

# Cost Analysis of Diffusion Tensor Imaging and MR Tractography of the Brain

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## Abstract

**Purpose:** To determine the total direct costs (fixed and variable costs) of diffusion tensor imaging (DTI) and MR tractography reconstruction of the brain. **Materials and Methods:** The direct fixed and variable costs of DTI with MR tractography were determined prospectively with time and motion analysis in a 1.5-Tesla MR scanner using 15 encoding directions. Seventeen patients with seizure disorders, 9 males & 8 females, with mean age of 13 years (age range 2 - 33 years) were studied. Total direct costs were calculated from all direct fixed and variable costs. Sensitivity analyses between 1.5 versus a 3-Tesla MR system, and 15 versus 32 encoding directions were done. **Results:** The total direct costs of DTI and MR tractography for a 1.5-T system with 15 encoding directions were US \$97. Variable cost was \$76.80 and fixed cost was \$20.20. Total direct costs for a 3-T system with 15 directions decreased to US \$94.5 because of the shorter scan time despite the higher cost of the 3-T system. The most costly component of the direct cost was post-processing analysis at US \$46.00. **Conclusion:** DTI with MR tractography has important total direct costs with variable costs higher than the fixed costs. The post processing variable cost is the most expensive component. Developing more accurate automated post-processing software for DTI and MR tractography is important to decrease this variable labor cost. Given the added value of DTI-MR tractography and the costs involved reimbursement codes should be considered.

## Keywords

Tractography, Diffusion Tensor Imaging, MRI, Pediatrics, Brain, Cost Analysis, Functional

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## 1. Introduction

Diffusion Tensor Imaging (DTI) is currently the most sensitive MR-technique utilized to assess white matter integrity [1]. DTI is based on a mathematical description (the tensor) of the 3D shape of the water diffusion occur-

ring in a fibrillary organized tissue (e.g. the brain) [2]. *Fractional anisotropy* (FA) and *mean diffusivity* are scalars that describe the asymmetry of such diffusion; the asymmetry is due to the barriers of the myelin sheet of the axons and cell membranes [3]. DTI images are coded with respect to the FA, the diffusivity (ADC), or the predominant direction of the tensor [4]. From these maps, it is possible to perform 3D-reconstructions of brain white matter using MR tractography (MRT) [5] [6]. The localization of white matter tracts in the brain has been demonstrated as an important factor affecting pre-surgical planning, counseling, and outcome [7]-[10]. In addition DTI is important in traumatic brain injury as an outcome surrogate [11] [12]. Therefore, there is mounting evidence of the added clinical value of diffusion tensor imaging and MR tractography in these patient populations [13]. However, this study requires additional sequences and rigorous imaging post processing hence, incurring additional scanning time and use of personnel resources. However, to our knowledge, no rigorous cost analysis of DTI and MR tractography has been done to determine the exact resources used and its exact cost, though some attempts have been made to characterize value [13]-[15]. The purpose of our study, therefore, was to determine the total direct costs (fixed and variable costs) of DTI and MR tractography [16].

## 2. Materials and Methods

The inclusion of patients in this prospective study was based on the following criteria: history of seizures, consideration for surgical treatment, and resultant need for evaluation of potentially involved eloquent white matter tracts. Institutional review board approval was obtained. Informed consent was obtained for all patients studied [17]. Between February 2006 and July 2010, 17 patients (9 males and 8 females) between 2 - 33 years of age with a mean age and standard deviation of 13 years  $\pm$  4 years were recruited and evaluated by DTI and MR tractography at Miami Children's Hospital. Demographic and clinical data for the patients evaluated are shown in **Table 1**.

