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Johanna Ronkainen

COSTS IN TODAY'S RADIOLOGY

ABC ANALYSIS OF TYPICAL SITUATIONS IN THE TRANSITIONAL PERIOD

FACULTY OF MEDICINE,
DEPARTMENT OF DIAGNOSTIC RADIOLOGY,
UNIVERSITY OF OULU

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ABC analysis of typical situations
in the transitional period

Academic dissertation to be presented, with the assent of the Faculty of Medicine of the University of Oulu, for public defence in Auditorium 7 of Oulu University Hospital, on June 15th, 2007, at 12 noon

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Abstract

The purpose of this study was to analyze the costs incurred during the transitional period when a radiology department is gradually digitalized and magnetic resonance imaging (MRI) is gaining ground as guidance for interventions. The specific aims were: to compare the costs of computed (CR) radiography with the costs of conventional radiography, to analyze the cost structures of procedures and the effects of procedure volumes in a multipurpose interventional MRI (IMRI) unit, to compare the costs of MRI and computed tomography (CT)-guided bone biopsies, and to compare the costs of MRI-guided laser ablation and surgery in the treatment of osteoid osteoma.

34 140 plain-film examinations were analyzed; 3/4 of them were CR and 1/4 conventional radiography. The costs of CR were 9% higher compared to conventional radiography, due to the higher capital cost.

In the IMRI unit, 563 diagnostic MRI examinations, 89 MRI-guided interventions, and 39 MRI-guided neurosurgical operations were performed. The cost analyses of the alternative simulation models of IMRI usage showed that the volume of diagnostic imaging had an effect on the unit costs of these procedures. Volume was not such a deterministic factor in interventions due to the high material costs. The volume of the neurosurgical use of IMRI had a major effect on the costs of radiological procedures.

The costs of 18 MRI-guided and 12 CT-guided bone biopsies were compared. The cost of MRI-guided biopsy was 2.55-fold compared to CT-guided biopsy, due to the longer procedure time and the expensive MRI-compatible instrumentation.

The costs of 7 MRI-guided laser ablations and 6 surgical treatments of osteoid osteoma were compared. The cost of laser ablation was higher than the cost of excision of a superficial osteoid osteoma. The cost of excision of a deep osteoma with metallic fixation was considerably higher, due to the higher material, personnel, and ward costs. Laser ablation diminishes the need for sick days and the duration of restricted weight bearing.

In conclusion, a higher cost of a new method should be anticipated. The use of a new method should be justified by other factors, such as better efficiency, accuracy, lack of radiation, or mini-invasiveness.

Keywords: bone biopsy, computed radiography, cost and cost analysis, interventional magnetic resonance imaging, laser therapy

To my family

"The human brain starts working the moment you are born and never stops until you stand up to speak in public."
George Jessel

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Oulu, May 2007 Johanna Ronkainen

Abbreviations

3D	three-dimensional
ABC	activity based cost analysis
CBASS	completely balanced steady state
CEA	cost effectiveness analysis
CE MRA	contrast enhanced magnetic resonance angiography
CR	computed radiography
CT	computed tomography
D	diameter
DHS	dynamic hip screw
DSA	digital subtraction angiography
FSE	fast spin-echo
E	energy
FOV	field of view
G	gauge
HIS	hospital information system
ICU	Intensive Care Unit
IMRI	interventional magnetic resonance imaging
L1-3	lumbar vertebras 1-3
L2	second lumbar vertebra
MR	magnetic resonance
MRI	magnetic resonance imaging
Nd-Yag	neodymium-doped yttrium aluminium garnet
OR	operating room
PACS	picture archiving and communication system
PNA	percutaneous needle aspiration
PNB	percutaneous needle biopsy
QALY	quality-adjusted life-year
RF	radiofrequency
RIS	radiology information system
SPR	storage phosphor radiography
STIR	short tau inversion recovery
T	tesla
T1	longitudinal relaxation time
T2	transverse relaxation time

TE	time of echo
TR	time of repetition

List of original publications

I Alanen J, Keski-Nisula L, Laurila J, Suramo I, Standertsköljd-Nordenstam C-G & Brommels M (1998) Costs of plain-film radiography in a partially digitized radiology department, An activity-based cost analysis. Acta Radiologica 39: 200-207.

II Ronkainen J & Tervonen O (2006) Cost analysis of an open low-field (0.23 T) MRI unit: Effect of procedure shares in combined imaging, interventional and neurosurgical use. Acta Radiologica 4: 359-365.

III Alanen J, Keski-Nisula L, Blanco-Sequeiros R, & Tervonen O (2004) Cost comparison analysis of low-field (0.23 T) MRI- and CT-guided bone biopsies European Radiology 14: 123-128.

IV Ronkainen J, Blanco-Sequeiros R & Tervonen O (2006) Cost comparison of low-field (0.23 T) MRI-guided laser ablation and surgery in the treatment of osteoid osteoma. European Radiology 16: 2858-2865.

Contents

1 Introduction

Technological innovations have changed the ways of working and the ways of storing images in radiology. Since the 1990s, conventional plain-film radiography has been increasingly replaced by digital radiographic techniques with picture archiving and communication systems (PACS). These systems vary from large, hospital-wide installations aimed at a filmless hospital to mini-PACS systems, which link workstations to digital radiography, computed tomography (CT), and magnetic resonance imaging (MRI) facilities and a local digital image archive.

The development of CT equipment, especially helical and multidetector CT scanners, has enabled the achievement of more accurate, faster information and multiplanar and three-dimensional reconstructions. The development of CT fluoroscopy has further advanced the use of CT as a guiding method in interventions. Despite its shorter history, MRI has emerged as an alternative that is, in many indications, superior to CT in diagnostic imaging and also in image guidance in different interventions. Due to the rapid development of equipment and materials, minimally invasive image-guided therapeutic procedures have replaced many surgical treatments. The development of multipurpose and multidisciplinary interventional magnetic resonance imaging (IMRI) units has enabled the use of the advantages of MRI guidance in minimally invasive therapies and open surgery, especially neurosurgery.

The rapid growth and development of medical technology and procedures has increased considerably the costs of radiology as well as the overall costs of health care. This has increased the interest of health care organizations and policy makers in economic analyses. Cost awareness has become part of everyday life even in radiology departments. It is important to have detailed information about the direct and indirect costs of the resources used in each procedure to be able to define their actual price and to plan future functions and investments in the department.

Activity-based cost (ABC) accounting has been successfully used in industrial and service-providing units. In the literature, there is scant information about the use of ABC accounting in health care and in radiology. There is particularly scarce information about the cost structure of today's transitional period in radiology.

2 Review of the literature

2.1 Diagnostic x-ray imaging

Despite the rapid evolution of radiology during the past thirty years (1970-2000), about two thirds of the examinations performed at radiology departments are still traditional projection X-ray images, which account for an important part of the total costs in a radiology department. Despite the development of CT and MR imaging, traditional chest and bone X-ray examinations have maintained their status as primary radiological examinations in various lung, mediastinal, pleural, heart, and musculoskeletal diseases.

2.1.1 Conventional technology

In conventional radiography, X-rays create an image directly on a photographic film after passing through the patient's body. The film is covered on both sides by a layer of photographic emulsion which contains gelatine with silver bromide crystals. The X-rays create a latent image within the emulsion, which becomes visible after processing with liquid developer. The image on the film consists of varying degrees of blackness, and the darkest areas have been exposed to the biggest radiation dose. The radiographic cassette contains two fluorescence-intensifying screens located on both sides of the film. These screens absorb effectively X-ray photons and emit light protons, which are the main cause of film blackening. The intensifying screens make reduction of the radiation dose possible. The film-screen combinations have different characteristic curves, and their sensitivity, noise, and spatial resolution are determined by the intensifying screen. This is utilized in imaging different targets with different demands for image quality.

The process of conventional plain-film imaging includes many manually performed procedures, and several assisting persons are needed. The imaging of the patient and the development and printing of the image in a darkroom or in a daylight processor is performed by radiographers. The assisting persons retrieve previous images and patient records from archives and hang all images on alternators. The films are interpreted and reported by a radiologist. After that, the films are collected and returned to the archive. The final report is written by a secretary.

2.1.2 Digital radiography

The last 20 years have seen a rapid increase in the use of digital radiographic techniques, and many radiology departments have installed Picture Archiving and Communication Systems (PACS). The use of digital modalities is increasing despite the bigger initial investments needed compared to conventional equipment. Owing to the economic restrictions on health care in Europe, a sudden transition from a conventional film-based system to a digital filmless hospital is mostly impossible. Hence, the change must be accomplished step by step. The arguments in favor of acquiring digital equipment include such benefits as lower costs, rationalization of operations, and better image quality (Arenson 2000, Dalla 2000, Straub & Gur 1990). The main advantage of PACS is the improvement of efficiency due to electronic data processing (Strickland 2000).

The first digital radiography system was the storage phosphor radiography system (SPR) developed by Fuji and introduced to the market in the early 1980s (Sonoda *et al.* 1983). Image quality has continued to improve over the past years, and the technique has made its way to routine clinical radiography. A consensus conference in Germany showed SPR to be suitable for most clinical applications (Braunschweig *et al.* 1997). The recent developments in digital radiography have also resulted in direct-readout flat-panel detectors. The results of phantom studies suggest that flat-panel detector radiographs provide high spatial and contrast resolution and allow reduction of the radiation dose compared to conventional film-screen systems (Aufrichtig 1999, Chotas *et al.* 1999, Strotzer *et al.* 1998). Fink *et al.* (2002) reported equal or even superior image quality for flat-panel detectors compared with conventional film-screen chest radiographs. Strozer *et al.* (2000) evaluated the image quality of a digital system compared with a conventional system and reported no significant loss of image quality in the case of flat-panel detectors using a radiation dose reduced by 50%.

The digital image is composed of pixels, each of which contains a shade of grey according to the corresponding number in the digital matrix. After passing through the patient's body, the radiation is stored on the image plate in proportion to the absorbed radiation dose. A laser beam is used to release the trapped energy as emitted light. This light is transformed into electronic signals using a photomultiplier. The electronic signal is digitized and transferred to an image processor, which makes the calculations to produce a digital image, which is then transmitted to a laser printer.

Flat-panel detectors are divided into direct-conversion and indirect-conversion detectors (Chotas *et al.* 1999). Indirect-conversion detectors have a scintillator that converts x-ray photons into visible light. This light is then converted into an electric charge by photodetectors. Direct-conversion detectors have an x-ray photoconductor that converts x-ray photons into an electric charge directly without an intermediate stage. The electric charge in both systems is sensed by an electronic read-out mechanism and digitized.

Constant image quality has been considered an advantage in digital imaging because it reduces the need for retakes due to faulty exposure (Glazer *et al.* 1994, Murphey *et al.* 1992). This increases the examination capacity and reduces the examination times, patient doses, and film costs. Another major advantage of digital imaging is the possibility for image transmission and manipulation. Digital image information can also be transferred to PACS, which, if used in combination with high-resolution monitors for diagnostic work, can eliminate the use of films.

Digitalization shortens the work process of X-ray imaging. After the imaging of the patient, the digital information is transferred online to a workstation, where the image can be manipulated and interpreted by a radiologist. Previous images can be rapidly transferred through PACS to the workstation for comparison. Images can also be easily transferred outside the radiology department and be made available even simultaneously to the clinician. Image information can be stored in digital archives, which eliminate the need for film transportation and large archives for film prints.

2.2 Image-guided biopsies

Despite the fact that the imaging methods have developed and provide increasingly accurate information, image-guided biopsies are often needed for correct diagnostic information. Image-guided percutaneous needle biopsy is a well-established and safe technique for obtaining tissue specimens from various regions of the body (Gupta 2004). Information about pathological lesions can be obtained from cytological, bacteriological, or histological samples. The main issue in image-guided biopsies is their minimal invasiveness compared to surgical biopsies. Fine-needle aspiration biopsy is a safe, simple, and cost-effective procedure, and it can be performed on outpatients (Amedee & Dhurandhar 2001). Core needle biopsy provides a histological sample without surgery.

Various imaging modalities, including ultrasound, fluoroscopy, and CT, have been used as guiding methods for percutaneous biopsies. In recent years, interest in MRI as a guidance method for interventions has emerged. The development of a wide variety of MRI-compatible needles has enabled the performance of MRI-guided percutaneous biopsies.

2.2.1 Bone biopsy

A correct diagnosis of a bony lesion, whether it is benign, malignant, or infectious in origin, is needed for correct treatment. Although imaging findings, especially MRI, are pivotal, biopsy is also needed in the majority of cases. Previously, bone biopsies used to be performed surgically, but the percutaneous approach has now become the method of choice in investigating bony lesions (Ghelman 1998, Nimsky *et al.* 2004, Tikkakoski *et al.* 1992, Jelinek *et al.* 1996, Leffler & Chew 1999). Percutaneous bone biopsy has been shown to be more cost-effective than surgical biopsy (Fraser-Hill *et al.* 1992, Ruhs *et al.* 1996). It is also less invasive and minimizes the need for anesthetics and the risk of complications compared to surgical biopsy. Bone biopsies have been performed under CT and fluoroscopic guidance (Ghelman 1998, Tikkakoski *et al.* 1992, Jelinek *et al.* 1996, Leffler & Chew 1999, Fraser-Hill *et al.* 1992, Jelinek *et al.* 2002). Recently, MRI has been shown to be accurate as a guiding method in performing bone biopsies (Parkkola *et al.* 2001, Blanco *et al.* 2002).

2.2.2 Computed tomography as a guiding method

CT has been established as a suitable guidance method in interventional procedures. Haaga & Alfidi (1976) first published the benefits of CT guidance in biopsies. The benefits of CT include the qualification of different tissue densities, good spatial resolution, which still makes CT the method of choice in biopsies of the spine, and its superior ability to detect pneumothorax, which makes it the favored method for transcutaneous chest interventions (Adam *et al.* 1999). The development of helical and multidetector CT has further enhanced the use of CT as a guiding method in interventions. CT fluoroscopy was first introduced by Katada and colleagues (Katada *et al.* 1994, 1996), and it has been shown to be a safe and effective guidance tool for percutaneous interventional procedures (Silverman *et al.* 1999, Meyer *et al.* 1998, Gianfelice *et al.* 2000). CT fluoroscopy enables real-time guidance and has improved the efficacy of CT-guided interventions by reducing the procedure time. In the study of Silverman *et al.*

(1999), the mean needle placement time for CT fluoroscopy was significantly shorter than that for conventional CT.

