risk of death associated with it was high. It was also the commonest single recorded reason for emergency readmissions. Recently it has been emphasised that early mobilisation after hip replacement reduces the incidence of postoperative thromboembolic disease.[21] Investigation of the possibility of further reduction in postoperative deaths from circulatory disease in general, and perhaps thromboembolic disease in particular, is warranted.

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Cost effectiveness of magnetic resonance imaging in the neurosciences

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Abstract

Objectives—To measure, in a service setting, the effect of magnetic resonance imaging on diagnosis, diagnostic certainty, and patient management in the neurosciences; to measure the cost per patient scanned; to estimate the marginal cost of imaging and compare this with its diagnostic impact; to measure changes in patients' quality of life; and to record the diagnostic pathway leading to magnetic resonance imaging.

Design—Controlled observational study using questionnaires on diagnosis and patient management before and after imaging. Detailed costing study. Quality of life questionnaires at the time of imaging and six months later. Diagnostic pathways extracted from medical records for a representative sample.

Setting—Regional superconducting 1·5 T magnetic resonance service.

Subjects—782 consecutive neuroscience patients referred by consultants for magnetic resonance imaging during June 1988-9; diagnostic pathways recorded for 158 cases.

Main outcome measures—Costs of magnetic resonance imaging and preliminary investigations; changes in planned management and resulting savings; changes in principal diagnosis and diagnostic certainty; changes in patients' quality of life.

Results—Average cost of magnetic resonance imaging was estimated at £206.20/patient (throughput 2250 patients/year, 1989-90 prices including contrast and upgrading). Before magnetic resonance imaging diagnostic procedures cost £164.40/patient (including inpatient stays). Management changed after imaging in 208 (27%) cases; saving an estimated £80.90/patient. Confidence in planned management increased in a further 226 (29%) referrals. Consultants' principal diagnosis changed in 159 of 782 (20%) referrals; marginal cost per diagnostic change was £626. Confidence in diagnosis increased in 236 (30%) referrals. No improvement in patients' quality of life at six month assessment.

Conclusions—Any improvement in diagnosis with magnetic resonance imaging is achieved at a higher cost. Techniques for monitoring the cost effectiveness of this technology need to be developed.

Introduction

Magnetic resonance imaging is recognised as a potentially useful,[1-6] although expensive,[7-9] imaging technique. Early evaluations of its clinical benefits have been criticised recently,[10-12] and its clinical efficacy still has to be rigorously shown.[13-16] Meanwhile, clinicians and managers are faced with decisions on when and how to introduce this new medical technology.[17]

In 1988 the West Midlands region opened its first magnetic resonance imaging service, based in Coventry. It was expected that the main user would be the neurosciences,[4 18-20] and that demand would outstrip supply. Therefore, population based quotas were allocated to each of the region's four neuroscience centres. In addition, a service evaluation was commissioned to measure the extent to which magnetic resonance imaging in routine neuroscience clinical practice is worth its costs. As a result a large database has been built up and a full analysis is available elsewhere.[21] This paper presents some of the findings of the study.

Methods

After a three month learning period we entered into the study all 782 patients scanned by the service as part

of the NHS quota during the service's first year of operation. The imager is superconducting and runs at 1·5 T.

COSTS OF SCANNING

At the end of the first year we undertook a detailed study of costs, examining staff, consumables, capital, maintenance, and indirect costs. Staffing costs included employer's costs (national insurance, superannuation, etc) as well as basic salary or wage costs. In the case of radiologists an additional sum representing a regional average for merit awards, travelling expenses, domiciliary visits, etc was added. Consumable costs included cryogens, electricity, films, film processing chemicals, stationery, computer tapes, and replacement parts. Capital costs were calculated using the annuity method.[17] The economic life of the imaging system was assumed to be seven years (other studies have used lifetimes ranging from five to seven years).[9 15 22] A 25 year life was used for accommodation, rather than the more usual NHS value of 40 years, because of its specialised nature; other studies have used lifetimes of 10-25 years.[9 15 20] Once global annual expenditure had been calculated, costs were divided equally between all referrals to produce an average cost per patient scanned.