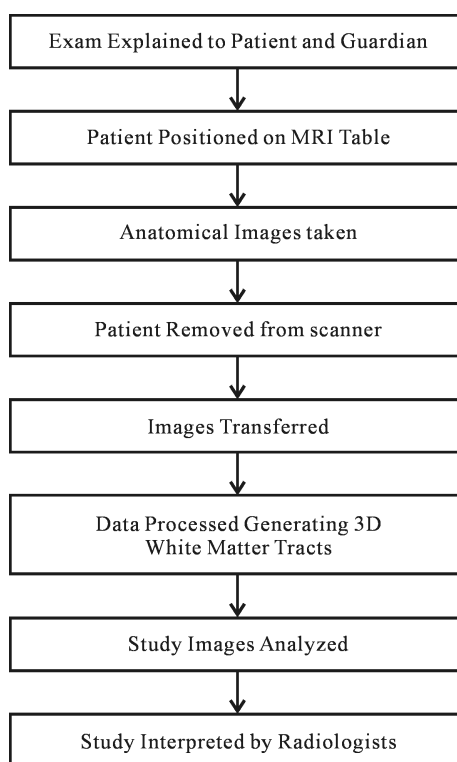
A flowchart of the procedure used for DTI and MRI is shown in **Figure 1**.

After the procedure was explained to the patient and guardian, the patient was positioned in a 1.5-T MR imager (Philips Intera, Philip Medical Systems software release V. 11) utilizing a SENSE head coil. All subjects had a 15-gradient direction scan DTI sequence, performed with a single-shot, spin-echo-planar imaging sequence with diffusion weighting. A single reference volume with no diffusion weighting was obtained; diffusion weighting (b) of 800 s/mm<sup>2</sup>; repetition time of 8326 ms; echo time of 94 ms; number of excitations 3; FOV of 240  $\times$  240 mm<sup>2</sup>; scan matrix of 112  $\times$  112; reconstruction matrix 256  $\times$  256; 50 2-mm axial slices and no slice gap. Images were transferred to the post-processing work station where FA, mean diffusivity, and color anisotropy maps were generated in the axial, sagittal and coronal planes utilizing Volume-One (<http://www.volume-one.org>). Eddy current artifacts were minimized by the intra-sequence registration tool utilized in the post-processing analysis [18] [19]. Subsequently a neurologist and/or a computer scientist selected

**Table 1.** Study population demographics.

Parameter	DTI and MR tractography
No. of patients	17
Male	9
Female	8
Age range*	2 - 33
Age (y) <sup>†</sup>	13 $\pm$ 8
Tumor	9
Vascular malformations	3
Not biopsied	3
Cortical dysplasia	1
Abscess	1

Note: Data are numbers of patients unless otherwise indicated. \*Years; <sup>†</sup>Mean  $\pm$  standard deviation in years.



**Figure 1.** Flowchart of diffusion tensor MR imaging.

the regions of interest (ROI) to generate the three dimensional white matter tracts and calculate the ROI-based FA and diffusivity values. Tractography was performed using a region-growing algorithm that merges voxels having similar tensor direction in neighboring voxels of the seeding ROI [20]. Thresholds for the tracking algorithm were set at 0.15 for FA, and  $45^\circ$  for maximum voxel-to-voxel fiber bending, as has been interrogated previously [21]. White matter tracts generated included corpus callosum, corticospinal tracts in the internal capsules, superior longitudinal and arcuate fasciculi, plus the inferior fronto-occipital fasciculi [22] [23]. Subsequently, the images were interpreted by a radiologist and a report was generated. The radiologist's interpretation time was recorded. Time needed for notification or discussion with the referring physician, was not included in the analysis. Teaching time was not included either in the analysis. From entries in the departmental logbook, the mean daily use of the MR scanner was determined to be 14 hours.