The disadvantage of CT-guided interventions is the radiation exposure to the patient and the personnel (Silverman *et al.* 1999, Paulson *et al.* 2001, Teeuwisse *et al.* 2001). Radiologists need to be aware of the factors that contribute to radiation exposure in CT fluoroscopy (Silverman *et al.* 1999). By using a low-milliampere technique and the quick-check method, radiation exposure can be minimized (Paulson *et al.* 2001). Another disadvantage of CT is that the gantry allows real-time imaging in only the axial or near axial plane and limits the usage of long instruments. Reconstructions can be done before or after the imaging, and they may be time-consuming, although useful in the planning of the operation (Wolf *et al.* 2001).

2.2.3 Magnetic resonance imaging as a guiding method

MRI was first used as a guiding method in interventional procedures in the 1980s (Mueller *et al.* 1989). It was first used for biopsies and aspiration biopsies (Mueller *et al.* 1989, Duckwiler *et al.* 1989) and later also for drainage (van Sonnenberg *et al.* 1988). In therapeutic procedures, MRI was experimentally used by Matsumoto *et al.* (1992) and Cline *et al.* (1992).

MRI has been shown to have several features that favor its use as a guiding technique. MRI has high soft-tissue contrast with or without contrast medium (Tung & Davis 1993), and it provides relatively good spatial and temporal resolution (Jager & Reiser 2001). Oedematous lesions in bone can often be visualized only in MRI as bright involvement of bone marrow in heavily T2-weighted and short tau inversion recovery (STIR) sequences (Adam *et al.* 1999, Kaplan *et al.* 1998). Contrast medium provides more accuracy in detecting viable parts in, for example, recurrent malignancies and certain types of cartilaginous lesions (Geirnaerdt *et al.* 1998). Parkkola *et al.* (2001) showed that, with dynamic contrast-enhanced MRI, biopsies can be taken from the vital part of the tumor, avoiding the necrotic areas. Blanco Sequeiros *et al.* (2002) reported an initial technical accuracy of almost 100% without complications in performing bone biopsies. MRI has multiplanar imaging capability and allows the operator to choose the imaging and puncture routes in any plane. This enables the biopsy or puncture of targets in difficult locations such as the subdiaphragmatic region. MRI also permits monitoring of thermal changes in tissue (Germain *et al.* 2001). This is especially useful in MRI-guided percutaneous laser ablation of tumors.

The lack of exposure to ionizing radiation is a significant advantage, especially in the case of young patients. It is also an important advantage in view of interventional radiologists' radiation burden.

MRI-guided interventions can be performed in open low-field (0.2 and 0.35 Tesla) and mid-field (0.5 Tesla) scanners and also in closed high-field (1.0 and 1.5 Tesla) scanners. Horizontally open MR systems and systems with the C-arm configuration allow horizontal access to the patient from several angles (Gupta 2004). However, the limited anteroposterior space between the magnet poles occasionally makes decubitus or oblique positioning of the patient necessary. The vertical "double-doughnut" configuration allows unrestricted vertical and horizontal access to the patient. A conventional high-field strength MR scanner with or without combined fluoroscopy differs from the open low-field MR system. In a low-field open MR system, the biopsy can be performed inside the magnet, whereas in a closed high-field system the patient has to be moved in and out of the magnet. In the case of very obese patients, MRI-guided biopsy may be impossible because of the restricted space within the conventional high-field MR. The high-field MR system has superior image speed and quality because of the higher signal-to-noise ratio.

2.3 Image-guided therapy

The current trend is towards minimally invasive therapy. This favors the use of image guidance in interventions. Various image-guided therapies, such as aspiration and drainage of pathological fluid collections, vascular intervention for manifestations of atherosclerotic diseases, and tumor ablation using chemical and thermal therapies (Men *et al.* 2002, Cwikiel *et al.* 2002, Goldberg *et al.* 2005) are important applications of image guidance. Some of these therapeutic procedures require a combination of two or more guiding methods. In nephrostomy and cholecystostomy, for example, the initial puncture is performed under ultrasound guidance, after which a drainage catheter placed with the help of a guide wire under fluoroscopic control. During the last 20 years, the techniques of interventional neuroradiology have been developed into safe and effective procedures, which are used daily to treat hundreds of patients throughout the world (Strother 2000).

Image-guided (ultrasound, CT, or MRI) tumor ablations are performed by direct percutaneous application of chemical or thermal therapy to a focal tumor (or tumors) in an attempt to achieve eradication or substantial tumor destruction.

In chemical ablation, coagulation necrosis of the tumor is achieved by installation or injection a chemical agent such as ethanol or acetic acid. In thermal ablation, the tumor is destroyed by means of thermal energy, heat (laser, radiofrequency energy), or cold (cryoablation) (Cantwell *et al.* 2004).

The main advantage of all image-guided therapy is its minimal invasiveness compared to the alternative surgical treatment. The minimal invasiveness leads to shorter inpatient periods, fewer complications, and shorter recovery times, which minimize the costs and have a major impact on the patient's quality of life.

2.3.1 Osteoid osteoma

Osteoid osteoma is a benign bone tumor characterized by an osteoid-rich nidus in a highly vascular connective-tissue stroma. It accounts for approximately 10% of benign bone tumors (Greenspan 1993). Osteoid osteoma occurs most commonly in children and young adults; ages vary between 2 to 50 years, and 90% of tumors occur before the age of 25 years (Kransdorf *et al.* 1991). Severe pain related to the lesion is a common symptom. The pain is typically worse at night and is dramatically relieved by aspirin. The combination of clinical symptoms and X-ray, CT, and/or MRI findings gives an accurate diagnosis of osteoid osteoma (Assoun *et al.* 1994, Radcliffe *et al.* 1998, Cerase & Priolo 1998, Shankman *et al.* 1997, Spouge & Thain 2000).

2.3.2 Surgical treatment of osteoid osteoma

Traditionally, osteoid osteoma has been treated surgically either by wide resection or by removal of the nidus using curettes and burrs and possibly an autologous bone batch (Yildiz *et al.* 2001, Campanacci *et al.* 1999). The removal of the nidus usually leads to complete pain relief. Wide block resection of the nidus and surrounding bone may lead to difficulties in the location of the nidus and may necessitate the use of bone grafts, metallic fixation, and post-operative immobilization. The other technique is to unroof the nidus by gradual removal of the overlying reactive bone and excision with curettes and burrs (Campanacci *et al.* 1999). Campanacci *et al.* (1999) reviewed 100 patients with osteoid osteoma, 97 of whom had surgery; 89 underwent intralesional excision and 8 wide resection. All except one patient were mobilized at a mean of two days, and full weight-bearing was allowed after a mean of 20 days. All patients reported complete relief of pain. Yildiz *et al.* (2001) operated 104 patients with osteoid osteoma with either wide resection or curettage, and 91 of them experienced immediate pain relief. For osteoid osteomas in the femoral neck or talus, they performed a limited block resection and bone grafting. The average hospital stay was 5 days, and the patients resumed normal function after 4-6 weeks.

2.3.3 Percutaneous treatment of osteoid osteoma

Percutaneous tumor ablation using radiofrequency (RF) electrodes or laser photocoagulation has become an alternative to surgery (Vanderschueren *et al.* 2002, Cioni *et al.* 2004, Rosenthal *et al.* 1998, Cove *et al.* 2000, DeFriend *et al.* 2003, Witt *et al.* 2000, Rosenthal *et al.* 2003, Cantwell *et al.* 2004, Sequeiros *et al.* 2003, Gangi *et al.* 1997a). Percutaneous treatment is less invasive and results in shorter convalescence compared to surgical treatment, and it thus requires less utilization of health care resources. CT guidance has been successfully used in both RF and laser photocoagulation of osteoid osteomas (Vanderschueren *et al.* 2002, Cioni *et al.* 2004, Rosenthal *et al.* 1998, Cove *et al.* 2000, DeFriend *et al.* 2003,Witt *et al.* 2000, Rosenthal *et al.* 2003, Cantwell *et al.* 2004). MRI has also been established as a feasible guidance method in percutaneous interstitial laser ablation of osteoid osteomas (Sequeiros *et al.* 2003). MRI permits monitoring of thermal changes in tissue and provides quantitative information about thermal changes (Germain *et al.* 2001). Cryotherapy and ethanol therapy of osteoid osteoma are infrequently performed. There is only one published case report about successful MRI-guided excision and cryo-treatment of osteoid osteoma (Skjeldal *et al.* 2000).

RF ablation of osteoid osteoma has been shown to be a safe and effective technique (Rosenthal *et al.* 2003). In the review of Cantwell *et al.* (2004), the clinical success of RF ablation ranged from 76 to 100%. In RF ablation, the nidus of the osteoid osteoma is destroyed by heating through a probe with high-frequency alternating current. Probe placement is guided by either CT or fluoroscopy. The significant interference between RF generators and MR imagers has previously prevented simultaneous imaging and RF ablation. Recently, MR-compatible RF electrodes have also been developed, and there are a few studies (Lewin *et al.* 2004, Aschoff *et al.* 2002) where MRI has been successfully used as a guidance method for RF ablation in indications other than the treatment of osteoid osteoma. Yet, there are no published studies on MRI-guided RF ablation of osteoid osteoma.

Percutaneous laser ablation of osteoid osteomas has been reported to be a precise and minimally invasive alternative to traditional surgical and percutaneous ablations (Gangi *et al.* 1997a). In laser ablation, the osteoid osteoma nidus is destroyed by heating. A good correlation between the energy applied and the extent of necrosis can be achieved (Gangi *et al.* 1997b). Cantwell *et al.* (2004) reviewed the current trends in the treatment of osteoid osteoma. They found 87% to 100% clinical success rate for laser ablation treatment. Defriend *et al.* (2003) treated five patients with osteoid osteomas with CT-guided laser photocoagulation and obtained total pain relief in four cases. One patient was symptom-free after a second laser treatment. Blanco Sequeiros *et al.* (2003) treated five patients with MRI-guided laser ablation and found a 100% initial success rate. After six months of follow-up, there was one recurrent osteoid osteoma. Gangi *et al.* (2007) published the study on the largest series of interstitial laser treatment of osteoid osteoma. 114 patients suspected of having osteoid osteoma were treated with CT-guided or CT- and fluoroscopy-guided laser ablation. The treatment proved to be effective in 112 of the 114 patients. At follow-up (mean 58.5 months), six patients reported recurrence of pain. They were successfully treated with a repeat laser ablation, and only one unsuccessful treatment was encountered. Percutaneous interstitial laser treatment has also been reported to be a safe and effective way to treat spinal osteoid osteoma (Gangi *et al.* 1998).

2.3.4 Comparison of percutaneous and surgical treatments of osteoid osteoma

Rosenthal *et al.* (1998) compared percutaneous radiofrequency coagulation of osteoid osteoma with operative treatment. They found no significant difference between the two treatments with regard to the rate of recurrence. The frequency of persistent symptoms was higher than the rate of recurrence. It was also higher in the group of operatively treated patients (30%) than in the group of percutaneously treated patients (23%). Two operatively treated patients had complications necessitating five additional operations. There were no complications associated with the percutaneous method. Rosenthal *et al.* concluded that the percutaneous method should be preferred for the treatment of extraspinal osteoid osteoma, because it does not require hospitalization, is not associated with complications, and is associated with rapid convalescence.

In their review of the current trends in the treatment of osteoid osteoma, Cantwell *et al.* (2004) found that percutaneous radiofrequency is a highly effective, minimally invasive, and safe method to treat osteoid osteoma. Surgery still remains the standard treatment when the histology of the lesion is in doubt, neurovascular structures are within a distance of 1.5 cm, or there is repeated failure of less invasive techniques.

2.4 Multipurpose use of IMRI

Besides radiology, MRI guidance is also used in other specialities, especially in neurosurgery. Since the MRI scanner is expensive, and so far the amount of applications is small, multipurpose and multidisciplinary use is mandatory. In their review of interventional and intraoperative MR, Schulz *et al.* (2004) concluded that IMRI is likely to play an important role in the future of interventional radiology, minimal invasive therapy, and guidance of surgical procedures. The associated high costs require careful evaluation in order to ensure cost-effective medical care.

2.4.1 Intraoperative MR imaging

Intraoperative MRI has been shown to be a promising method for image guidance in minimally invasive neurosurgery (Black *et al.* 1999, Hall *et al.* 1999, Tronnier *et al.* 1997). MRI provides multiplanar imaging and high soft-tissue resolution compared to CT and ultrasound. Intraoperative use of MRI requires a combination of imaging and surgical environments. In the mid-1990s, the development of open MR systems made intraoperative MR imaging possible. Black *et al.* (1997) first introduced intraoperative MR imaging into neurosurgery with open 0.5 Tesla (T) MR equipment.Tronnier *et al.* (1997) and Steinmeier *et al.* (1998) adapted an 0.2 T open MR scanner to intraoperative use in neurosurgery. Schwartz *et al.* (1999) and Black *et al.* (1999) reported a large series of patients treated with MRI-guided neurosurgery. High-field MRI scanners have also been successfully adapted for intraoperative use (Sutherland *et al.* 1999, Liu *et al.* 2000, Hall *et al.* 2000, Martin *et al.* 2000, Nimsky *et al.* 2004). High-field MRI scanners have better image quality than low-field system and a capability for MR angiography, functional or diffusion-weighted imaging, and MR spectroscopy.

2.4.2 IMRI environment

Different IMRI units can be used to introduce the MRI technology into the operating room. Both low- and high-field MRI scanners are used at field strengths varying within 0.12-1.5 T. The other factors to be considered are access to the patient, ease of imaging, and the navigation system (Lipson *et al.* 2001). There are different ways to integrate the MRI equipment to the operating room (OR) layout. The first system to fully integrate the surgical site and the MR scanner was developed in Brigham and Women's Hospital in Boston in the early 1990's. The double doughnut, i.e. the 0.5 T intraoperative MRI system (Signa SP, GE Medical Systems, Milwaukee, WI), was integrated to a fully equipped OR. Neither the patient nor the operating equipment needs to be moved during the operation. The disadvantage of this solution is that it requires an operating theatre where all instruments and equipment must be of MR-compatible, non-ferromagnetic material. This increases the costs of the technology. Over 900 neurosurgical procedures have been performed at Brigham and Women's Hospital from 1995 to 2004 (Lipson *et al.* 2001, Black *et al.* 1999).