EFFECTS OF MAGNETIC RESONANCE IMAGING

We used a controlled observational study to measure the impact of magnetic resonance imaging. This technique requires clinicians to specify their differential diagnosis and treatment plan before and after an investigation, thereby reducing the bias produced by retrospective evaluation.[23] All patients were referred by a consultant. For each referral consultants completed a structured request form detailing the probable site of lesion, category of diagnosis (up to three differential diagnoses with level of certainty (0-100% on a linear scale)), further investigations or treatment

TABLE I—*Number (percentage) of neuroscience patients scanned by magnetic resonance imaging for two main specialties†*

Anatomical region	Specialty	
	Neurology (n=437)	Neurosurgery (n=320)
Brain	327 (75)	113 (35)
Pituitary fossa	4 (1)	1 (<1)
Brain and spine*	48 (11)	36 (11)
Cervical spine	26 (6)	78 (24)
Dorsal spine	1 (<1)	
Lumbar spine	13 (3)	52 (16)
Spine*	17 (4)	39 (12)
Not specified	1 (<1)	1 (<1)

*Multi-site investigation.
†25 patients referred by paediatricians and others.

TABLE II—*Reported annual cost (£) of magnetic resonance imaging service*

	Coventry (1989 prices)	United Kingdom*[15] (1988 prices)	Perth[22] (1989 prices)	United States†[9] (1990 prices)
Field strength (T)	0·5-1·5	0·5	1·5	0·97
Magnet type	Cryogenic	Cryogenic	Cryogenic	Cryogenic
Annual No of examinations	2250	2000	2189	3146
Capital costs:				
Equipment (annual equivalent)	881 050 (157 830)‡	1 041 000 (180 000)‡	Not available	Not available
Accommodation (annual equivalent)	228 795 (17 898)‡	173 500 (12 300)‡	Not available	Not available
Total annual equivalent	175 728‡	192 300‡	333 600§	389 520‖
Revenue costs:				
Staffing	105 272	65 400	146 380	68 110¶
Operating	52 452	35 300	54 140	90 770
Service and maintenance	63 419	66 500	56 910	85 710
Total costs	221 143	167 200	257 430	244 590
Total cost	396 871	359 500	591 030	634 110
Direct cost/patient	176.40	179.80	270.00	201.60¶
Indirect costs	6 350	–	51 070	130 630

*Cost modelled using figures from the National Hospital, Queen Square.
†Average values for 45 imaging facilities.
‡Assumes seven year equipment life, 25 year accommodation life at 6% discount rate.
§Assumes five year equipment life, 10 year accommodation life, and straight line depreciation.
‖Assumes five year equipment life, 18 year accommodation life at 10% discount rate.
¶Professional billing (radiologists) not included, average £123.30/patient.

planned if magnetic resonance imaging was not available, plus basic data on the patient including sex, age, and prognosis. Each report on the results of magnetic resonance imaging had a follow up questionnaire attached to measure the impact on diagnosis, diagnostic certainty, patient management, and confidence in management. The same consultant provided both sets of information to ensure consistency for variables such as diagnostic certainty. Non-responders were followed up and notified that no benefit would be assumed if the questionnaire was not returned. Finally, the radiologist performing each scan completed two questionnaires (prospective and retrospective) to identify the benefit of magnetic resonance imaging in locating, identifying, and determining the extent of the disease.

PATIENT OUTCOMES

Before their scan patients completed a health status questionnaire using the Rosser 29 state classification based on disability and distress; scores range from +1·00 for no disability or distress to a minimum of −1·49.[24] A follow up questionnaire was sent to all patients six months after the scan. Questionnaires were completed by a close relative for children or severely incapacitated patients.