## 2.1. Definition of Costs

Costs were categorized as direct or indirect [24]-[27]. Direct costs were those directly associated with the performance of the examination and included fixed and variable costs, according to the system of classification used by the US Panel on Cost Effectiveness in Health and Medicine and by our medical center's cost accounting departments [28]. Fixed costs were those that did not change with the procedure, such as costs of equipment purchase, maintenance service contract, physical housing such as shielding, and depreciation [29]. Variable costs were those that depended on the procedure, such as costs of labor (MR technologist, post processing personnel and radiologist) and supplies (e.g., hardware and software for image creation and storage) [30]. Indirect costs are those incurred independently of the procedure, including expenses for grounds (e.g., walkways, parking areas, and landscaping) and general administration, human resources, utilities, housekeeping and general maintenance [31]. Because indirect costs are incurred regardless of the procedure performed, they were excluded from the statistical analysis.

In this study, fixed direct costs included the costs of equipment purchase, depreciation, maintenance, and service [32]. Variable direct costs included the costs of labor and materials directly attributable to the performance

of the procedures [27]. Cost analysis was performed from a medical center perspective [33] [34]. All costs were adjusted to year 2010 US dollars.

## 2.2. Measurement of Costs

The direct fixed and variable costs of DTI with MR tractography were determined prospectively with time and motion analysis methodology [24].

### 2.2.1. Fixed Direct Costs

All fixed direct costs were determined from accounting records of the medical centers. The fixed direct costs of each patient examination were based on utilization calculations and on total costs incurred during the measurement period, as reported in the management departmental logbooks [27] [28] [30]. Fixed costs of equipment were calculated on the basis of assumed 5-year linear depreciation, in accordance with guidelines of the American Hospital Association Health Data and Coding Standards Group [27] [28] [30].

### 2.2.2. Variable Direct Costs

Variable direct costs were tracked using a standardized form for all patients studied [24]. All materials used during the procedures were recorded, and their costs were assigned on the basis of the actual prices paid by the medical center's purchasing department.

Labor costs were measured with time and motion analysis. The amount of time spent by personnel involved in patient examinations and post procedural care was recorded to the nearest minute and entered into the time and motion analysis model. Laborers included physicians, technologists and post processing personnel. For salaried workers, labor cost calculations were based on total annual compensation, including benefits and salary, divided by the estimated number of billable labor hours per year [35]. The time spent by radiologists in image interpretation was also measured. All images were interpreted and reported by the attending radiologist. Teaching time was not included as part of the analysis.

## 2.3. Statistical Analysis

Total direct costs were tabulated for each examination and classified as either fixed or variable costs [36]. Variable direct costs were further subdivided into variable costs of computer scientist and neurologist post-processing, radiologist, MR technologist and storage cost. **Table 2** shows the unit cost estimates used in the analysis.

**Table 2.** Unit cost estimates for base case.

Resource	
Purchase of 1.5-T MR imager with shielding costs	2,000,000
Purchase of 3.0-T MR Imager with shielding costs	3,000,000
Yearly service and maintenance contract for 1.5-T MR imager	120,000
Purchase and yearly service DTI and MR tractography	6000
Yearly service DTI MR imaging post processing software & workstation	5500
Weekly use of 1.5-T MR imager (h)	70
Cost of images storage	3 - 7
Hourly salary per radiologist	150
Hourly salary per MR technologist	30
Hourly salary per DTI computer scientist	41
Hourly salary per neurologist	67

Cost in 2010 US dollars unless otherwise specified.

Means ( $\pm$ SDs) for each cost category were calculated [37]-[39]. Sensitivity analyses were performed for important cost variables including a 3-Tesla MR scanner and using the longer 32 direction DTI sequence. Spreadsheet software (Excel; Microsoft, Redmond, Washington) was used in the statistical analysis.

### 3. Results

The direct fixed and variable costs of examination with DTI and MR tractography are shown in **Table 3**, and relative correlations are expected among various vendors given the disparate costs of acquisition and purchasing of 1.5-T vs. 3-T systems.