Bernstein *et al.* (2000) reported a series of 36 cases treated between 1998 and 1999, with 21 tumor resections, 12 tumor biopsies, 1 transsphenoidal endoscopic resection, and 2 catheter placements for Ommaya reservoirs. These were performed in Toronto Western Hospital with a low-field 0.2 T vertically open, biplanar conventional magnet with the patient positioned on a sliding table top, which enabled the use of non-MR-compatible instruments. With this solution, there still exist the disadvantages of patient transport, although the patient may remain on the MRI table throughout the surgery.

The "twin operating room" concept, where the open 0.2 T MRI scanner (Magnetom OPEN, Siemens Medical Systems, Erlangen, Germany) is placed next to the OR, has been used by Tronnier *et al.* (1997) and Steinmeier *et al.* (1998) in neurosurgical operations. This system has fewer restrictions on instrument compatibility and the surgical technique. The disadvantage is the need to move the patient into and out of the magnet, which increases the operation time and the risks to patient sterility. This also limits the possibility for real-time MRI guidance during the operation.

There are also IMRI units that use high-field MRI equipment for intraoperative MRI guidance. At the University of Minnesota, a high-field 1.5 T MR scanner (Philips Gyroscan ACS-NT, Philips Medical Systems, Best, the Netherlands) is integrated into a fully equipped neurosurgical suite. Hall *et al.*

(2000) reported the first 101 procedures performed in this IMRI unit, including 39 brain biopsies, 30 tumor resections, 9 cases of functional neurosurgery, 8 cyst drainages, 5 laminectomies, and 10 miscellaneous cases. Intraoperative functional techniques were used to facilitate neurosurgical decisions. All surgery was performed by using MRI-compatible instruments within the 5-gauss line and conventional instruments outside that line. They found 1.5 T IMRI a safe and effective technology for assisting neurosurgeons. The advantages of the high-field environment include better spatial and contrast resolution and a capability for functional imaging during the operation. However, even in this solution, the patient needs to be moved in and out of the MR unit to perform craniotomies.

The Calgary group developed a different solution for a high-field 1.5 T IMRI unit (IMRIS, Calgary, AB, Canada). This allows the magnet to be moved out of the surgical field without a need to move the patient. Sutherland *et al.* (1999) demonstrated that high-quality MR images can be obtained in the operating room with reasonable time constraints by using this mobile 1.5 T MR system. Procedures can be conducted without compromising or altering the traditional neurosurgical, nursing, or anesthetic techniques.

2.5 Cost accounting

2.5.1 Cost analyses

Conventional cost accounting is based on the assumption that costs are caused by products. This practice has failed to keep pace with the evolution of product and process technologies in radiology. Conventional cost accounting exaggerates the costs of high-volume products and underestimates the costs of low-volume products, thus misrepresenting the relationship between production and costs (Ames & Hlavacek 1990). Activity-based cost (ABC) accounting was originally designed for use in industrial and service-providing units. It has also been recommended for use in hospitals (Chan 1993). When ABC accounting is used, the analysis is based on the assumption that activities create costs. This enables the analyst to trace different activities and allows more precise allocation of the costs in the final products. Especially indirect costs are allocated more accurately to products than in conventional accounting (Cohen *et al.* 2000).

Direct costs consist of fixed and variable costs. An example of fixed costs is personnel salaries. They remain unchanged, although activity increases, until more capacity is needed. Material costs are examples of variable costs. They follow the changes in activities. In the costs analyses for hospitals (Roberts *et al.* 1999), fixed costs accounted for 84% and variable costs for 16%. The share of variable costs varied between 25 and 42% (Roberts *et al.* 1999, Lave & Lave 1984). In radiology departments, the share of variable costs varies in different modalities. At a university hospital, they were 10% in conventional radiography, 26% in contrast examinations, 37% in CT, and 19% in MRI (Lääperi *et al.* 1998). At an interventional radiology unit in a Finnish university hospital, the share of variable costs was 67% (Rautio *et al.* 2003). Radiological procedures involve a large number of indirect costs, such as administrative, overhead, and allocation costs.

2.5.2 Cost-effectiveness

The increase of available medical technologies has made cost-effectiveness analyses (CEA) increasingly important in medicine during the past 20 years. Cost-effectiveness analysis provides a tool for assessing whether a new or a more effective technique is worth the additional cost (Soimakallio & Vanninen 1998). Financial resources are limited. The use of these resources to obtain a certain benefit means that some other benefit that would have been gained if the resources had been used differently must be given up (Sintonen & Pekurinen 2006). In 1996, the US Public Health Service established a panel on cost-effectiveness to develop consensus-based recommendations guiding the conduct of CEA to improve the comparability and quality of studies. Summaries of these reports have been published in journals (Russell *et al.* 1996, Weinstein *et al.* 1996, Siegel *et al.* 1996). CEA incorporates the costs and outcomes of an intervention and an alternative intervention (Weinstein *et al.* 1996). Radiological CEAs often use intermediate outcomes, such as the length of hospital stay, readmission rates, or the number of unnecessary surgical operations avoided (Thornbury 1999). Cost-minimization analysis compares the costs of different interventions assumed to have similar outcomes (Singer & Applegate 2001, Carlos 2004). Cost-utility analysis uses a subjective measure of effectiveness, namely the patient's preference for avoiding a disease. This is measured as quality-adjusted life-years (QALY), where each year lived with the disease is adjusted in comparison to a year lived without the disease (Singer & Applegate 2001, Carlos 2004). Cost-benefit analysis compares the costs of an intervention with its health benefits (Singer & Applegate 2001).

2.5.3 Cost analyses in radiology

Radiological cost analyses have generally been done with a conventional cost accounting method. There are fewer studies about the costs of radiological procedures where ABC accounting has been applied.

Cohen *et al.* (2000) used this method in an academic radiology department to determine the effect of the current teaching paradigm on clinical productivity. They concluded that ABC analysis can differentiate academic radiology into three businesses – teaching, research, and clinical – and provide a detailed understanding of the cost structure of each. Their analysis identifies opportunities for improved quality of service, productivity and cost within each business.

Nisenbaum *et al.* (2000) determined the costs of CT procedures in a large academic radiology department by analyzing actual resource consumption using the ABC method and comparing them with Medicare payments. They found that the ABC method allows more precise and detailed allocation of direct and overhead costs. In that setting, Medicare underimbursed professional costs and overimbursed technical costs.

Laurila *et al.* (2000b) analyzed a pediatric radiology department to obtain an informative and detailed view of resource utilization in order to support pricing and management. They found that costing is more detailed and precise, and the percentage of unspecified allocated overhead costs diminishes drastically when ABC is used. The new information enhances effective departmental management, as the whole process of radiological procedures is identifiable by single activities amenable to corrective actions and process improvement.

Saini *et al.* (2001) measured the technical costs of different categories of computed tomography examinations. They concluded that, although CT is based on sophisticated technology, the mean technical cost is less than 200$.

Enzmann *et al.* (2001) made a financial analysis of a mammography service to determine whether the key underlying economic drivers of this service were in line with the public's expectations. They found that the reimbursement rate for mammography procedures needs to be increased to reflect the current reality of the resources necessary to maintain the accessibility and accuracy of this evolving mix of clinical services.

Rautio *et al.* (2003) analyzed the costs of an interventional radiology unit and identified the cost factors in the different activities of catheter-based angiographies and interventional radiology. They found that material costs constituted the majority of costs, especially in the newest and most complicated endovascular treatments. Despite the high cost of the angiography equipment, its share of the total costs is small. In their experience, ABC is suitable for analyzing costs in interventional radiology.

Klose & Bottcher (2002) compared traditional cost accounting in departmental budgets with ABC accounting. They concluded that the introduction of process-oriented cost analysis is feasible for radiology departments, and that ABC plays a central role in the set-up of decentralized controlling functions within institutions.

King-Im *et al.* (2004) used ABC analysis to compare the costs of performing contrast-enhanced MR angiography (CE MRA) and intra-arterial digital subtraction angiography (DSA) for the evaluation of carotid atherosclerotic disease. They concluded that, assuming equal clinical efficacy, medical institutions may incur substantial cost savings if CE MRA is used instead of DSA. The variability of the previously reported "estimated" costs is very wide.

2.5.4 Cost analysis of plain-film radiography

The effect of digital plain-film radiography on the operating costs of a radiology department has most frequently been assessed in hospitals where radiological imaging is almost totally digitized (Andrienssen *et al.* 1989, Beard *et al.* 1990, Cywinski & van der Brink 1989, Drew 1993, Nissen-Meyer *et al.* 1996, van Poppel *et al.* 1990). Cost analyses of the use of CR on Intensive Care Unit patients have also been published (Don *et al.* 1995, Peters *et al.* 1992, Tucker *et al.* 1995). Replacement of conventional radiography with a PACS system throughout the hospital has been considered cost-effective, because the operating costs of the radiology department and the hospital stay of patients decrease (Beard *et al.* 1990, Mosser *et al.* 1994, Siegel 1994). Thus, digital radiology has been shown to pay itself back in five to eleven years (Cywinski & van der Brink 1989, van Poppel *et al.* 1990). On the other hand, it has been argued that PACS does not diminish the costs of a radiology department (Andrienssen *et al.* 1989, Drew 1993, Saarinen *et al.* 1989). As a rule, these analyses have been based on traditional cost accounting.

A hospital-wide PACS installation leads to potential cost savings in films and chemicals, archives, and salaries. The savings in film cost can be largely offset by the PACS equipment maintenance costs (Saarinen *et al.* 1989). Digital archiving represents an activity change, which increases the costs and improves the quality of the activity (Maass 2002). The only cost-effective compensation can be found in the shortening of the inpatient stay (Andrienssen *et al.* 1989). The hidden costs of patient care that result from delayed access to diagnostic information because of an inefficient archival system are difficult to measure. The study of Straub& Gur (1990) suggests that the major savings of PACS in health care may lie in these hidden costs.

In her study, Lantto aimed to create a new practical and economical radiological service system for Central Finland in the 2000s. She concluded that the present number of X-ray units could be reduced to almost a half by installing digital imaging equipment and by setting up a shared regional archive system (Lantto 2002).

2.5.5 Cost analysis of image-guided bone biopsy

There are only a few cost analysis studies concerning image-guided bone biopsies. Fraser-Hill *et al.* (1992) showed that, in the case of suspected primary tumors, the cost-effectiveness of percutaneous needle biopsy (PNB) was similar to that of open biopsy: fluoroscopically directed PNB was slightly more cost-effective than open biopsy, whereas CT-directed PNB was slightly less cost-effective. Either type of PNB was cost-effective for suspected metastatic deposits and infections, axial and appendicular lesions, radiolucent or lytic lesions, and soft-tissue lesions. Ruhs *et al.* (1996) showed that metastatic skeletal neoplasms could be reliably diagnosed by percutaneous needle aspiration (PNA), followed by open biopsy if the PNA result is negative or non-diagnostic, at a significant cost saving compared with open biopsy. Tikkakoski *et al.* (1992) considered CT-guided bone biopsy cost-effective but performed no cost analysis. Ward, Sr. & Kilpatrick (2000) concluded that fine-needle aspiration biopsy is cost-effective in diagnosing primary bone tumors. None of these cost analyses were performed with ABC accounting. Costs were based on estimates, hospital charges, or cost-charge ratios.

2.5.6 Cost analysis of the treatment of osteoid osteoma

The earlier results on percutaneous ablation of osteoid osteomas have shown this technique to be essentially equivalent to operative treatment (Rosenthal *et al.* 1998). It is, however, less invasive and results in shorter convalescence compared to surgical treatment and thus requires less utilization of health care resources. Articles concerning the percutaneous treatment of osteoid osteoma often mention that the short hospital stay and recovery time lead to cost savings compared to surgical treatment, but no actual cost analysis has been performed. Lindner *et al.* (1997) compared CT-guided RF ablation with traditional techniques. Fifteen patients were treated by wide excision removing a bone block, 26 patients underwent a marginal resection, 36 patients had intralesional resection by curettage or a high-speed burr technique. Four patients were treated percutaneously by a CT-guided drilling technique and 10 patients with CT-guided RF ablation. They concluded that CT-guided RF ablation of osteoid osteoma allows the orthopedic surgeon to cure osteoid osteoma with minimal trauma, functional restrictions, and costs. Interstitial laser ablation of osteoid osteoma has been reported to be a precise and minimally invasive alternative to traditional surgical and percutaneous ablations (Gangi *et al.* 1997a). Gangi *et al.* evaluated the largest series of percutaneous laser ablations of osteoid osteoma. They discussed that laser ablation is more economical compared to the costs incurred during the several days of hospitalization after surgery (Gangi *et al.* 2007). Because of the higher costs of the laser generator and probes, however, this method has not attained the same degree of use as RF ablation. A cost analysis is needed when a new treatment method, such as percutaneous laser ablation of osteoid osteoma, is found to have similar effectiveness as the alternative traditional treatments.

2.5.7 Cost analysis of an IMRI unit

The interest in low-field MRI units may be explained by the public pressure to reduce the cost of health care (Sepponen 1996). A low-field system will cause less financial strain on the reimbursing organization and the service provider. The costs of investing in high- and middle-field units are 2.7- and 1.8-fold, respectively, compared to low-field units. On the other hand, the patient throughput may be up to 50% greater in high-field systems than in low-field systems (Marti-Bonmati & Kormano 1997), which improves the cost benefit of high-field systems.

Because the use of MRI-guided surgical systems is rapidly evolving, the cost-effectiveness of MR-guided procedures must also be assessed. Hall *et al.* (1999) compared the financial costs and clinical benefits of brain tumor resection performed in an IMRI suite compared to a conventional operating room at the University of Minnesota. Length of inpatient stay, hospital charges, total hospital costs, repeat resection rate, interval to repeat tumor resection, and net health outcome were evaluated in relation to the conventional technology. The authors found that neurosurgical resection of brain tumors under MR guidance is safe, efficacious, and cost-effective.