DIAGNOSTIC PATHWAY

We studied the medical records of 158 of the 782 patients in detail. A sampling frame was used so that records were representative in terms of total requests per centre and level of use per consultant. Cases were limited to referrals in weeks 1-21 and weeks 35-52, to monitor changes over time. All investigations and procedures performed during the illness (or in the previous 12 months if the condition was chronic) and during the six weeks after the scan were determined. We calculated costs for each radiographic procedure using a cost modelling approach; several British sources (all including capital costs) were converted to 1989-90 prices and averaged to produce a representative cost (Trent region, personal communication).[15 25]

Results

One in three scans were judged to show no abnormality. The majority of patients (437 (56%)) were referred by neurologists. Table I shows the importance of spinal imaging for neurosurgery. Almost a fifth of patients were referred for multisite investigations (75 (23%) in neurosurgery, 65 (15%) in neurology), an important factor in a time related examination such as magnetic resonance imaging. Most scans were requested to confirm an existing diagnosis (345, 44%), or to exclude a suspected disease (270, 35%); 114 (15%) were ordered to monitor a diagnosed condition. Most neurologists referred for the first two reasons (90% of referrals), whereas neurosurgeons monitored recognised conditions more frequently (35%). Consultants completed a request form for all the patients, the questionnaire on magnetic resonance imaging results was completed for 654 (84%).

COSTS OF MAGNETIC RESONANCE IMAGING

Table II shows the annual cost of the Coventry service (1989-90 prices at a throughput of 2250 patients/year) with international comparisons; the average cost of scanning a patient in Coventry was £176.40 (£179.20 including indirect costs). The high level of fixed costs (capital and maintenance) makes cost per patient sensitive to throughput. The Coventry capital cost figure includes upgrading of software but magnetic resonance imaging systems need to have hardware and software constantly upgraded to keep up with technological developments. Estimates of the cost

of upgrading are as high as £120 000-£200 000 every three to five years.[22] Table II does not include the cost of gadolinium-diethylenetriamine penta-acetic acid (DTPA) (intravenous contrast medium) as this was not available at the time of the study. If contrast media and upgrading hardware are included in the Coventry figure a further £15.50-£38.50 is added, bringing the final figure to £206.20 (average) per patient.

PATIENT CHARACTERISTICS

In all, 410 patients completed health status questionnaires. The average quality of life score at the time of the scan was 0·904, which is lower than the 0·982 recorded in a 1988 survey of 390 West Midlands residents[26] and that reported for 100 patients having cranial and spinal magnetic resonance imaging (0·986 and 0·942 respectively).[16] This cannot be attributed to age weighting. The age and sex breakdown mirrors that in the United Kingdom as a whole,[27] and the breakdown for all 936 patients imaged was similar to that reported for other patients having magnetic resonance imaging (table III). Over the six months after the

TABLE III—Age and sex of patients referred for magnetic resonance imaging

| Age (years) | West Midlands | | | Australia[41] Both sexes* (n=16 178) |
	Females (n=511)	Males (n=420)	Both sexes (n=936)	
0			1 (<1)	1 (<1)
1-9	11 (2)	14 (3)	25 (3)	647 (4)
10-19	40 (8)	34 (8)	74 (8)	1617 (10)
20-29	67 (13)	49 (12)	117 (13)	2427 (15)
30-39	103 (20)	80 (19)	183 (20)	3074 (19)
40-49	132 (26)	92 (22)	225 (24)	3074 (19)
50-59	94 (18)	90 (21)	186 (20)	2264 (14)
60-69	44 (9)	50 (12)	94 (10)	1941 (12)
70-79	20 (4)	8 (2)	28 (3)	971 (6)
80-89		3 (<1)	3 (<1)	162 (1)

*Australia 49% female; Coventry 54% female.

scan the quality of life score fell, with the average score decreasing by 0·059 to 0·845. This was predicted by consultants at the time of referral (no change or don't know for 547 (70%) patients, slight deterioration for 164 (21%), and some improvement for 40 (5%)).

REPORTED INCREASES IN ACCURACY

The principal benefits predicted by radiologists were increased accuracy in identification (368 (47%) scans), determining the extent (110 (14%)), and location (39 (5%)) of disease and other benefits (23 (3%)); for 242 (31%) scans no benefit was identified. Examination shows that when increased accuracy in assessing the extent of the disease was expected, radiologists reported 88% (97) of scans delivered this; when increased accuracy in location was predicted, 82% (32) of scans delivered this; but when improved identification was expected only 45% (166) of scan delivered this.