The mean total direct cost was \$97 with a range of \$73.22 to \$115.65. The mean direct fixed cost was \$20.20 representing 20.8% of the total direct costs. The mean direct variable cost was almost four times higher than the fixed cost at \$76.80 representing 78.2% of the total direct costs. The largest components of the variable costs were the post-processing costs by the computer scientist and neurologist at \$31.43 and \$13.95, respectively for a total of \$45.38. This represents 59.1% of the total variable costs and 46.4% of the total direct costs. This is the largest cost component since post-processing and generation of the 3-D tractography images is labor intensive requiring in average 46 minutes for the computer scientist and 12.5 minutes for the neurologist. Radiologist interpretation of the study was less labor intensive with a mean of 10 minutes at an average variable cost of \$25.00.

#### Sensitivity Analyses

Sensitivity analyses for 1.5 versus 3-Tesla MR system and 15 versus 32 directions were done. Results are shown in **Table 4** and **Figure 2**.

Scanning time increased when DTI was done with 32 directions in the 1.5-Tesla MR system, hence, increasing the mean total direct cost to \$113.70.

Overall total direct costs between the 1.5 and the 3-Tesla systems were similar at comparable number of directions with differences under three dollars (**Table 4**). However, there was an increase of greater than ten percent in total direct costs for both Tesla systems when the directions were increased from 15 to 32 because of

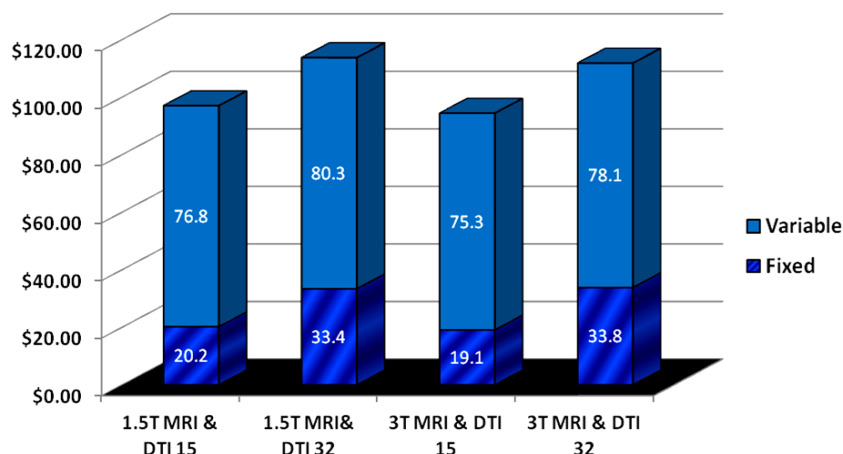
**Table 3.** Direct fixed and variable costs for DTI and MR tractography at 1.5-Tesla with 15 directions.

Cost category	Test mean (%)	Range
Fixed cost (\$)	20.2 (20.8)	19.25 - 21
Variable costs (\$)	76 (78.2)	53.97 - 94.85
Computer scientist post-processing	31.43	23.9 - 34
Neurologist post-processing	13.95	11.17 - 16.75
Radiologist interpretation	25	12.50 - 37.50
MR technologist	4.50	3.95 - 4.95
Transcription and voice recognition	1.9	
Storage cost	2.55	
Total direct cost (\$)	97	74.14 - 114.82

**Table 4.** Sensitivity analysis.

	Average minutes	Total cost	Fixed cost	FC (%)	Variable cost*	VC (%)
1.5-T @ 15 directions	9	\$97.0	\$20.2	(20.8)	\$76.8	(79.2)
1.5-T @ 32 directions	16	\$113.7	\$33.4	(29.4)	\$80.3	(70.6)
3-T @ 15 directions	6.1	\$94.5	\$19.1	(20.2)	\$75.3	(79.8)
3-T @ 32 directions	11.7	\$111.9	\$33.8	(30.2)	\$78.1	(69.8)

\*Mean-post processing cost \$45.38.



**Figure 2.** Fixed, variable, & total costs for DTI 1.5 MRI vs. DTI 3.0 MRI.

significant increase in scanning time (**Table 4**).