3 Purpose of the study

The purpose of this study was to analyze the costs incurred during the transitional period of gradual digitalization of the radiology department, when MRI gains ground as a guidance method for interventions and minimally invasive therapies. The study aimed to detect the potential differences in cost structure between the new method compared to the conventional one. The analyses were done from the hospital's perspective. The specific aims were

1. to compare the costs of digital plain-film radiography with the costs of conventional radiography.
2. to evaluate the cost structures of procedures in a multipurpose IMRI unit and to analyze the effect of procedure volumes on cost structure.
3. to compare the costs of MRI- and CT-guided bone biopsies.
4. to compare the costs of MRI-guided laser ablation and surgery in the treatment of osteoid osteoma.

4 Materials and methods

4.1 Materials

4.1.1 Cost analysis of plain-film radiography (I)

This study concentrated on the cost of all plain radiographic examinations (plain-film examinations) done in the Radiology Department during the year 1994. The study material was gathered at Vaasa Central Hospital, which is a medium-sized Finnish general hospital with approximately 500 beds. In 1994, the Radiology Department performed about 46 000 examinations; 34 140 (75%) of them were skeletal and chest radiographies, of which approximately 3/4 were done using CR and 1/4 using conventional film-screen radiography (Table 1). The plain-film examinations were divided into three groups: CR (other than chest CR unit examinations), chest CR unit examinations, and conventional plain-film radiography.

Table 1. The plain-film radiography examinations during a one-year period.

Examinations in the Radiology Department	n	%
CR (other than chest CR unit examinations)	13434	40
Chest CR unit examinations	8303	24
Conventional plain-film radiography	4570	13
Radiography outside the Radiology Department		
Bedside CR	4029	12
Conventional plain-film radiography in the oncologic department	3658	11
Unclassified	146	0,4
Total	34140	100

The digital imaging modalities of the Radiology Department were connected to an image archive and to two laser printers (3M) by an image distribution network. There were two workstations in the Radiology Department, one with programs designed for processing and interpreting computed radiographs (Siemens Magic View 1102) and another designed especially for working with CT. The third workstation was in the Intensive Care Unit (ICU) and served as an image viewing workstation (Siemens Litebox). The digital image information was transferred to the workstation from the CR reader and the chest CR unit. At the workstation, the radiographer could post-process the images if necessary and print them on 34 × 43 cm laser film. Several images of a patient were combined on one film.

The radiologist reported the examination based on the film and used the workstation if a more detailed analysis was needed. The images were stored online at three levels: on workstations, on an archive server, and on optic disks in a jukebox. There was also a film archive for hard copies. Radiographs from conventional film-screen examinations were developed in a daylight processor (Agfa Curix Capacity).

4.1.2 Cost analysis of an IMRI unit (II)

In this study, the cost structure of the current procedures performed in a multipurpose IMRI unit was analyzed, and three alternative utilization models of open MRI were designed to simulate different local institutions and different development scenarios. In the year 2000, the Department of Radiology in Oulu University Hospital performed about 140 600 examinations, of which 691 were performed in the open MRI unit. The capacity of the scanner was divided in such a way that diagnostic MRI examinations were performed for about 60% of time, while MRI-guided interventions and MRI-guided neurosurgical operations both took about 20% of the total utilization time. During the one-year period 1 January to 31 December 2000, altogether 691 procedures were performed in the IMRI unit, of which 563 were diagnostic MRI examinations, 89 MRI-guided interventions, and 39 MRI-guided neurosurgical operations (Table 2).

Table 2. The open MRI procedures during a one-year period.

Diagnostic MRI examinations		MRI-guided interventions		MRI-guided neurosurgical operations n
Target	n	Procedure	n	
Head, face, neck	141	Biopsies		
Spine	214	Bone	18	
Extremities and joints	192	Soft tissue	15	
Breast	11	Injections		
Abdomen	4	Nerve root infiltrations	39	
Blood vessels	1	Sacroiliac joint arthrographies	11	
		Injections and punctures	6	
Total	563		89	39

4.1.3 Cost comparison of MRI- and CT-guided bone biopsies (III)

The study focused on a cost comparison of MRI- and CT-guided bone biopsies. The study site was the Oulu University Hospital with a local catchment area of 360 000 inhabitants and tertiary-care responsibility for 730 000 inhabitants. In the year 2000, the Radiology Department performed about 140 600 examinations, of which 82 were MRI-guided and 32 CT-guided interventions; biopsies, injections, and drainages. The material of the study consisted of 18 MRI-guided bone biopsies performed during the one-year period 1 January to 31 December 2000 and 12 CT-guided bone biopsies performed during 1 January to 31 December 1997. The targets of the MRI- and CT-guided bone biopsies were comparable (Table 3). The spinal vertebra was the target of most bone biopsies in both MRI (n=8) and CT (n=9). All patients had a bone lesion that had been detected in a previous radiographic, MRI, or CT examination. In MRI, the indications for bone biopsies were suspected infection (n=4), suspected neoplasm (n=12), and bone lesion of unknown origin (n=2). In CT, the indications were also suspected infection (n=3) or neoplasm (n=8) and bone lesion of unknown origin (n=1). Ten of the patients undergoing MRI and in 7 of the CT patients were biopsied under general anesthesia and 8 MRI patients and 5 CT patients under spinal anesthesia.

Table 3. Targets of bone biopsies.

Target	MRI-guided	CT-guided
Vertebra	8	9
Sacrum	2	1
Os ileum	1	1
Acetabulum	0	1
Caput femoris	5	0
Tibia	1	0
Costa	1	0
Total	18	12

4.1.4 Cost analysis of MRI-guided laser ablation and surgery of osteoid osteoma (IV)

The cost comparison of MRI-guided laser ablation and surgery in the treatment of osteoid osteoma was carried out at Oulu University Hospital. During the one-year period (1 January to 31 December 2002), seven patients (five women and two men, mean age 24 years, range 13 to 61 years) with clinical and previous imaging findings (MRI and X-ray or CT) of osteoid osteoma were treated with interstitial laser ablation in the IMRI unit (Table 4). Five of the lesions were located in femurs, one in a tibia, and one in an ulna, and all lesions were cortical or subperiosteal. Laser ablation was chosen as the treatment by a clinician after radiological consultation. The surgically treated reference group consisted of six patients (four women and two men, mean age 27 years, range 14 to 50 years) with clinical and imaging findings (X-ray, MRI, or CT and scintigraphy) of osteoid osteoma (Table 4). The operations were performed during the years 1998 to 2004. Three lesions were located in femurs, one in a tibia, one in a second metatarsal, and one in the pedicle of a second lumbar vertebra (L2). All lesions were cortical or subperiosteal, two lesions were deeply located (collum femoris and L2), and four lesions were superficial (two in femur diaphyses, one in a tibia diaphysis, and one in a second metatarsal diaphysis) relative to the skin surface (Table 4). Two patients were operated because percutaneous laser ablation treatment was not yet available in 1998-2000. The method of surgical treatment for four patients was chosen by the clinician without radiological consultation. Depending on the patient's age, co-operation, and lesion location, either spinal or general anesthesia was used. Four MRI-guided laser ablations and one surgical treatment of osteoid osteoma were performed under spinal anesthesia and three laser ablations and five surgical excisions under general anesthesia. After the treatment, both laser ablation and surgery patients were monitored in the recovery room.

Table 4. MRI-guided laser ablation and surgery of osteoid osteoma: number and age of patients, localization of lesion, nidus size, and result of biopsy.

Procedure	Number of patients	Mean patient age (years)	Localization	Mean nidus size (mm)	Result of biopsy
MRI-guided laserablation	7	24 (range 13 to 61 years)	5 femur (3 cortical, 2 subperiosteal) 1 tibia (cortical) 1 ulna (cortical)	10	5 osteoid osteoma 2 fibrosis
Surgery	6	27 (range 14 to 50 years)	3 femur (2 cortical, 1 subperiosteal) 1 tibia (cortical) 1 lumbar vertebra (cortical) 1 metatarsal (cortical)	7	3 osteoid osteoma 2 reactive transformation 1 fibrosis

4.2 Methods

4.2.1 Activity-based cost analysis

The costs were analyzed by using a software application for ABC analysis. The analysis is based on the assumption that activities create costs. The principles of ABC analysis are presented in Figure 1. The cost factors are allocated to resources. The product (examination or intervention) is divided into activities, to which the costs of the resources are allocated according to cost drivers. Activity costs are allocated to products using activity drivers. One or several resources can be utilized for an activity, and an activity can be part of one or several products. All cost analyses were performed retrospectively over a 12-month period to achieve actual costs, not estimates or cost-charge ratios.

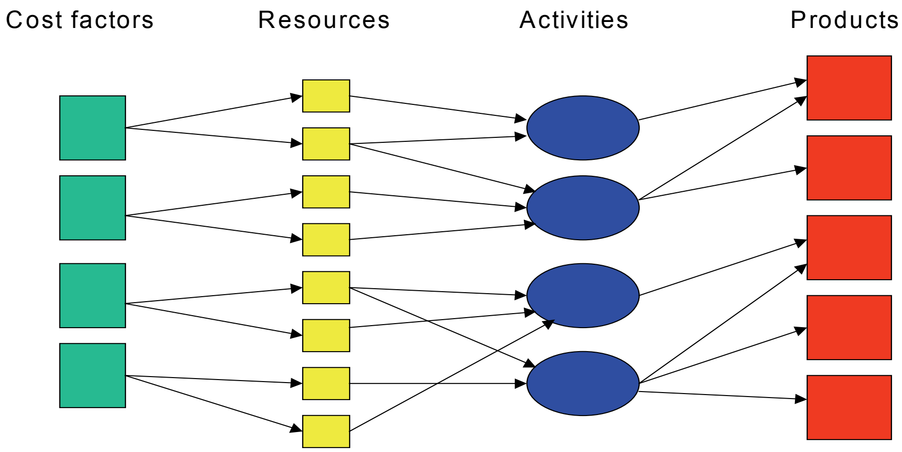

Fig. 1. Principles of ABC accounting

The information concerning cost and consumption was acquired from the hospital's accounting department and from the inventory files of the final accounts of each year. Material costs consisted of actually used material, such as biopsy and puncture instruments, films and contrast media, and sterile supplies, i.e. patient drapes, syringes, and bowls. Personnel costs consisted of salaries, taxes, and social security payments. Equipment costs consisted of the amortization and service costs of the imaging equipment, monitors, and workstations. The costs of the premises consisted of rents of the examination room and the assistant room, including capital investments and running costs, such as electricity, water, cleaning, and furnishing. Administrative and overhead costs, the share of the hospital's administrative costs, and the educational and allocation costs of the Department of Radiology were included in the analysis. The low inflation rate (approximately 2%) was not taken in account.

Plain-film radiography (I)

The plain-film radiography examinations were divided into three groups: CR (other than chest CR unit examinations), chest CR unit examinations, and conventional plain-film radiography. The distribution of examinations was equal in the groups of computed and conventional plain-film radiography.

The costs of the resources (personnel, equipment, materials, premises, general costs, etc.) were allocated into resource pools, each of which contained functionally or spatially related resources. For example, the pool for "chest imaging room" consisted of the costs of the premises, the chest imaging equipment, and the materials used in the room. The resources were allocated to pools according to real use. All separate activities needed to carry out the examinations were defined. Costs were allocated to activities according to resource use as expressed by cost drivers. The cost drivers for personnel, equipment, and premises were defined as the time required for the activity multiplied by the frequency of this activity, and those for materials as the actual amount used. The number of personnel required was taken in account when allocating the personnel costs. The information on the average time and number of personnel required was collected in a five-month follow-up study using the Radiology Department Information System. Other information concerning cost and consumption was acquired from the hospital's accounting department and from inventory files. Activity-based costs were allocated to examinations in proportion to the number of examinations performed. The Radiology Department budget for 1994, including capital costs, was 3.3 million euros. Of this sum, personnel costs accounted for 1.3 million euros, material costs for 0.9 million euros, maintenance costs and rent for 0.3 million euros, and the capital and maintenance costs of equipment for 0.7 million euros. The total value of the Radiology Department equipment was 3.9 million euros. The costs of maintenance and updating the software used in the digital equipment were included in the annual operating costs. Acquisition costs were distributed over the period 1983-1993. The mini-PACS, the CT scanner, and the plain-film radiography equipment were purchased in 1993 at a cost of 1.5 million euros. The capital investment was depreciated with equal instalments. The amortization period of the X-ray machines was fifteen years, with the exception of the X-ray tubes, which were amortized three years.

IMRI unit (II)

All costs directly related to activities in the open MRI unit were calculated from the perspective of the Department of Radiology. The information concerning costs and consumption was acquired from the hospital's accounting department and from the inventory files in the final accounts of the year 2000. In neurosurgical operations, only the personnel costs of the Department of Radiology were included. The personnel costs of the Department of Neurosurgery were not included in the cost analysis. The material costs concerning only the Department of Radiology were included.

The cost of anesthesia in MRI-guided interventions was also included in the calculations. General or spinal anesthesia was used, depending of the biopsy target and the patient's needs. The Department of Anesthesiology charged the Department of Radiology according to their price list. It was based on the previous activity–based cost analysis performed by the Department of Anesthesiology. The anesthesia needed in neurosurgical operations was charged from the Department of Neurosurgery, and it was therefore not included in the cost analysis of the IMRI unit.

All activities done in the IMRI unit were identified. There were a total of 26 different activities, which were divided into four main categories: main procedure, supplementary activities, anesthesia, and business activities. The main procedure in diagnostic examinations included the imaging of the patient by two radiographers and the interpretation by a radiologist. The main procedure in MRI-guided interventions included the biopsy or injection as well as the necessary imaging performed by a radiologist and two radiographers and the interpretation performed by a radiologist. The main procedure in MRI-guided neurosurgical operations consisted of imaging before, during, and after the operation performed by two radiographers and interpretation of the findings performed by a radiologist. The supplementary activities in MRI-guided interventions and neurosurgical operations consisted of the preparation and aftercare of the patient. The business activities in all examinations and interventions consisted of educational, administrational, and overhead costs.

