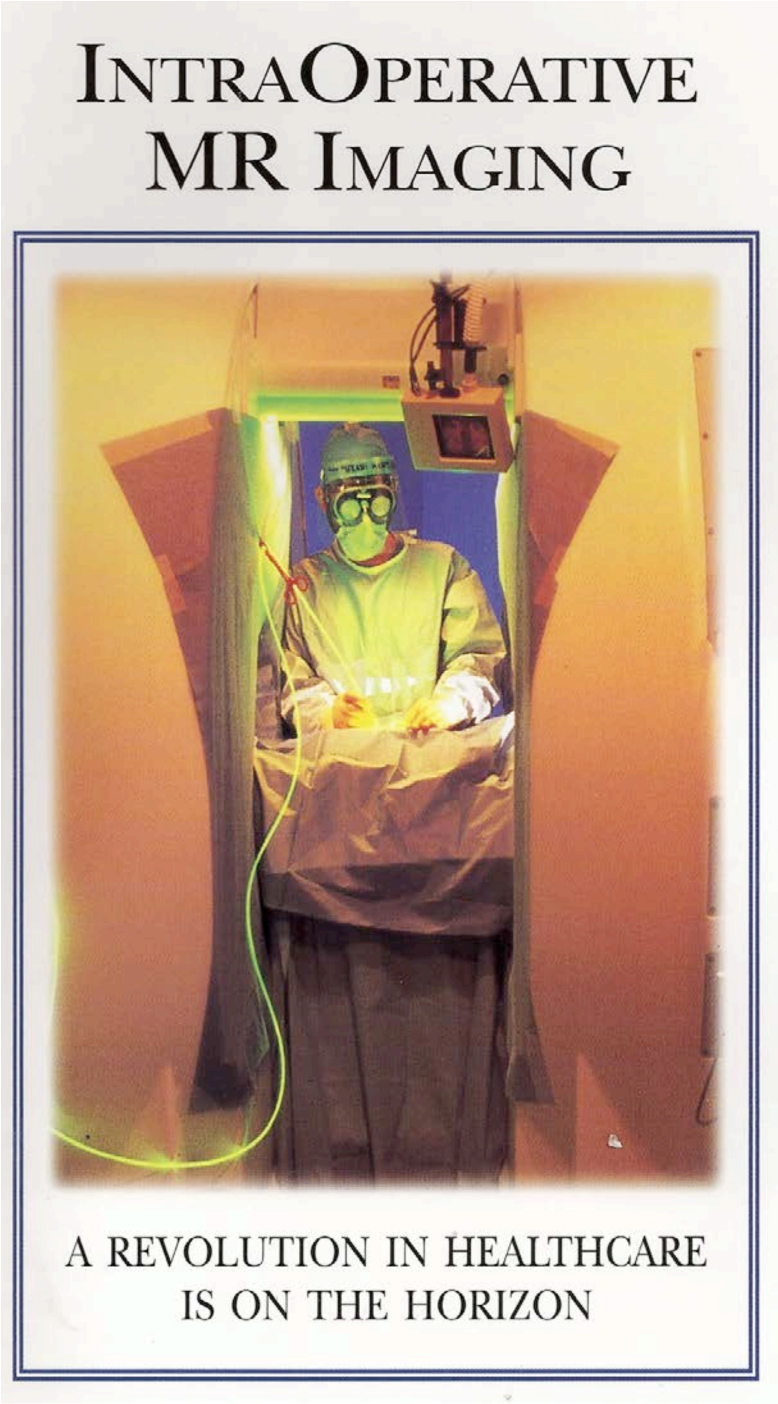

Fig.32. the Cover of the GE 1994 Annual Report

Fig. 33. Ferenc explaining the Signa SP to John Trani, the CEO of GE Medical Systems

Fig 34. The first delivery of the Signa SP to BWH in March 1994

Fig. 35 The team that worked on the first Signa SP, from GE Medical Systems, GE Research Center and BWH (taken before selfies)

Fig 36. Dr Dan Castro (a current image courtesy Google)

Fig 37. Dr Bill Lotshaw (a current image courtesy Google)