Scanning times were less on the 3-Tesla MR system for both the 15 and 32 directions given the higher signal to noise ratio and hence shorter scan time (**Table 4**). Although the 3-Tesla MR system is overall more expensive than the 1.5-Tesla MR system, the time scanning reduction produced overall a small decrease in the 3-Tesla total direct cost being \$94.5 for 15 directions and \$111.9 for 32 directions. This mild decrease in cost is primarily due to the mild decrease in MR technologist variable cost given the shorter scanning times.

#### 4. Discussion

The results of this study indicate that performing DTI and MR tractography uses significant resources which incur on fixed and variable cost with total direct cost in the range of \$94.5 and \$113.70. There is no significant difference in the total direct cost between 1.5- and 3-Tesla MR systems at comparable number of directions. However, for both systems there is a just over ten percent increase in cost by increasing the total directions from 15 to 32. There is mounting clinical research data showing the added value of DTI and MR tractography in seizure and brain neoplasm neurosurgical planning plus traumatic brain injury, therefore separate test generation and reporting with an appropriate reimbursement or CPT code should be considered.

The most expensive cost component of DTI and MR tractography is the post processing costs accounting for a mean variable cost of \$45.38 (46.4% of the total direct costs). Further development of more robust automated MR tractography software incorporating artificial intelligence should be done to decrease this time consuming process and hence, decrease variable costs.

Cost analysis of other advanced brain MR imaging has been done using similar methodology. The mean total direct cost of functional MR imaging is \$301.82 [24]. Therefore, the mean total direct cost of DTI and MR tractography is about a third of functional MR imaging. Functional MR imaging has added value by providing information about eloquent brain areas in seizure and brain neoplasm patients being consider for surgical intervention [40]-[43]. DTI and MR tractography also provides added value in this population by depicting the tracts which connect these eloquent brain areas [1] [44]-[48]. Given functional MR imaging added value and costs approved CPT codes are currently available for reimbursement purposes [49]. Although DTI and MR tractography have added diagnostic value no CPT codes are currently available to pay for their significant total direct costs [50]-[52]. Therefore consideration into developing specific reimbursement or CPT codes for DTI and MR tractography should be consider given its added value and additional total direct cost not covered by conventional brain MRI.

We chose to define costs from the perspective of the medical center because managed health care and discounted fee for service have become the predominant models of health care expense reimbursement in the United States [53]-[57]. With capitation, health care providers bear the burden of actual costs and have no possibility of reimbursement for expenses that exceed prepaid premiums [58]. To maintain appropriate net revenue, health care providers must know the costs of each procedure. Our time and motion analyses of direct fixed variable costs enabled rigorous quantification and eliminated the assumptions inherent in estimated cost measure-

ment [55] [59]-[63], charge-based analyses [64]-[67], analyses based on ratio of costs to charges [68]-[74], and relative value unit-based analyses [75] [76]. Our results, however, may not be generalizable to all medical institutions and centers. First, the data used in this study was collected from one institution rather than from multiple medical centers with different physician and patient constituencies. Furthermore, because all costs, particularly those of labor, are based on regional standards, the absolute costs reported in this study may diverge from absolute costs incurred in other regions. The relative costs, however, should be generalizable to most institutions in the United States [77].

## 5. Conclusion

In conclusion, DTI and MR tractography have significant total direct costs and resource utilization. No significant cost difference is seen between 1.5- and 3-Tesla MR systems for comparable number of directions used. However, the increase in directions from 15 to 32 increases the total direct cost just over 10% for both Tesla systems. Post processing is the most expensive component of this test. Therefore, further development of faster and robust post-processing software is a priority to decrease overall total direct costs. Given the increasing research data showing the added value of DTI-MR tractography, dedicated reimbursement CPT codes must be developed so appropriate cost compensation is ensued given the additional resources utilized for this useful test.

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