Cost factors and resources were identified for each activity. All costs were collected into 27 resources, each of which contained functionally or spatially related cost factors. In MRI-guided biopsies, for example, the amortization and service costs of the open MRI equipment, monitors, and workstation were allocated to the resource "open MRI equipment", while the resource "MRI biopsy instruments" consisted of the costs of MRI-compatible biopsy needles and drills. The costs of the resources were allocated to activities according to their use as expressed by cost drivers. The cost drivers for personnel, equipment, and premises were defined as the time required for the activity multiplied by the frequency of this activity, and those for materials as the actual amount used. The number of personnel was taken into account when allocating personnel costs. The average time of activities was obtained from the internal information system of the Department of Radiology. The activities were allocated to products, which were the examinations and interventions performed, according to the times required multiplied by the number of examinations or interventions. The procedures were divided into three main categories: diagnostic MRI examinations, MRI-guided interventions (biopsies and injections), and MRI-guided neurosurgical operations. In Finland, hospitals are largely publicly funded, which means that all equipment to be purchased is paid immediately, which is why an interest rate of 0% was used in the analysis.

MRI- and CT-guided bone biopsies (III)

All costs directly related to the activities in the open MR and CT units were calculated from the perspective of the Department of Radiology. The cost of anesthesia was included in the calculations. General or spinal anesthesia was used, depending of the biopsy target and the patient's needs. The Department of Anesthesiology charged the Department of Radiology according to their price list**,** based on the previous cost analysis. The main cost factor of anesthesia was the time the anesthesia took.

The MRI and CT units had a total range of 63 activities, which were divided into main categories. For example, the main categories of the volume-based activities of bone biopsies were "biopsy procedure" (MRI-guided biopsy, CT-guided biopsy), "supplementary activities" (preparation and aftercare of the patient and the instruments) and "anesthesia". The business activities consisted of "education", "administration", and "overheads". The biopsy procedure was defined as the time spent by the patient in the examination room. It included the main procedure, which was performed by a radiologist and two radiographers. The process model was defined for each product line. Cost factors and resources were identified for each activity. All costs were allocated to 118 resources, each of which contained functionally or spatially related cost factors. For example, the amortization and service costs of the open MRI equipment, monitors, and workstation were allocated to the resource "open MRI equipment", and the resource "MR bone biopsy instruments" comprised the costs of MRI-compatible biopsy needles and drills. The costs of the resources were allocated to activities according to their use as expressed by the cost drivers. For example, the costs of the resource "open MRI equipment" and "contrast material" were divided with the help of cost drivers into activities that utilize those resources. The cost drivers for personnel, equipment, and premises were defined as the time required for the activity multiplied by the frequency of this activity, and those for materials as the actual amount used. The number of personnel was taken into account when allocating personnel costs. One radiologist and two radiographers were needed to perform MRI- and CT-guided biopsies. The average time of activities was obtained from the Radiology Department's internal information system, and other information was obtained from the hospital's accounting department and inventory files. The activities were allocated to products, which are procedures performed, according to the times required multiplied by the number of procedures. The amortization period of the MRI and CT equipment was six years.

MRI-guided laser ablation and surgery of osteoid osteoma (IV)

In the cost analysis of MRI-guided laser ablation of osteoid osteomas, all costs directly related to the activities in an IMRI unit were calculated from the perspective of the Department of Radiology. The information concerning costs and consumption was acquired from the final accounts of the year 2002, which were available at the hospital's accounting department. Material costs consisted of the costs of the actually used materials, which, in the case of laser ablations, included laser fiber, bone biopsy instruments, coaxial needles, and other materials, such as films and sterile supplies (patient drapes, syringes, and bowls). The cost of anesthesia was included in the calculations. General or spinal anesthesia was used, depending on the biopsy target and the patient's needs. The Department of Anesthesiology charged the Department of Radiology and the Department of Orthopaedics and Surgery according to their price list based on the previous cost analysis in the Department of Anesthesiology. The analysis includes all cost factors used in anesthesia. The time spent by the patient in the recovery room was also included.

The authors identified all activities needed in the IMRI unit. There were a total 28 activities, which were divided into two main categories: procedure and anesthesia. The procedure included the laser ablation performed by a radiologist and two radiographers and the supplementary activities, including the preparation and aftercare of the patient by two radiographers. The business activities (administrative and overhead costs) were also included in the procedure. Cost factors and resources were identified for each activity. All costs were allocated to 32 resources, each of which contained functionally or spatially related cost factors. For example, the amortization costs of the open MRI equipment, monitors, and workstation were allocated to the resource "open MRI equipment", and the resource "bone biopsy instruments" consisted of the costs of the MRI-compatible biopsy needles and drills. The costs of the resources were allocated to activities according to their use as expressed by cost drivers. For example, the costs of the resource "open MRI equipment" and "bone biopsy instruments" were divided with the help of cost drivers into activities that utilize these resources. The cost drivers for personnel, equipment, and premises were defined as the time required for the activity multiplied by the frequency of this activity, and those for materials as the actual rate of use. The number of personnel was taken into account when allocating personnel costs. The activities were allocated to products, which are procedures performed, according to the times required for the activity multiplied by the number of procedures. The average time of activities was obtained from the internal information system of the Department of Radiology. The amortization period of the MRI and laser equipment was seven years. In 2002, in Finland, the interest rate for investment was 4.5%.

The costs of superficial and deep surgical treatments of osteoid osteoma in the Department of Orthopedics and Surgery were divided into two main categories: procedure and anesthesia. The procedure included the preparation, operation, and aftercare of the patient performed by two surgeons and two nurses. The material costs included the costs of the actually used materials, such as scalpels, bone drills, gouges, other surgical instruments, and sterile supplies (patient drapes, syringes, and bowls). The quantity of materials used depended on the location of the lesion, the depth and extent of the resection, and the need for metallic fixation. The amortization period of the fluoroscopy machine was six years. The operating room costs and the administrative and overhead costs of the Department of Orthopedics and Surgery were also included. As in MRI-guided laser ablation, the Department of Anesthesiology also charged the Department of Orthopedics and Surgery according to their price list. This included the time spent by the patient in the recovery room.

The six surgical treatments of osteoid osteoma were performed between the years 1998 and 2004. The costs of these operations were standardized to the level of the year 2002, to make them comparable with the laser ablations performed in the year 2002.

The mean length and cost of each patient's hospital stay were recorded. One day in the hospital ward cost 222 euros per patient in both groups, which does not include the procedural costs of laser ablation or surgery. This was based on a cost analysis previously performed in the Department of Orthopedics and Surgery. The number of sick days or restricted weight-bearing after the ablation or the operation was also recorded. There was a clinical examination three months after laser ablation. The surgically treated patients had a clinical examination with plain-film radiography one month after the treatment. In both groups, further examinations were arranged only if the patient had a recurrence of symptoms.

4.2.2 Sensitivity analyses and simulation models

In the baseline calculations of the cost analysis of plain-film radiography (I), the amortization period of the mini-PACS was set as ten years, and the interest rate for invested capital was defined as 0%. Three cost comparisons were performed to analyze the effect of the length of the amortization period of capital goods on the cost of the examination by setting the amortization period for the mini-PACS equipment and the daylight processor used in conventional imaging as five, ten, and fifteen years and by setting the interest rate as 0%. In addition, a sensitivity analysis in which the amortization period for the mini-PACS was set as five and fifteen years and the interest rates as four and eight percent, respectively, was carried out.

In the cost comparison analysis of MRI- and CT-guided bone biopsies (III) in the baseline calculations, the amortization period of the MRI and CT equipment was six years. The effect of the length of the amortization period of the new MRI equipment was analyzed by changing it to ten years. This was done because of the different time of use of the equipment in different hospitals. In Finland, hospitals are largely community-subsidized, meaning that all equipment to be purchased is paid immediately, not loaned, which is why the interest rate in the analysis was 0%.

Multipurpose use of the open MRI equipment is mandatory at the present because of the small number of MRI-guided interventions done at the hospital. Both the development of MRI-guided interventions and the local circumstances lead to different models of IMRI unit usage and different shares of procedures. In the cost analysis of IMRI unit (II), three alternative models of IMRI utilization were created to simulate different local circumstances and to analyze the effects of procedure shares on cost structure. The simulation models of utilizing open MRI equipment were created by adjusting the proportions of different procedures. In "Imaging IMRI", only those MRI-guided interventions are performed in which MRI has proved to be the primary method. The estimated share of MRI-guided interventions is then 15% of the total procedure time. The remaining 85% of the procedure time consists of diagnostic MRI examinations. In "Intervention IMRI", it is assumed that the evolution of MRI-guided interventions will show a continuous increase, and that the estimated share of MRI-guided interventions will be 30%. The share of diagnostic MRI examinations will be 70%. In these two models, no MRI-guided neurosurgical operations are performed. In "Neurosurgery IMRI", in which the main motivation for investment is MRI-guided neurosurgery, the estimated proportion of operations is 50%. The share of necessary MRI-guided interventions is 15%, and the remaining 35% consist of diagnostic MRI examinations. The cost analyses of the simulation models were also performed by using ABC accounting. The correlation between two continuous variables was measured with simple linear regression analysis.

4.2.3 Image guidance and procedures

In CT-guided bone biopsies (High Speed, General Electrics, MI, USA), CT fluoroscopy was not available. The site, direction, and depth of punctures were estimated from scans obtained just prior to the biopsy. The puncture site was marked on the skin with a bullet and a felt-tip pen. The direction of the trocar-tipped needle was adjusted by visual estimation, and the skin and subcutaneous tissues were punctured. Before entering the deep tissues and perforating the bony cortex, the site and direction of the needle were checked with control scans.

The open MRI unit consists of an examination room, a room with workstations for interpretation, and a room for the preparation and aftercare of patients and instruments. The imaging room is equipped as a full-scale OR, to allow the radiological interventions and neurosurgical operations to be performed in the same facility as the diagnostic examinations. The horizontally open-configuration, low-field (0.23 T) MRI scanner (Outlook Proview, Philips Medical System, Vantaa, Finland) was acquired by Oulu University Hospital in 1998. All the instruments and equipment used in radiological interventions were MRI-compatible because these interventions were performed under continuous MRI guidance. Optical tracking equipment and software (Outlook Proview, Marconi Medical Systems, Cleveland, Ohio) were used in the interventions. This technique is based on the presence of infrared reflecting spheres in the instrument holder and in the scanner and a camera that detects the reflected signal. Unique to this scanner is the possibility to turn off the magnet, allowing normal OR activities and devices. The turn-on time of the magnet is only six minutes. Most of the neurosurgical instruments were regular OR products that could be moved outside the 5-Gauss line, which was less than two meters from the scanner, or out of the imaging room before the magnetic field was turned on. The brain biopsy instruments were MRI-compatible.

In MRI-guided bone interventions, the instrument dimensions were calibrated with tracking software before the puncture. The instrument and its trajectory were shown in real time as a graphic overlay in the image or the image set during the procedure. The lesion and the puncture route were visualized with T1-weighted fast spin-echo (FSE) imaging (TR/TE 16 ms/400 ms, five 7.0 mm slices at 8.0 mm intervals, FOV 380 × 380, matrix 324 × 324, acquisition time 23 s), completely balanced steady-state (CBASS) imaging (TR/TE 8.4 ms/4.2 ms, eight 5.0 mm slices at 5 mm intervals, FOV 380 × 380, matrix 256 × 256, acquisition time 24 s), and T2-weighted FSE images (TR/TE 150 ms/3500 ms, nine 7.0 mm slices at 8.0 mm intervals, FOV 380 × 380, matrix 192 × 192, acquisition time 35 s) were also obtained whenever no previous MR imaging had been done. The site of skin puncture and the procedural route were determined by means of optical tracking. In order to visualize the biopsy set before and during the puncture, fast T1-weighted gradient (TR/TE 95 ms/7 ms, three 7.0 mm slices at 7.0 mm intervals, FOV 380 × 380, matrix 300 × 300, acquisition time 12 s; TR/TE 130 ms/11 ms five 10.0 mm slices at 10 mm intervals, FOV 380 × 380, matrix 256 × 256, acquisition time 18 s) or CBASS imaging (TR/TE 8.4 ms/4.2 ms, eight 5.0 mm slices at 5.0 mm intervals, FOV 380 × 380, matrix 256 × 256, acquisition time 24 s; TR/TE 9.1 ms/4.5 ms, one 10.0 mm slice, FOV 380 × 380, matrix 256 × 256, acquisition time 1.5 s) was performed.

In MRI-guided laser ablation of osteoid osteoma, a 14-g bone biopsy drill (Cook Medical, USA) was used to enter the nidus, after which a biopsy was extracted. A 14-g coaxial needle (MRI devices, Daum, USA and Germany) was introduced into the channel via a MRI-compatible 0.35-in. stiff guide wire (Somatex, Berlin, Germany), and its position was controlled with imaging. After that, the guide wire was removed, a laser fiber was introduced into the needle shaft, and the needle was retracted 0.5-1 cm, after which its position was again controlled before the laser treatment was initialized. The laser device used was of the Nd-Yag type, maximum power 100 W (Fibertom medilas, Dornier Medizin Technik, Germany), and it was acquired by Oulu University Hospital in 2000. A laser fiber with a diameter of 400 μm was used (Dornier Medizin Technik, Germany). Constant energy flow and power of 2 W was used. The mean amount of energy delivered to the bone tissue was 1000 J (minimum 650 J, maximum 1200 J). The mean laser treatment time was 8 min 20 s (minimum 5 min 25 s, maximum 10 min). One patient underwent two laser ablations because of the large size of the lesion (nidus size 20 mm). The treatment was monitored by using 3D CBASS MR imaging (eight 6 mm slices at 6 mm intervals, TR/TE 3.8 ms/ 7.7 ms, flip angle 63 degrees, FOV 380x380, matrix 160 × 160, acquisition time 24 s). The monitoring was done by following the changes in signal intensity caused by the temperature change in the heated tissue. When a signal change was detected, the treatment was considered complete. If no signal changes in the procedural thermal MRI images were detected, the treatment time was determined using the formula ($D = 2.389 \times \ln(E) - 10.58$, where D is the coagulation diameter in millimeters and E the laser energy) depicting the thermal effect of laser on the bone over time. A detailed description of this method and the method of thermal monitoring by MRI is given by Blanco Sequeiros *et al.* (Sequeiros *et al.* 2003). As all the lesions were successfully identified, targeted, and treated under MRI guidance, the initial technical success rate of the MRI-guided procedures was 100%.