IMPACT ON DIAGNOSIS

A change in diagnosis was reported in 159 cases (20% of referrals). In 107 the change was major, with a shift in categories; table IV gives the diagnoses before magnetic resonance imaging. Of those patients with unknown and "other, physical" diagnoses, 27 had the diagnosis changed after imaging. Nevertheless, the number of patients with an unknown diagnosis increased from 44 to 59 overall. Twelve patients with unknown diagnoses had their condition classified, but 27 with a provisional diagnosis were reclassified as having an unknown diagnosis after the scan. The overall number of patients with a diagnosis of "other, physical" did not change. Change in diagnosis was associated with an increase in diagnostic certainty; the mean value of the distribution rising from 66% to

TABLE IV—Diagnosis before magnetic resonance imaging

Diagnosis	No (%) of patients
Congenital	76 (10)
Infection	19 (2)
Traumatic	43 (5)
Demyelinative	150 (19)
Vascular	45 (6)
Tumour	108 (14)
Alcohol or drug	3 (<1)
Degenerative	100 (13)
Unknown	44 (6)
Other, physical	51 (7)
Other, psychological	1 (<1)
Missing	142 (18)
Total	782 (100)

87·5% (excluding diagnosis unknown). In a further 236 (30%) cases diagnostic confidence was increased.

IMPACT ON PATIENT MANAGEMENT

Changes in management were reported in 208 (27%) cases. Eleven of 138 proposed operations were abandoned. Three procedures were deferred, three replaced by radiotherapy, and two patients were transferred to other surgeons or hospitals for surgery. In six cases the surgical approach was changed and in a further 11 it was made more precise. Twenty five myelograms, 21 computed tomograms, and three angiograms were abandoned. In a further 226 (29%) cases confidence in planned management was increased.[28] Table V shows the relation between the impact of magnetic resonance imaging on diagnosis and that on patient management; changes in the two were closely, but not exclusively, linked.

TABLE V—Impact of magnetic resonance imaging on patient management and diagnosis

| | Management altered | | |
	No	Yes	Total (No (%))
Diagnosis altered:			
No	539	84	623 (80)
Yes	35	124	159 (20)
Total (No (%))	574 (73)	208 (27)	782 (100)

DIAGNOSTIC PATHWAYS AND INVESTIGATION COSTS

Analysis of the 158 diagnostic pathways identified 93 computed tomograms, nine angiograms, 28 myelograms, and 12 combination computed tomograms and myelograms taken before magnetic resonance imaging. There was no significant difference between patients referred early and late in the study, indicating that consultants did not change their diagnostic working as they became more familiar with magnetic resonance imaging. The cumulative cost of the radiographic procedures was £25 979 (£164.40/patient) compared with an average £206.20 for magnetic resonance imaging. In addition, there were 61 planned admissions, primarily or exclusively for investigations, with an average length of stay of 6·5 days. Assuming average neuroscience inpatient costs of £119 a day at 1989 prices for non-surgical cases,[15] inpatient stays added £298.60 to the average investigation cost per referral. Twelve computed tomograms, four angiograms, and three myelograms were carried out in the six weeks after imaging. The low level of myelography is indicative of effective displacement by magnetic resonance imaging.

MARGINAL COSTS OF MAGNETIC RESONANCE IMAGING

Some of the cost of magnetic resonance imaging should be offset by displacement of other investigations. In Coventry the average cost saving associated with displaced radiographic procedures was relatively small, calculated to be an average £12.50 per neuroscience referral. Inclusion of associated inpatient stay

costs (based pro rata on investigation patterns before magnetic resonance imaging) increased this to £30.70 per case. Surgical savings were slightly higher. The average length of stay for a single surgical procedure in the sample was 19·5 days; assuming neuroscience inpatient costs of £183 per day at 1989 prices (including surgery costs),[15] the 11 abandoned surgical procedures produced a further estimated saving of £50.20 per patient scanned. Overall the cost savings were an average £80.90 per patient.