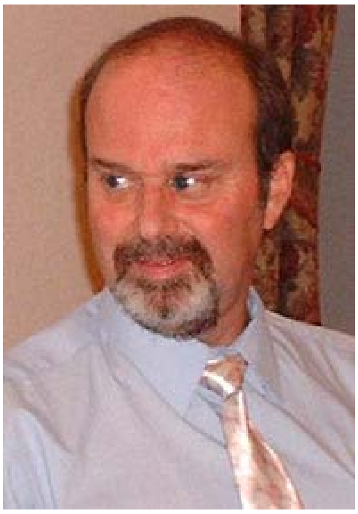

Fig 38. Dr. Tividar Lippényi, (a current image courtesy Google)

Fig 39. Tungsram, Budapest


Fig. 40. Professor Dennis Gabor, the inventor of holography


Fig. 41. RealView Imaging's Holoscope for Interventional Oncology

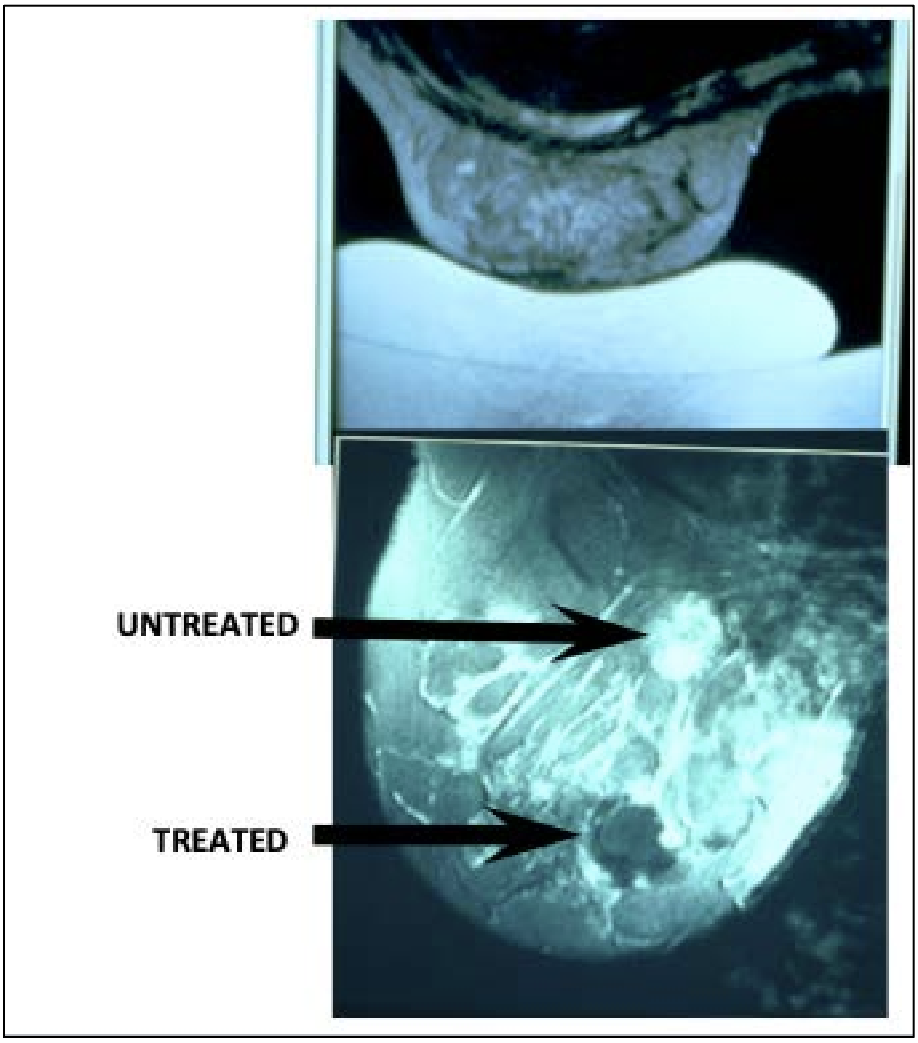

Fig. 42 initial application of MR guided Focused ultrasound to ablate benign breast tumors.