There were two different types of surgical treatment of osteoid osteoma, depending on the location of the lesion (relative to the skin surface). In superficial lesions, the nidus and the surrounding sclerotic bone were removed by using curettes and burrs. In deep lesions, the resection was wider, and metallic fixation and possibly a bone batch were needed to stabilize the bone. Four superficial excisions on one osteoid osteoma in a tibia, two in femurs, and one in a second metatarsal were performed. The series of cases included two deep excisions with metallic fixations. One deeply located osteoid osteoma was resected from collum femoris, the remaining cavity was filled with bone graft, and the collum was fixed with a DHS plate. The other deep osteoid osteoma in an L2 pedicle was removed by unilateral resection of the lamina, processus articularis, and the pedicle of the vertebra, after which L1-3 spondylodesis was performed followed by metallic fixation. In all operations, fluoroscopy was used to locate the lesion and a biopsy was taken.

5 Results

5.1 Cost analysis of plain-film radiography

5.1.1 Baseline cost analysis

The baseline cost analysis showed CR examinations (other than chest CR) to have 9% higher total cost than conventional plain-film radiography (Table 5). The cost of the chest CR unit was equal to the cost of conventional radiography.

The capital cost of digital imaging was almost twice as high as the capital cost of conventional imaging. The personnel cost was lowest in chest CR imaging, but for other modalities of CR imaging it was approximately the same as for conventional imaging. Film costs were equal in all groups, despite the higher price of the laser film used in digital imaging. The costs of premises, allocated hospital costs, and administrative costs were similar for both CR and conventional imaging, although slightly lower in chest CR.

Table 5. Mean cost of one plain-film radiography examination (Euro).

Examination	Capital costs		Personnel costs		Film and chemicals		Other		Total	
	Euro	%	Euro	%	Euro	%	Euro	%	Euro	%
CR (other than chest CR unit examination)	5.2	18	13.1	45	2.4	8	8.6	29	29.3	100
Chest CR unit examinations	5.9	22	11.6	42	2.4	9	7.4	27	27.3	100
Conventional plain-film radiography	2.7	10	13.6	51	2.4	9	8.2	30	26.9	100

The higher cost of CR examination was due to the "image processing" activity, in which the phosphorus plates were loaded into the reader unit, processed on the workstation, and printed on film with a laser printer (Table 6). The cost of this activity was 56% higher than the processing of conventional radiographs. On the average, 1.5 films per CR examination could be saved using the workstation to combine several images on one film sheet. Thus, approximately 3-4% of the total cost of the CR examination could be saved, compared to working without a workstation.

The costs of a radiographer's work and the running of an examination room (including equipment) were allocated to the activity termed "main procedure". On the average, the patient occupied the room for ten minutes in CR and conventional imaging and for seven minutes in chest CR. Despite these differences, the costs of the main procedure (examination) for conventional and digital plain radiography were similar (Table 6).

Table 6. Mean costs of activities during one plain-film radiography examination (Euro).

Activity	CR (other than chest CR)		Chest CR unit examination		Conventional plain-film radiography	
	Euro	%	Euro	%	Euro	%
Time reservation and registration	4.2	14	4.2	15	4.2	16
Main procedure (examination)	10.8	37	10.4	38	10.8	40
Image processing	6.6	23	4.9	18	4.2	16
Image interpretation and reporting	3.5	12	3.5	13	3.5	13
Film processing and transport	2.2	8	2.2	8	2.2	8
Clinical film demonstration	1.3	4	1.3	5	1.3	5
Quality control	0.7	2	0.7	3	0.7	3
Total	29.3	100	27.2	100	26.9	100

5.1.2 Sensitivity analysis

The shorter amortization period of capital goods increased the cost of digital imaging more than the cost of conventional imaging. When the amortization period was set as five years, the cost of CR was 16% higher than the cost of conventional radiography. Defining the amortization period as ten years resulted in a cost difference of 9%, while 15 years resulted in a 6% difference. Changes in the interest rate also increased the cost of digital examinations more than the cost of conventional examinations. At an interest rate of 0%, a digital examination was 9% more expensive than a conventional examination. An interest rate of 4% resulted in a 12% difference and an 8% interest rate in a 15% difference between digital and conventional radiography.

5.2 Cost analysis of an IMRI unit

5.2.1 Baseline cost analysis and cost structure

In the year 2000, diagnostic MRI examinations accounted for 61%, MRI-guided interventions for 31%, and MRI-guided neurosurgical operations for 8% of the total procedure costs of the IMRI unit. The mean cost was 241 euros for one diagnostic MRI examination, 1238 euros for MRI-guided biopsy, and 523 euros for MRI-guided injection. The cost for the use of IMRI in one MRI-guided neurosurgical operation was 481 euros (Table 7).

The cost of the main procedure (including material, personnel, equipment, and premises) was the most significant cost in all procedures, accounting for 66-89% of the total costs (Table 7). In MRI-guided biopsies, the anesthesia cost was the second biggest, accounting for 27% of the total cost. The cost of supplementary activities was less significant, accounting for 5-13% in MRI-guided interventions and neurosurgical operations. The cost of business activities (educational, administrative, and allocation) was similar in all procedures, accounting for 2-11% of the total cost.

In diagnostic examinations (Table 7), the personnel cost accounted for the largest part of the procedure cost (51%), and the share of equipment and premises cost was also high (29%). The share of material cost per examination was smaller (9%).

Table 7. Mean costs of activities during one MRI procedure in the measured model (Euro).

Activity	Diagnostic MRI examination		MRI-guided intervention: Biopsy		MRI-guided intervention: Injection		MRI-guided neurosurgical operation	
	Euro	%	Euro	%	Euro	%	Euro	%
Main procedure	215	89	818	66	433	83	391	81
material	22	9	394	32	199	38	141	29
personnel	123	51	299	24	154	29	167	35
equipment and premises	70	29	125	10	80	15	83	17
Supplementary activities			64	5	64	12	64	13
Anesthesia			330	27				
Business activities	26	11	26	2	26	5	26	5
Total	241	100	1238	100	523	100	481	100

In MRI-guided interventions, material cost accounted for the largest part of the procedure cost, ranging within 32-38% (Table 7). This was due to the high-priced MRI-compatible instruments, such as drills in MRI-guided bone biopsies. The personnel cost in MRI-guided interventions was the second largest category (24-29% of the total costs per intervention), and it was highest in such interventions as MRI-guided bone biopsies and soft-tissue biopsies because of the long procedure time (128 and 135 min). The equipment and premises cost was less significant, i.e. 10-15%, also depending on the procedure time.

When IMRI was used in a neurosurgical operation, the personnel cost (35%) was slightly higher than the material cost (29%). The cost of equipment and premises was 17% per procedure (Table 7). These costs included only those related to the use of the IMRI unit and not direct surgical costs.

5.2.2 Simulation models

During a one-year period, the number of procedures in the "Imaging IMRI" model (no neurosurgery) was 865, of which 798 were diagnostic MRI examinations and 67 MRI-guided interventions (25 biopsies and 42 injections), corresponding to 85% and 15% of scanner time, respectively. The diagnostic MRI examinations accounted for 92% and the MRI-guided interventions for 8% of the total procedure costs in the IMRI unit. The most significant change compared to the measured model occurred in the unit cost of diagnostic MRI examinations, which decreased by 16% (Table 8). The change in the unit cost of MRI-guided interventions was smaller, as the cost was lower by 2-4% than in the measured model. The larger total number of procedures, especially diagnostic MRI examinations, reduced the personnel, equipment, and premises costs and also the business costs per procedure.

Table 8. Mean cost of one procedure in the measured and simulated models of the IMRI unit (Euro).

Procedure	Measured model Euro	Imaging IMRI Euro	Intervention IMRI Euro	Neurosurgery IMRI Euro
Diagnostic MRI examination	241	202	218	310
MRI-guided intervention				
Biopsy	1238	1216	1190	1357
Injection	523	500	488	594
MRI-guided neurosurgical operation	481			556

"Intervention IMRI" included 791 procedures, of which 657 were diagnostic MRI examinations and 134 MRI-guided interventions (50 biopsies and 84 injections), corresponding to 70% and 30% of scanner time, respectively. The diagnostic MRI examinations accounted for 59% and the MRI-guided interventions for 41% of the total procedural costs. The unit cost of MRI-guided interventions decreased by 4-7% (Table 8), and the unit cost of diagnostic MRI examinations by 10%

compared to the measured model. The decrease was more marked in MRI-guided interventions and smaller in diagnostic MRI examinations than in "Imaging IMRI".

"Neurosurgery IMRI" consisted of 493 procedures, of which 328 were diagnostic MRI examinations, 67 MRI-guided interventions (25 biopsies and 42 injections), and 98 MRI-guided neurosurgical operations, corresponding to 35%, 15%, and 50% of scanner time, respectively. The diagnostic MRI examinations accounted for 47%, the MRI-guided interventions for 28%, and the MRI-guided neurosurgical operations for 25% of the total procedure costs in the IMRI unit. The cost changes were more prominent and opposite to those in the other two simulation models. There was a strongly positive correlation between the unit costs of radiological procedures and the number of neurosurgical operations (Pearson correlation coefficient (r)=0.99, r^2=0.97). The most significant change occurred in the unit cost of diagnostic MRI examinations, which increased by 29% compared with the measured model (Table 8). The unit cost of MRI-guided interventions and the use of IMRI in neurosurgical operations also increased; the costs were 10-14% higher in interventions and 16% higher in neurosurgical operations than in the measured model. The increase was due to the higher personnel, equipment, premises, and business costs per examination. Although the number of MRI-guided neurosurgical operations was considerably higher (98) in the "Neurosurgery IMRI" than in the measured model (39), the small total number of all procedures in the IMRI unit resulted in higher costs per operation.

5.3 Cost comparison of MRI- and CT-guided bone biopsies

The cost comparison showed that the cost of MRI-guided bone biopsy was 2.55-fold compared to CT-guided bone biopsy. The cost difference was biggest in the biopsy procedure activity (3.23-fold) and smaller in the anesthesia, supplementary, and business activities (1.94-, 1.71-, and 1.41-fold) (Table 9). In both MRI- and CT-guided bone biopsies, the cost categories termed "biopsy procedure" and "anesthesia" were the significant ones, representing over 80% of the costs, while the supplementary and business activities were less costly.

Table 9. Mean costs of activities in one bone biopsy (Euro).

Activity	MRI-guided	CT-guided
Biopsy procedure	774	240
Materials	351	63
Personnel	303	111
Equipment and premises	120	66
Supplementary activities	77	45
Anesthesia	330	170
Business activities	24	17
Total	1205	472

The 3.23-fold cost of the biopsy procedure in MRI was mainly due to the higher material (5.57-fold) and personnel (2.73-fold) costs (Table 9). The difference in material costs was due to the need for MRI-compatible bone biopsy instruments, which cost 219 euros per examination. The bone biopsy instruments in CT-guided bone biopsy cost only 61 euros per examination. The longer time needed to perform a biopsy with MRI (128 min) than CT guidance (66 min) was caused the higher personnel cost. This also caused the higher cost of anesthesia in MRI (1.94-fold) than in CT.

There was a smaller difference (1.82-fold) in the costs of the equipment and premises between MRI- and CT-guided biopsies. This difference was mainly due to the higher initial capital cost of the open-configuration MRI equipment. The effect of the length of the amortization period of capital costs on the cost of MRI-guided bone biopsies was analyzed by defining the amortization period for the MRI equipment as 6 and 10 years. A longer amortization period reduced the total cost of one MRI-guided bone biopsy by only 2%, from 1205 euros to 1180 euros.

5.4 Cost analysis of MRI-guided laser ablation and surgery of osteoid osteoma

The mean cost of MRI-guided laser ablation (2392 euros, Table 10) was higher than the cost of excision of superficially located osteoid osteoma (1807 euros Table 11). The mean cost of the excision of deeply located osteoma with metallic fixation (4996 euros) was considerably higher compared to laser ablation. This was due to the higher material, personnel, and ward costs (Table 11).

Table 10. Mean cost of one MRI-guided laser ablation of osteoid osteoma during hospital stay (Euro).

Cost category	Euro	% of the procedure costs	% of the hospital costs
Procedure (laser ablation)			
Personnel	335	25.2	
Material	406	30.5	
Equipment	507	38.1	
Premises and service	77	5.8	
Business	6	0.4	
Total	1331	100	55.6
Anesthesia	617		25.8
Ward costs	444		18.6
Total	2392		100

The cost category termed "procedure" was the most significant in all treatments, representing 55.6% of the total cost of MRI-guided laser ablation, 47.8% of the total cost of superficial excision, and 61.1% of the total cost of deep excision. The shares of anesthesia and ward costs were smaller (Tables 10 and 11).

Material cost (406 euros) made up the most significant part of the procedure cost in MRI-guided laser ablation (Table 10). This was due to the high price of MRI-compatible bone biopsy instruments (132 euros/ablation) and coaxial needles (129 euros/ablation). The cost of laser fiber in one ablation was relatively low (55 euros) because an average of ten ablations could be performed using the same fiber. The type of surgery and especially the need for metallic fixation had a marked effect on material costs. The material cost of superficial excision (151 euros) was lower and that of deep excision with metallic fixation (1866 euros) much higher than the material cost of MRI-guided laser ablation (Table 11). In MRI-guided laser ablation and superficial excision, the materials used were rather standard. In deep excisions, especially fixation materials were different, depending on the need to stabilize the resected bone. The material cost was 507 euros in deep resection from collum femoris and 3225 euros in resection from the L2 pedicle.

Table 11. Mean costs of one superficial and one deep excision of osteoid osteoma during hospital stay (Euro).

Cost category	Superficial excision			Deep excision		
	Euro	% of the procedure costs	% of the hospital costs	Euro	% of the procedure costs	% of the hospital costs
Procedure (operation)						
Personnel	531	61.4		885	29.0	
Material	151	17.5		1866	61.1	
Equipment	6	0.7		10	0.3	
Business	176	20.4		293	9.6	
Total	864	100	47.8	3054	100	61.1
Anesthesia	499		27.6	832		16.7
Ward costs	444		24.6	1110		22.2
Total	1807		100	4996		100

The personnel cost was lower in MRI-guided laser ablation (335 euros) than in either superficial (531 euros) or deep (885 euros) excisions. A team of two surgeons and two nurses performed the surgical excisions, while the laser ablation was done by a team of one radiologist and two radiographers. This caused the higher personnel costs of surgical excisions. In deep excisions, the procedure time was also longer, which further increased the personnel cost.