Discussion

Our evaluation highlights the tensions between ensuring maximum clinical impact and minimising overall costs. To use magnetic resonance imaging most effectively in "a situation where restriction seems necessary"[29] it might be argued that patients need to be thoroughly investigated by conventional techniques before they are referred for magnetic resonance imaging. But by doing this some of the savings that could be realised through displacing these earlier procedures will be lost and the total costs of investigation may prove unnecessarily high. However, using magnetic resonance imaging too early in the diagnostic pathway may also not be cost effective if the most suitable patients are not correctly identified. In this instance effects on patient management will be less common and any consequent cost savings lower. It cannot be cost effective for expensive magnetic resonance imaging to be substituted for less expensive techniques if there is little or no difference in diagnostic efficacy unless there are sufficiently large benefits in patient safety or comfort.

We found that the diagnosis was altered in 20% of cases after magnetic resonance imaging. This is a similar level to that recently reported elsewhere in Britain.[16] Management was changed in 27% of cases, lower than in the recent British study,[16] but in a further 29% of cases confidence in management increased. We estimated that management changes reduced the cost of imaging from £206.20 (including contrast media and upgrading costs) to a marginal cost of £125.30 per patient. There was no indication that patients' quality of life improved after magnetic resonance imaging; this agrees with the other British study.[16]

The West Midlands population could support five magnetic resonance imaging units.[29-31] If provided, the resulting marginal cost to the region would be about £1·4 million a year at 1989-90 prices, assuming that similarly high effects on patient management are maintained in all centres and all specialties (for example, orthopaedics). In the service setting, therefore, it seems that although magnetic resonance imaging can improve diagnosis this is achieved only at a higher overall cost.

One possible strategy to improve cost effectiveness would be to reduce the use of other radiographic procedures in the run up to magnetic resonance imaging. The diagnostic pathway information shows that in the neurosciences magnetic resonance imaging was used as an add on test and that invasive procedures such as myelography and combined computed tomography and myelography were often used before magnetic resonance imaging. If half of these procedures had been displaced this would have reduced the marginal cost (£125.30) by £62.20 per patient (including the cost of admission to hospital). However, this might result in a larger number of inappropriate patients having magnetic resonance imaging.

If the costs of investigating patients cannot be reduced sufficiently to make the marginal cost of magnetic resonance imaging zero and patients' quality of life is not improved, the question which next needs to be asked is: What additional benefits does magnetic resonance imaging provide in terms of diagnostic impact which might be set against these costs? One way of describing this is in terms of the marginal cost per diagnostic change[28]; this was calculated to be £626 (for a marginal magnetic resonance imaging cost of £125). Although 29 of these diagnostic changes were moves from a provisional diagnosis to diagnosis unknown, the overall increase in patients with unknown diagnosis (5·5% to 7·5%) was substantially less than that reported in a recent study where magnetic resonance imaging was used as a first line diagnostic procedure (3% to 27%).[15] This effect might therefore be limited by more extensive radiographic investigation before magnetic resonance imaging.

Even after implementing a series of controls (setting quotas, introducing a structured request form, and restricting referral to consultants) it has not proved possible to introduce a magnetic resonance imaging service for the neurosciences at zero cost. It is imperative for clinicians and managers to audit further use of this expensive imaging procedure, perhaps using a management systems approach.[32] Even if minimisation of costs is the prime objective systematic monitoring is required of the degree to which cost savings from changes in patient management are maximised and costs of other investigations used in the diagnostic pathway are minimised.

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Intensified conventional insulin treatment and neuropsychological impairment

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Abstract

Objective—To assess whether intensified insulin treatment, with an increased frequency of hypoglycaemic episodes, leads to cognitive deterioration.

Design—Prospective randomised trial of intensified conventional treatment and standard treatment.

Setting—Outpatient clinic for patients with insulin dependent diabetes.

Subjects—96 patients with insulin dependent diabetes, high blood glucose concentrations, and non-proliferative retinopathy were randomised to intensified conventional treatment (n=44) or standard treatment (n=52).