Fig 43. Ferenc is surrounded by the two key management personnel from Insightec, Oded Tamir Finance, and Kobi Vortman the CEO

Fig. 44. The first brain Surgery at BWH, David Freundlich from InSightec, Kullervo Hynynen, Ferenc, and standing up is Nathan MacDonnald

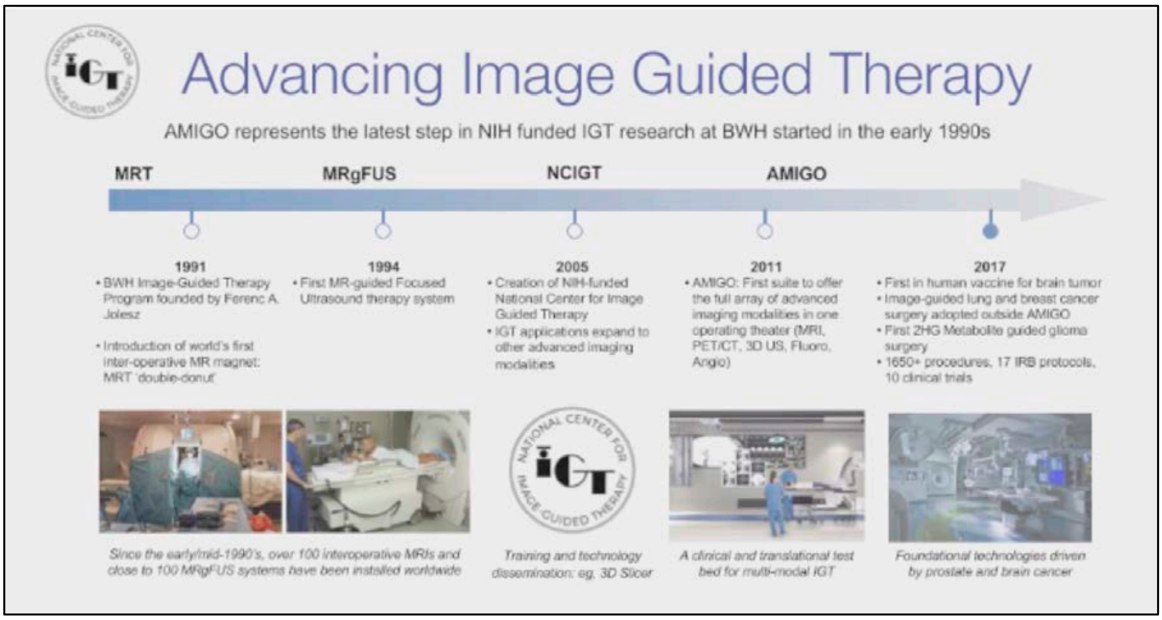

Fig. 45. The Ferenc Jolesz National Center for Image Guided Therapy

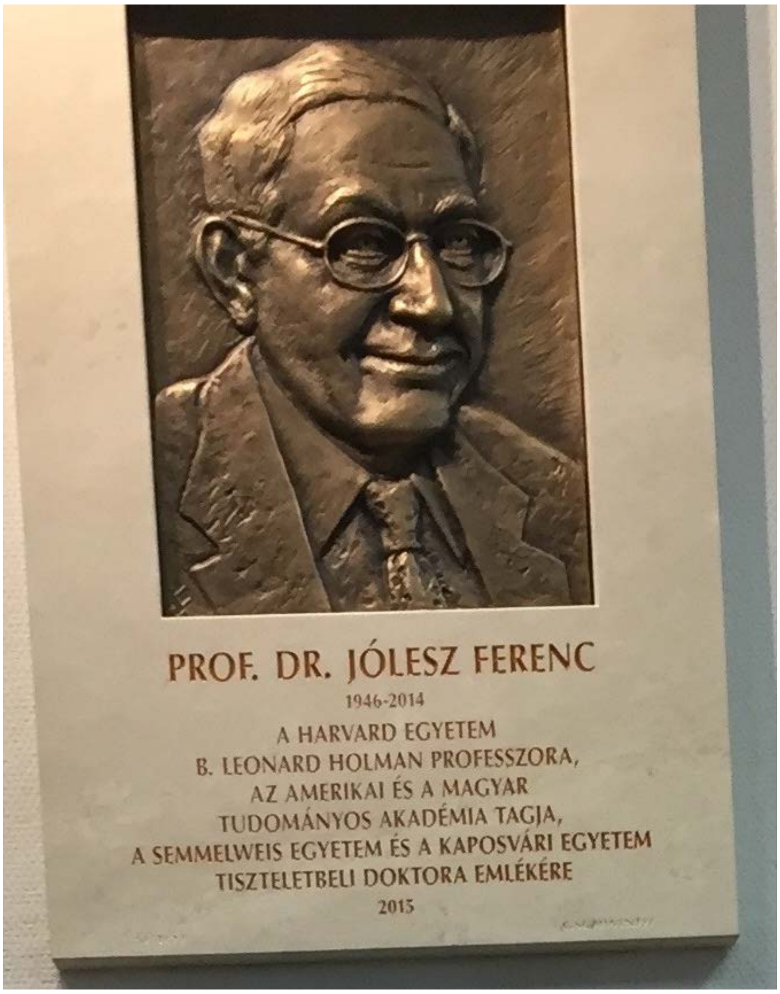

Fig. 46. Tribute to Ferenc Jolesz from his Hungarian Friends

(translation: Prof. Dr. Ferenc Jolesz, 1946 -2014, the Harvard University B. Leonard Holman Professor, an American Member of the Hungarian Academic Academy, and an Honorary doctorate from the University of Semmelweis and Kaposvar University)

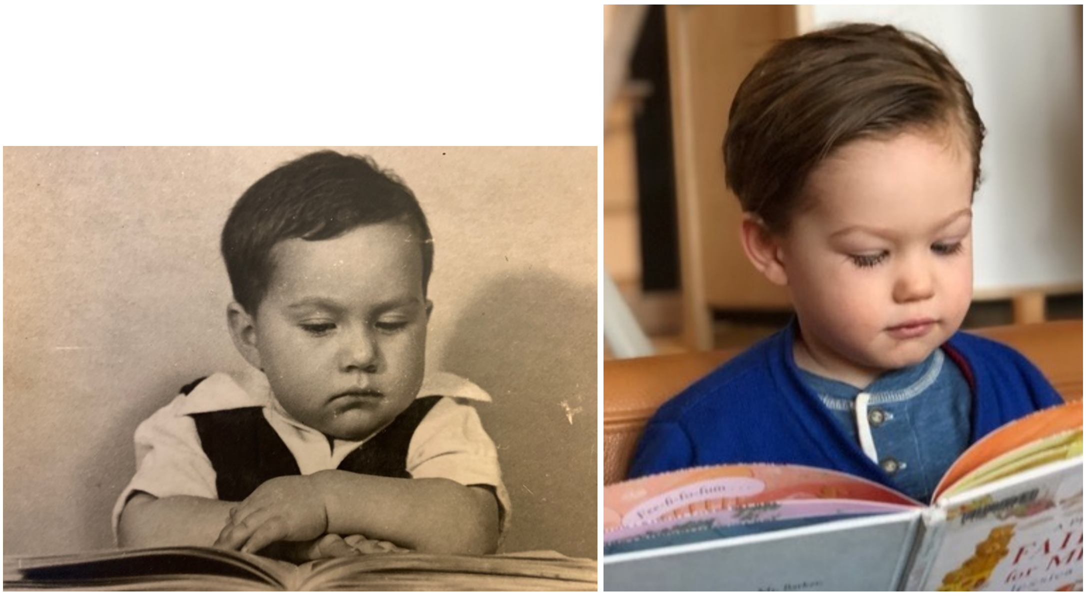

Fig. 47. The legacy continues . . .   Ferenc Jolesz at age 2 ½ in Nov/Dec 1948, and his grandson, Ferenc also at age 2 ½, the grandson he never met!

Acknowledgements: This "Slide Essay" could not have been written without the help of Anna Jolesz, Clare Tempany, Ron Kikinis, Nobuhiko Hata, Scot Hinks, Kirby Vosburgh, Joe Sardi, and of course, Dr. Google. There are some Figures that I have on my computer from the past that I do not remember where they came from – but I hope that the originators of those Figures will forgive me for the lapse.

1. R. Scott Hinks, PhD, Michael J. Bronskill, PhD Bruce D. Collick, PhD R. Mark Henkelman, PhD, Walter Kucharczyk, MD, Mark Bernstein, MD: MR Systems for Image-Guided Therapy; Journal of Magnetic Imaging, 1998, 8, 19-25