Equipment cost was higher in laser ablation (507 euros) than in superficial (6 euros) or deep (10 euros) excisions (Table 10 and 11). In laser ablation, this cost item consisted mainly of the cost of the laser device, which was 430 euros per one ablation. The cost of the open MRI equipment was considerably smaller (77 euros). In surgical excisions, the equipment cost included only the cost of the fluoroscopy machine.

Anesthesia cost depended on the total procedure time. This also included the time spent by the patient in the recovery room, which was 2.5 hours after laser ablation and superficial excision and 11.5 hours after deep excision. The anesthesia cost for laser ablation (617 euros) fell between the anesthesia costs of superficial excision (499 euros) and deep excision (832 euros). Ward cost depended on the length of hospital stay (222 euros/day). In laser ablation and superficial excision, the mean length of hospital stay was 2 days, while in deep excision it was longer, 5 days. This resulted in higher ward cost in deep excision.

The mean number of sick days or days of restricted weight-bearing needed by the patients treated with MRI-guided laser ablation (3 days) was smaller than in the case of patients treated with superficial (38 days) and deep (24 days) excisions. In the year 2002, the mean cost of one sick day was 41 euros, which resulted in a cost of 123 euros for laser ablation, 1558 euros for superficial excision, and 984 euros for deep excision. The indirect costs of recovery time were not included.

The mean follow-up times were 1 year (range 3 months to 3 years 8 months) in the laser ablation group and 1 year 4 months (range 1 month to 3 years 6 months) in the surgery group.

Patients treated with MRI-guided laser ablation had neither immediate complications nor post-procedural pain requiring admission during the 3 months' follow-up. All patients treated with laser ablation were initially symptom-free after the treatment. Three of the seven patients treated with laser ablation had recurrent pain after an average of five months. One patient with recurrent pain was referred for repeated MRI-guided laser ablation, and two patients were operated. Five of the six surgically treated patients were initially symptom-free after the operation, two patients had recurrent pain later (on average, 17 months), and one patient had some residual pain. The patient who had an osteoid osteoma resected from collum femoris and DHS fixation had recurrent pain, and the DHS was removed. The other patient who had recurrent symptoms and the patient with some residual symptoms were treated conservatively with pain medication.

In MRI-guided laser ablations, osteoid osteoma was diagnosed in five of the seven biopsies (71%). (Table 4). In the remaining two cases (29%), the biopsy result was non-specific fibrosis, which may be associated with osteoid osteoma, but there was not definitive nidus to be seen in histology. However, their clinical and imaging findings were typical of osteoid osteoma, and they have been symptom-free after the treatment. In surgical biopsies, osteoid osteoma was found in three of the six (50%) (Table 4). One (17%) resulted in non-specific fibrosis, and reactive transformation was found in the remaining two (33%). The two patients had been previously biopsied and treated with MRI-guided laser ablation.

6 Discussion

6.1 Today's transitional period in radiology

Radiology is a rapidly developing speciality. Since the 1990's, digital radiography has gradually been replacing the conventional plain-film technology. Radiology departments are changing into fully digitalized filmless units with hospital-wide PACS (Bick & Lenzen 1999, Strickland 2000). This changes considerably the workflow of the radiology department and the whole hospital and requires careful planning. One possibility is to digitize one modality at a time, which will result in a transitional phase of both hard and soft copy images being simultaneous produced. Another possibility is to make the whole hospital filmless ”overnight” with no transitional period (Strickland 1996).

MRI has emerged as a rapidly developing guidance method along with the other modalities, such as ultrasound and CT. MRI has been shown to have several features that favor its use as a guiding technique (Jager & Reiser 2001, Tung & Davis 1993, Adam *et al.* 1999, Kaplan *et al.* 1998). MRI has a multiplanar imaging capability, and it is superior to the older techniques in discriminating between normal and pathologic tissues. Open-configuration MRI allows freedom to choose any imaging plane, good access to the patient, and the biopsy to be performed within the magnet. The increasing interest in the exposure of both patients and staff to radiation makes the lack of ionizing radiation in MRI-guided interventions a significant issue.

The development of image-guided therapies has made the differentiation between radiological and surgical procedures less distinct (Margulis & Sunshine 2000). Now that minimally invasive techniques are progressively gaining ground in medicine, MRI has simultaneously emerged as a guidance method for open surgery, especially neurosurgery (Cantwell *et al.* 2004, Hall *et al.* 1999, Tronnier *et al.* 1997). The aim at minimal invasiveness leads to shorter hospitalization and recovery times, fewer complications, and better patient compliance. The implementation of new treatment methods may cause confusion as to which speciality is responsible for the treatment of a given patient (Mäkisalo 2006). Especially the treatment of cancer may consist of many alternative treatment methods; surgery, image-guided treatment, oncologic treatment. This gives rise to questions of who decides what treatment should be chosen, and who treats possible complications. A multidisciplinary team of specialists is needed to make these decisions.

The rapid growth and development of medical technology and procedures has increased the costs of radiology (Blackmore & Smith 1998). In a world of limited financial resources, decision makers have to consider the benefits and costs of any new imaging or treatment method in relation to the older alternative methods. In developing radiology, it is also important to analyze the costs of a transitional period, such as the digitalization of a radiology department. MRI-guided interventions, therapies, and surgeries are expected to play a more and more important role in the future, and the associated high costs require careful evaluation (Schulz *et al.* 2004). The range of interventional and surgical applications of MRI is still rather limited, which has led to the development of multipurpose and multidisciplinary IMRI units, where diagnostic imaging, MRI-guided interventions, and surgeries are performed in the same facility. The key question at many institutions is still whether to make an investment in an IMRI unit, and whether the cost structure with the rather limited number of interventions is reasonable to justify the investment. Cost analyses of alternative simulation models of IMRI unit usage are a way of analyzing investments before purchase.

The purpose of this study was to analyze the cost structures and to find differences between a potential new imaging, guidance, and treatment method compared to the conventional methods. The study aimed to identify such cost factors that could be influenced to make the new method more comparable with the conventional. The analyses were done from the hospital's perspective. If the effectiveness of a new method or its importance to patients had been evaluated, the material should have been larger. A cost-utility analysis with measures of QUALY would be an appropriate method to evaluate this perspective.

6.2 ABC analysis

Activity-based cost accounting has been recommended for use in hospitals (Chan 1993). There are studies on the costs of radiological procedures which show that ABC can be utilized in many different areas in radiology, (Laurila *et al.* 2000a, Laurila *et al.* 2000b, Cohen *et al.* 2000, Enzmann *et al.* 2001, Saini *et al.* 2001, Klose & Bottcher 2002, King-Im *et al.* 2004). ABC analysis is based on the assumption that activities create costs, unlike in conventional accounting, where costs are created by products. When ABC accounting is used, especially indirect costs are allocated to products more accurately than in conventional accounting. In this study, ABC accounting was used because it enabled us to trace different activities, both direct and indirect, and gave more precise allocation of the final products than traditional cost accounting (Chan 1993). Accurate information of costs is especially important in the evaluation of new treatments or image guidance methods. Although ABC accounting has many advantages, it is also more laborious than indirect calculations using proxies for costs based on cost-charge ratios or other figures. Due to this, many studies combine ABC methods for the key cost elements, such as radiological imaging, and cost proxies for other costs, such as inpatient and outpatient care (Hollingworth 2005). In this study, in the cost analysis of MRI-guided laser ablation and surgery in the treatment of osteoid osteoma, the costs for the inpatient time were based on ABC accounting, while the costs of the recovery time were based on estimates of the Finnish National Pensions Institute.

Before a cost analysis can be performed, the investigators must define the perspective from which the analysis is done. In this study, all cost analyses were performed from the perspective of the hospital. That perspective was chosen because it is important to analyze accurately the costs and cost structure of a new, alternative imaging or interventional method and compare them with the traditional method. This is especially important if the outcome of these two methods is assumed to be similar. The perspective of society, third-party payers, or patients would have resulted in a different cost structure (Yin & Forman 1995). If the perspective had been that of the patient, the costs would have included his/her out-of-pocket payments, the time related to the procedure, including the time of hospitalization, travel, recovery, and other related costs incurred by the patient and his/her relatives and friends, and also the ill-defined cost of pain and stress related to the procedure and recovery. If the patient does not undergo the procedure, the time and money could be used in other purposes. The total cost of the procedure to the patient is the value of these foregone opportunities. The cost of an imaging or interventional procedure from the hospital's point of view is the value of the resources used (e.g. equipment and service, materials, personnel, space, administrative costs).

The implementation of ABC analysis starts by identifying the relevant activities performed in the department. The cost factors and resources are identified and allocated to activities according to their use as expressed by cost drivers. In this study, the costs were analyzed retrospectively from a 12-month period as recommended in the literature (Cohen *et al.* 2000). It is better to use the financial statements from previous years than from future budgets to achieve as accurate costs as possible.

ABC is an important management tool and gives accurate information about the costs of activities in a radiology department (Laurila *et al.* 2000b). It gives an opportunity to effective cost reduction by focusing on non-value-creating activities. Cost management can be directed to activities with an unfavorable cost-benefit balance. Different simulation models of cost analyses can be created with ABC accounting, as was done in this study. These give valuable information for planning resource use and the purchase and utilization of new equipment in a radiology department. Although cost analysis gives valuable information for decision-making, other things also need to be considered, including accuracy, invasiveness, radiation, and the possible complications of the procedure.

6.3 Costs of plain-film radiography in a partially digitized radiology department

In this study, computed radiography was 9% more expensive than conventional radiography. The difference was due to the higher initial capital cost of digital imaging. This cost was approximately twice as high as the initial capital cost of conventional film processing. The equipment was acquired in 1993, at a time when the purchased machines were a novelty, and thus more expensive than today. If the calculation had been performed with a 30% lower equipment price, the cost of CR would have been reduced very close to that of conventional imaging.

The effect of capital costs on total costs depends on the amortization period for the capital goods and the interest rate. A decrease of the amortization time from ten to five years increased the cost of digital imaging more than that of conventional imaging. Raising of the interest rate had a similar effect. The real lifetime of equipment varies according to its use. Lifetime estimates are important in accounting the cost effects of equipment acquisition. In cost accounting, amortization time has a greater effect on the cost of expensive equipment than less expensive equipment. Within the municipal health service in Finland, equipment is often acquired on accrued tax revenue. If digital equipment is not purchased, the capital saved is not usually consolidated. Therefore, the analysis of plain-film radiography was done by assuming an interest rate of 0%, and this result was compared with the results obtained by using interest rates of 4% and 8% for capital investment.

This study showed that the acquisition of CR equipment cannot be justified by cost benefits, unless the acquisition leads to a complete PACS with image archives and an image distribution network accessible in all parts of the hospital, which drastically reduces the use of film. Step-by-step acquisition of CR with a planned transition to more extensive digitization can be justified by the better examination quality in the transitional period. According to the experiences of Hruby and his team (Hruby 1995), a PACS that covers the entire hospital pays itself in five years. The cost benefit is claimed to come about as a result of diminished film and archive costs as well as the faster distribution of information, which may reduce the length of inpatient stay.

At the present, more and more radiology departments are adopting completely digital radiology and hospital information systems (RIS/HIS and PACS) accessible in all parts of the hospital. Compared to this study (study I), Image processing activity becomes unnecessary because there are no film prints. Film processing and transportation are also unnecessary, as images need not be hanged on alternators and previous images need not to be retrieved from the archive. Besides providing filmless radiology, digital patient records change considerably the activities in a radiology department. ABC accounting can be applied to the cost analysis of these changing activities. In health centers, the transition from conventional plain-film radiography to CR is still under way. Study I still provides useful information for this situation. There is also an aim to centralize small X-ray units, like those in most health centers. By reducing the number of units, the immediate rise in the cost due to digitalization of equipment could be better controlled (Lantto 2002). Centralization minimizes production costs, but increases patients' travel costs 2.5-fold (Vesala 2003).

6.4 Cost analysis of an IMRI unit

Interventional MRI has already gained an important position in interventional radiology and is rapidly developing. The clinical feasibility, safety, and efficacy of MR-guided biopsies as well as MR-assisted open and minimally invasive surgery have been proved. Treatment of brain and liver tumors, selected aspects of thermal ablation procedures, and endovascular applications of MRI are rapidly developing. MR systems, imaging sequences, software solutions, and MRI-compatible instruments are improving. The associated high costs of these new methods require careful evaluation to ensure cost-effective medical care (Schulz *et al.* 2004).

If the number of MRI-guided interventions is too small to fill a whole working day, multipurpose use of the equipment should be considered. Intraoperative MRI has turned out to be a promising method of image guidance in neurosurgery (Black *et al.* 1999, Hall *et al.* 1999, Tronnier *et al.* 1997). In Oulu University Hospital, the IMRI unit was planned for joint use by neurosurgeons and radiologists.

In diagnostic examinations at the IMRI unit, the cost structure of the main procedure was different from that of interventions and operations. In diagnostic MRI examinations, the procedure cost consisted mainly of the fixed costs, i.e. the costs of personnel, equipment, and premises. Due to the high-priced MRI-compatible instrumentation, the share of material costs was largest in MRI-guided interventions and second largest in MRI-guided neurosurgical operations. The large share of personnel costs in MRI-guided neurosurgical operations was directly due to the long duration of the operations.

Cost analyses of alternative simulation models of IMRI utilization give useful information when planning the purchase and utilization of open MRI equipment. In this study, three different simulation models of IMRI usage were created to simulate different local circumstances and to analyze the effects of the volumes of different procedures on cost structure.

In diagnostic MRI examinations, volume plays a key role in determining the cost of procedures because the procedure cost consists mainly of the fixed costs. From the perspective of the Department of Radiology, an increase of MRI-guided neurosurgical operations increased considerably the fixed costs, i.e. personnel, equipment, and premises costs per one diagnostic MRI examination and MRI-guided intervention. Under such circumstances, there may be problems in making the diagnostic use of IMRI profitable. From the perspective of the Department of Radiology, it is less expensive to perform diagnostic MRI examinations during the time when there are no interventions than to increase the number of MRI-guided neurosurgical operations. When planning joint use of the IMRI unit, the effect of the share of MRI-guided neurosurgery on cost structure should be considered in pricing the neurosurgical use of IMRI.