Main outcome measures—Glycated haemoglobin concentration (metabolic control); the number of hypoglycaemic episodes reported by patients at each visit; results of computerised neuropsychological tests performed at entry and after five years.

Results—Mean glycated haemoglobin concentration during the study was 7·2% (SE 0·1%) with intensified conventional treatment and 8·7 (0·1%) with standard treatment (p<0·001). During five years 34 (77%, 95% confidence interval 53% to 100%) of the patients given intensified treatment and 29 (56%, 36% to 75%) of the others had at least one episode of serious hypoglycaemia (p<0·05). The intensified conventional treatment group had a mean of 1·1 episodes of serious hypoglycaemia per patient per year compared with 0·4 episodes in the standard treatment group. Results of the neuropsychological tests were similar in the two groups after five years.

Conclusions—Intensified conventional insulin treatment led to lower blood glucose concentrations and a higher frequency of hypoglycaemic episodes, but patients showed no signs of cognitive deterioration.

Introduction

Intensified insulin treatment retards the development of microvascular diabetic complications at the expense of increasing the frequency of serious hypoglycaemic episodes.[1] After three years of intensified conventional treatment the hypoglycaemic episodes had not caused any permanent cortical dysfunction,[2] although earlier studies found that patients with serious hypoglycaemia showed neuropsychological deficits.[3-5] These studies, however, were either non-randomised or cross sectional and retrospective.

To clarify the long term effects of episodic hypoglycaemia on the brain has been suggested as a major scientific task.[6] We report the results of computerised neuropsychological tests after five years in patients randomised to intensified conventional insulin treatment or standard treatment.

Patients and methods

One hundred and two patients were selected for entry to the study, and after five years 96 patients remained in the study.[1] Five patients had died and one had moved away from Stockholm. The patients initially had insulin dependent diabetes, non-proliferative retinopathy, and unsatisfactory blood glucose control, as already described.[1] They were randomised to intensified conventional treatment (n=48 at entry and 44 after five years) or standard treatment (n=54 at entry and 52 after five years). The treatment regimens have been described.[7] The groups were similar with regard to sex distribution, age, duration of diabetes, insulin dose, body mass index (table I), smoking habits, alcohol consumption, and initial microvascular complications.[1 7]

After three years an effort was made to reduce glycated haemoglobin concentration below 9% in all the patients given regular treatment as nephropathy had been shown to increase steeply with higher concentrations.[8] Two patients receiving standard treatment could not participate in the neuropsychological tests after five years because of reduced visual acuity.

Glycated haemoglobin concentration (normal range 3·9-5·7%) was measured as described previously[1 7] and the numbers of serious hypoglycaemic episodes (during which the patient required help from someone else) and episodes of unconsciousness were carefully recorded and reported by the patients at each office visit.[1 2] The symptoms during hypoglycaemia were recorded at baseline and after five years and were categorised as either predominantly adrenergic or neuroglycopenic.[2 9]

NEUROLOGICAL EXAMINATIONS

Motor and sensory nerve conduction velocities were analysed in the ulnar nerve.[10] Vibration and thermal thresholds were measured on the hand.[11 12] Examinations were performed at entry to the study and after five years on the patient's dominant side and with his or her skin temperature well controlled.

NEUROPSYCHOLOGICAL TESTS

The automated psychological test system measures cerebral dysfunction by a battery of computerised neuropsychological tests.[13-16] It works on an Apple II microcomputer with a custom made keyboard. Each test was performed twice, two days apart to exclude training effects, the first time as an exercise. Only data from the second session were used for analysis. Each

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TABLE I—*Characteristics of diabetic patients given intensified conventional treatment and standard treatment at entry. Values are means (SE) unless stated otherwise*

Treatment group	No (male/female)	Duration of diabetes (years)	Age (years)	Insulin dose (IU/kg)	Body mass index (kg/m²)
Intensified conventional	44 (22/22)	18·0 (1·0)	29·5 (1·1)	0·73 (0·03)	22·5 (0·3)
Standard	52 (27/25)	16·1 (0·7)	31·6 (1·0)	0·75 (0·03)	22·8 (0·4)