In health care, any increase in capacity is usually completely utilized. From the perspective of society, an increase of MRI examinations may increase total costs. The larger number of examinations also increases the number of false positive diagnoses. This leads to additional examinations. An increase in mini-invasive surgery diminishes the costs per patient and is more comfortable to the patient. The extra capacity that thereby becomes available can be used to treat other diseases. From the perspective of society, the total costs diminish only if the total number of treatments diminishes (Ryynänen *et al.* 2006).

The simulation clearly demonstrates that volume is not the primary deterministic factor in MRI-guided interventions due to the high price of the instruments, which make the cost structure of these procedures very different from any other. It can be concluded that the purchase of a low-field system is justifiable even if the need for MRI-guided interventions is rather small. The main goal of IMRI is to develop new minimally invasive therapies that require these particular image guidance methods (Schulz *et al.* 2004).

6.5 Costs of MRI-guided musculoskeletal interventions

6.5.1 Bone biopsies

MRI has been suggested to provide additional value in interventional and diagnostic procedures (Vanel *et al.* 1998, Gehl & Frahm 1998, Adam *et al.* 1999, Buecker *et al.* 1998, Kaplan *et al.* 1998, Neuerburg *et al.* 1998). The percutaneous approach has become a method of choice in investigating bony lesions (Ghelman 1998, Tikkakoski *et al.* 1992, Jelinek *et al.* 1996, Leffler & Chew 1999). It is more cost-effective than surgical biopsy (Fraser-Hill *et al.* 1992, Ruhs *et al.* 1996). CT and fluoroscopy have been used as guiding methods. Blanco Sequeiros *et al.* reported an initial technical accuracy of almost 100% without complications in MRI-guided bone biopsies (Blanco *et al.* 2002). It can be assumed that the better visualization of the target leads to a lesser need for re-biopsies, which reduces costs. CT has superior spatial resolution in the axial skeleton, and CT is still recommended for biopsies of spinal lesions (Adam *et al.* 1999). However, in the study of Blanco Sequeiros *et al.* (2002), all thoracic bone lesions detected preoperatively with CT, high-field MRI, or scintigraphy were also seen in operative images obtained with a 0.23 T scanner. Image quality was sufficient to guarantee a safe biopsy in the thoracic region.

Open-configuration MRI provides at least equally good access to the patient as CT. It allows the operator to choose the imaging and puncture route in any plane as opposed to CT, where the gantry only allows procedures in the axial or near axial planes and limits the usage of long instruments. In study III, the procedure time of MRI-guided bone biopsy (128 min) was longer than that of CT-guided bone biopsy (66 min). This resulted in higher personnel costs in MRI. The main reason was the guiding and imaging technology, which is more time-consuming in MRI than in CT. Faster MR imaging and guiding technologies are likely to decrease this difference. This will also leave more time for diagnostic examinations, resulting in a smaller share of fixed costs for MRI interventions. The effect of better training and routines was quite small. During one year, the procedure time in MRI decreased from 128 minutes to 115 minutes (10%).

Neuerburg *et al.* (1998) took bone biopsies from 23 patients using a 1.5 T magnet combined with C-arm fluoroscopy. They obtained samples sufficient for a histopathological diagnosis in 17 out of 23 cases. Conventional high-field strength MR equipment combined with fluoroscopy differs from the open low-field MR system. In a low-field open MR system the biopsy can be performed inside the magnet, whereas in a closed high-field system the patient has to be moved in and out of the magnet. In the case of very obese patients, MRI-guided biopsy may be impossible because of the restricted space within the conventional high-field MR. The high-field MR system has superior image speed and quality because of the higher signal-to-noise ratio. Neuerburg *et al.* (1998) reported a biopsy time of 45 to 65 minutes. The high-field MR system has higher initial investing costs than the low-field system. It would be interesting to investigate if the faster imaging speed of the high-field MR system results in any cost savings.

Both patients and personnel may be exposed to high levels of radiation during CT-guided interventions (Nawfel *et al.* 2000). MRI involves no radiation burden. This is especially important in performing interventions on young patients with suspected benign bone disease and females potentially pregnant. It is also an important advantage in view of interventional radiologists' radiation burden. These factors may include some that would favor MRI in a large-scale cost comparison with CT. A high number of patients and biopsies are needed to define the amount of cost savings due to a lesser need for re-biopsies. A long follow-up period will be needed for the effects of MRI- and CT-guided bone biopsies on patients' life to be analyzed and compared.

6.5.2 Treatment of osteoid osteoma

Treatment of osteoid osteoma primarily aims to relieve pain, and successful treatment requires complete excision or destruction of the osteoid nidus. In surgery, a larger amount of bone tissue may have to be removed in order to avoid incomplete excision. Surgery hence has a success rate proportional to the extent of resection. Without image guidance, the nidus may be difficult to localize because it is usually less than 1 cm in size. The capacity for precise localization of the nidus makes CT or MRI suitable guidance methods for ablative treatment. CT guidance has been successfully used in both RF and laser photocoagulation of osteoid osteomas (Vanderschueren *et al.* 2002, Cioni *et al.* 2004, Rosenthal *et al.* 1998, Cove *et al.* 2000, DeFriend *et al.* 2003, Witt *et al.* 2000, Rosenthal *et al.* 2003, Cantwell *et al.* 2004). CT has good contrast resolution and adequate spatial resolution to guide the ablation of osteoid osteoma. The multidetector CT enables real-time fluoroscopy, which makes percutaneous procedures more straightforward. MRI has potential advantages compared to CT regarding the guidance of interventional procedures. The superior soft tissue differentiation helps to avoid critical structures, including nerves and vessels, on the puncture route. The multiplanar imaging capacity allows two- or three-dimensional image guidance. The nidus of osteoid osteoma can be reliably recognized in MRI (Spouge & Thain 2000). MRI also permits monitoring of thermal changes in tissue and provides quantitative information about thermal changes (Germain *et al.* 2001).

In study IV, no problems were encountered in locating small lesions with MRI. All niduses were also identified in the interventional MRI sequences used. There were some problems in detecting the thermal change in bone tissue, though. This does not compromise the fact that the treatment could be safely guided and performed under MRI guidance.

In laser ablation, the nidus is destroyed by heating. A good correlation between the energy delivered and the size of necrosis can be achieved (Gangi *et al.* 1997b). Due to these advantages, percutaneous interstitial laser treatment has also been reported to be a safe and effective way to treat spinal osteoid osteoma (Gangi *et al.* 1998). Gangi *et al.* (2007) treated twelve spinal osteoid osteomas successfully. Laser ablation can be applied through even a small 18 G coaxial needle, with the disadvantage that the histology may not be obtained. In study IV, a 14 G coaxial needle and a drill were used to obtain histological samples.

6.5.3 Cost structure of MRI-guided musculoskeletal interventions

So far, no cost analyses of MRI-guided bone biopsies or laser ablation of osteoid osteomas are available. The presence of two alternative guiding or treatments methods imposes a need for cost comparison analyses (Singer & Applegate 2001). The selection between the two optional methods must be based on cost-effectiveness analysis. Before that, a complete cost analysis must be performed.

This study showed (study III) that the cost of MRI-guided bone biopsy was 2.55-fold compared to CT-guided biopsy. Study IV showed that, from the hospital's perspective, the cost of MRI-guided laser ablation was higher than the cost of surgical excision of a superficial osteoma, but considerably lower than the cost of excision of a deeply located osteoma, where metallic fixation was needed. In both studies, the highly priced MR-compatible instrumentation accounted for a major part of the procedure-related cost in MRI-guided interventions. The cost difference between MRI- and CT-guided bone biopsies was mainly due to the higher material costs in MRI-guided biopsies.

In MRI-guided interventions, all equipment in the imaging room must be MR-compatible. At the moment, MR-compatible instrumentation is relatively highly priced. The instrumentation consists of disposable and multi-usable materials. In the beginning, material costs per procedure are high because all the new instrumentation must be acquired. Material costs per examination diminish as more interventions are performed. Instruments with a usable lifespan of less than three years were included in material costs. About 50% of the biopsy instruments had a real lifespan of about two years. If this is taken into account, material costs diminish by 25% per procedure. Re-use of the same fiber in an average of ten MRI-guided laser ablations decreased the cost of laser fiber. The used part of the fiber was cut off after the ablation, and the remainder was used again in the next procedure.

The main disadvantage of all MR-compatible instruments is that their tips are relatively blunt compared with stainless steel needles and their alloys are generally softer; therefore, overall needle performance is not as good as that of the normal stainless steel needles also used in CT. In this study, the MR bone biopsy set was made of a titanium alloy with special teeth that allow rotational drilling without axial pressure.

The acquisition of laser equipment is initially expensive. Its cost-effectiveness can be increased by using the equipment for other interventions, such as ablation of liver tumors and percutaneous disc decompression. In our institution, the laser device used for laser ablation of osteoid osteomas is also used for 10-20 liver ablations and 5-10 gynecological applications (treatment of feto-fetal transfusion) per year. The multipurpose use of the MRI scanner explained the relatively low cost of MRI equipment in one laser ablation of osteoid osteoma. The cost of the fluoroscopy machine used in surgical excision of osteoid osteoma was lower than the cost of MRI in laser ablation. This was due to the lower acquisition cost of the fluoroscopy machine and to the fact that the same machine was also used in other orthopedic operations.

In study III, the amortization period of the equipment had only slight effects on the costs of MRI-guided bone biopsies. A change of the period from six to ten years resulted in a maximal difference of 2% because of the high share of material and personnel costs. The amortization period is more critical in procedures where the share of equipment costs is larger and that of material and personnel costs smaller, such as chest X-ray examination.

In our institution, the Department of Anesthesiology charged according to a price list based on their previous cost analysis, in which the main determinant of cost was the duration of anesthesia. The longer procedure time caused higher costs of anesthesia in MRI-guided interventions compared to CT-guided bone biopsies or traditional superficial excision of osteoid osteoma. For the same reason, the anesthesia costs were highest in the deep excision of osteoid osteoma.

When the number and mean cost of sick days or days of restricted weight-bearing were also included, the cost of MRI-guided laser ablation was lower than the costs of either superficial or deep excision.

The surgical reference group for MRI-guided laser ablation was heterogeneous, including one case of spinal osteoid osteoma. In surgical excisions, the location of the lesion and thus the need for metallic fixation had a great impact on the material cost. In deep excisions, metallic fixation was needed to strengthen the resected bone. This increased the material cost in deep excision considerably compared to superficial excision and laser ablation. In my opinion, it is a benefit of laser ablation that deep lesions can also be treated in a less invasive manner and with the materials used to treat superficial lesions.

The percutaneous ablation of osteoid osteoma certainly enables earlier discharge than scheduled in our hospital's protocol. Rosenthal *et al.* (1998) compared percutaneous thermocoagulation and operative excision of osteoid osteoma in the lower extremity and reported similar efficacy of these two treatments. Percutaneous treatment, however, was associated with minimal hospital stay (average length 0.2 days), no complications, and short convalescence. Generally, outpatient-based (discharge on a same day as the procedure) or one-day hospital stay is all that is needed to monitor the initial effect of the treatment. In our hospital, there was no difference in the mean length of hospital stay (2 days) between the patients treated with MRI-guided laser ablation and superficial excision. However, this was due to the protocol used in our hospital, which requires all patients to arrive one day before the procedure.

This was only a precaution, which was not founded on any research and not necessary. Deep excision required a longer hospital stay (5 days) due to its more invasive nature.

Patients treated with MRI-guided laser ablation had no postoperative restrictions on exposing their affected extremity to stress. Surgically treated patients had longer postoperative restrictions and recovery times. Surprisingly, in study IV, recovery time was longer after superficial excision than after deep excision. This may be due to the protective role of the metallic fixation material used in deep excisions. The longer recovery time of surgically treated patients requires more health care resources and causes more discomfort to the patient. The shorter recovery helps to keep the cost of percutaneous laser ablation lower than the cost of surgery in the treatment of osteoid osteoma.

In this material, the treatment results of laser ablations were less than optimal, with three recurrences, but this success rate was quite comparable to the results of surgical treatment. It is known from an earlier study by Rosenthal *et al.* (1998) on a larger number of patients that the outcome of percutaneous RF ablation of osteoid osteoma is essentially equivalent to operative treatment. Apart from the lower cost, there are other aspects, such as the shorter recovery time and better quality of life, which further favor the use of laser ablation in the treatment of osteoid osteoma.

Cost analyses are generally susceptible to a variety of errors and confounding factors. When two analyses are compared, the main source of error may be due to differences in cost allocation. In this study, the application of the same principle to the cost analyses eliminated this. One limitation of this study was the small number of patients. For the time being, image-guided bone biopsies have been rare in our institution. However, the cost difference between MRI- and CT-guided bone biopsies was notable and likely to persist even when larger series are analyzed. In our institution, percutaneous treatment of osteoid osteoma is preferred due to its minimal invasiveness, and surgical treatment is therefore seldom chosen. Hence, there were some difficulties in recruiting a surgical reference group for laser ablations.

7 Conclusions

1. Partially digitized plain-film radiography was 9% more expensive than conventional radiography, due to the higher initial capital cost of digital imaging.
2. The volumes of the different procedures done on an IMRI unit had effects mainly on the unit cost of diagnostic MRI examinations. Due to the expensive instrumentation, the effect was smaller in MRI-guided interventions and neurosurgical operations. The simulation demonstrated that the volume of the operative use of IMRI has a major effect on the costs of radiological procedures: an increase of MRI-guided neurosurgical operations increases the unit costs of diagnostic MRI examinations and MRI-guided interventions.
3. The cost of MRI-guided biopsy was 2.55-fold compared to CT-guided bone biopsy, which was due to the longer procedure time and the higher material costs, especially the expensive MRI-compatible instrumentation.
4. The cost of MRI-guided laser ablation of osteoid osteoma was higher than the cost of surgical excision of superficial osteoma but considerably lower than the cost of excision of deeply located osteoma, where metallic fixation was needed. When the number of sick days and days of restricted weight bearing were also included, the cost of MRI-guided laser ablation was lower than the costs of either superficial or deep excision.

During a transitional period, one should be prepared for a higher cost of the new method. The use of the new method should be justified by other factors, such as better efficiency, accuracy, lack of radiation, or mini-invasiveness.

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