Current Problems in Diagnostic Radiology 49 (2020) 42–47

Current Problems in Diagnostic Radiology

journal homepage: www.cpdrjournal.com

Thoracic Duct Embolization—Value Analysis Using a Time-Driven Activity-Based Costing Approach: A Single Institution Experience

Spencer B. Lewis, MD[a], Ravi N. Srinivasa, MD[b], Prasad R. Shankar, MD[c], Jacob J. Bundy, MD, MPH[a], Joseph J. Gemmete, MD, FSIR[a], Jeffrey Forris Beecham Chick, MD, MPH[d,*]

[a] Department of Radiology Division of Vascular and Interventional Radiology, University of Michigan Health Systems, Ann Arbor, MI
[b] Department of Interventional Radiology, University of California Los Angeles, Los Angeles, CA
[c] Department of Radiology Division of Abdominal Radiology, University of Michigan Health Systems, Ann Arbor, MI
[d] Cardiovascular and Interventional Radiology, Inova Alexandria Hospital, Alexandria, VA

A B S T R A C T

Purpose: To quantify cost drivers for thoracic duct embolization based on time-driven activity-based costing methods.
Materials and Methods: This was an Institutional Review Board-approved (HUM00141114) and Health Insurance Portability and Accountability Act-compliant study performed at a quaternary care institution over a 14-month period. After process maps for thoracic duct embolization were prepared, staff practical capacity rates and consumable equipment costs were analyzed via a time-driven activity-based costing methodology. Sensitivity analyses were performed to identify primary cost drivers.
Results: Mean procedure duration was 4.29 hours (range: 2.15-7.16 hours). Base case cost, per case, for thoracic duct embolization was $7466.67. Multivariate sensitivity analyses performed with all minimum and maximum values for cost input variables yielded a cost range of $1001.95 (minimum) to $89,503.50 (maximum). Using local salary information and negotiated prices for materials as cost parameters, the true cost per case of thoracic duct embolization at the study institution was $8038.94. Univariate analysis demonstrated that the primary driver of staffing costs was the length of time the attending anesthesiologist was present. The predominant modifiable cost drivers included cyanoacrylate glue volume used (minimum $4467; maximum $12,467), cost of glue utilized (minimum $5217; maximum $10,467), and cost of coils utilized (minimum $7377; maximum $10,917). Univariate analysis predicted that the use of Histoacryl glue in place of TRUFILL cyanoacrylate glue resulted in a cost savings of $2947.50 per case.
Conclusions: The base cost per case for thoracic duct embolization was $7466.67. Costs, namely anesthesia staffing costs, cyanoacrylate glue, and coils were large, potentially modifiable drivers of overall cost for thoracic duct embolization.

Introduction

The cost of healthcare in the United States exceeds $2.7 trillion annually, accounting for 18% of the gross domestic product.[1] While increasing administrative, pharmaceutical, and home healthcare expenses are responsible for a large portion of this increase, the direct costs of providing hospital care are still the primary driver of overall healthcare costs.[1-3] As providers and hospitals prepare to move from a relative value units-based system to a value-based payment system there is an increasing need to be able to determine the true costs of delivering care and services. Accurate cost accounting represents an opportunity to identify novel avenues for cost reduction in clinical interventions.

Time-driven activity-based costing (TDABC) is an accounting method which has gained popularity in business and is gaining increasing prominence as a tool for estimating healthcare delivery costs.[2,4-6] TDABC allows healthcare providers to measure the costs of treating patients for a specific medical or surgical condition across a full longitudinal care cycle. It uses process mapping from industrial engineering and activity-based costing from accounting.[6] TDABC relies on estimates of capacity cost rates and utilization times to estimate the overall cost associated with a system or intervention.[4,7] Capacity cost rate is defined as the monetary cost of a resource per unit time (in dollars per hour), calculated by dividing the total cost of a resource by the approximate time the resource is utilized.[4] This may be calculated for all resources employed in a system, including staff (as wages plus benefit costs divided by hours worked), equipment (as purchase cost divided by lifetime use), and occupancy (as rental costs divided by total annual productive occupancy time).[4,7,8]

The TDABC model allows for accounting of multiple layers of cost, allowing for a more nuanced examination of cost contributors than existing estimates such as relative value units and charge-cost ratios.[4,7] TDABC allows for both the identification of cost-driving

All authors have read and contributed to this manuscript.
Authors have no relevant disclosures.
Informed consent was obtained from all individual participants included in the study.

*Reprints requests: Jeffrey F. B. Chick, MD, MPH, Cardiovascular and Interventional Radiology, Inova Alexandria Hospital, 4320 Seminary Road, Alexandria, VA 22304.
E-mail address: jeffreychick@gmail.com (J.F.B. Chick).

https://doi.org/10.1067/j.cpradiol.2018.12.007

steps in a process and the assessment of cost-reduction strategies. In addition, the calculations required for TDABC estimation are straightforward, requiring only estimates of time and capacity cost rate.[7]

The objective of this study was to develop process maps for thoracic duct embolization using the TDABC model with cost components throughout the care episode, including preoperative holding, procedure costs, and postanesthesia care costs. Accurate estimation of cost will help identify opportunities for cost savings in interventional radiology, and serve as a foundation for future comparative analyses between minimally invasive interventions like thoracic duct embolization and open surgical procedures.

Materials and Methods

Process Map Generation

This was an Institutional Review Board-approved (HUM00141114) and Health Insurance Portability and Accountability Act-compliant study. All costs are listed in United States dollars ($) as of October 2017. Model developments began with process maps for all parties involved in thoracic duct embolization, created after interviews with representatives from each party. The process map for thoracic duct embolization demonstrating all steps, decision points, and individuals present or responsible for each step as shown in Figure 1. The duration of each step was estimated from chart review using the electronic medical record (Epic; Verona, WA) of the most recent 22 thoracic duct embolization encounters from July 2017 to October 2017 or obtained from interviews with relevant parties.

Unit Time Estimation

Time estimates for each step of a thoracic duct embolization were obtained from a chart review. Event logs depicted the entry and exit of each team member as well as the duration for which each resource was utilized. These times were averaged to obtain a representative time for each step in the thoracic duct embolization process map.

Practical Capacity and Capacity Cost Rates

Practical capacity was defined as the actual time a resource, whether human or capital, was available.[4] While practical capacity varies based on the resource, a commonly used assumption is that most resources may be used 80%-85% of their full capacity.[5] In consultation with the Director of Clinical Operations at this institution, practical capacity was estimated as 85%, based on the number of hours a typical employee works per day and the number of days that employee works per year, less holidays, sick days, educational time, and break time. Capacity cost rates were estimated for all relevant resources by dividing annual salary cost estimates by practical capacity time (in hours per year).

Staff Practical Capacity Costs

Salaries and hourly wages, including employee benefits, were calculated from payroll records, the United States Bureau of Labor Statistics occupational employment statistics database, and publicly available data from other institutions.[9-13]

Capital Equipment

Capital equipment is nondisposable equipment purchased by the institution for long-term use, and includes anesthesia machines, fluoroscopy tables, and other fixed components of the interventional radiology suite. Capital equipment costs were obtained from the Director of Clinical Operations. The total equipment cost of an interventional suite without computed tomography capability at the University of Michigan is $4.5 million, with a 7-year depreciation timeline and a 10-year replacement time horizon. Equipment is assigned a value of $0 at the end of its lifespan. Based on historical data from the institution, budgeted capacity of the interventional

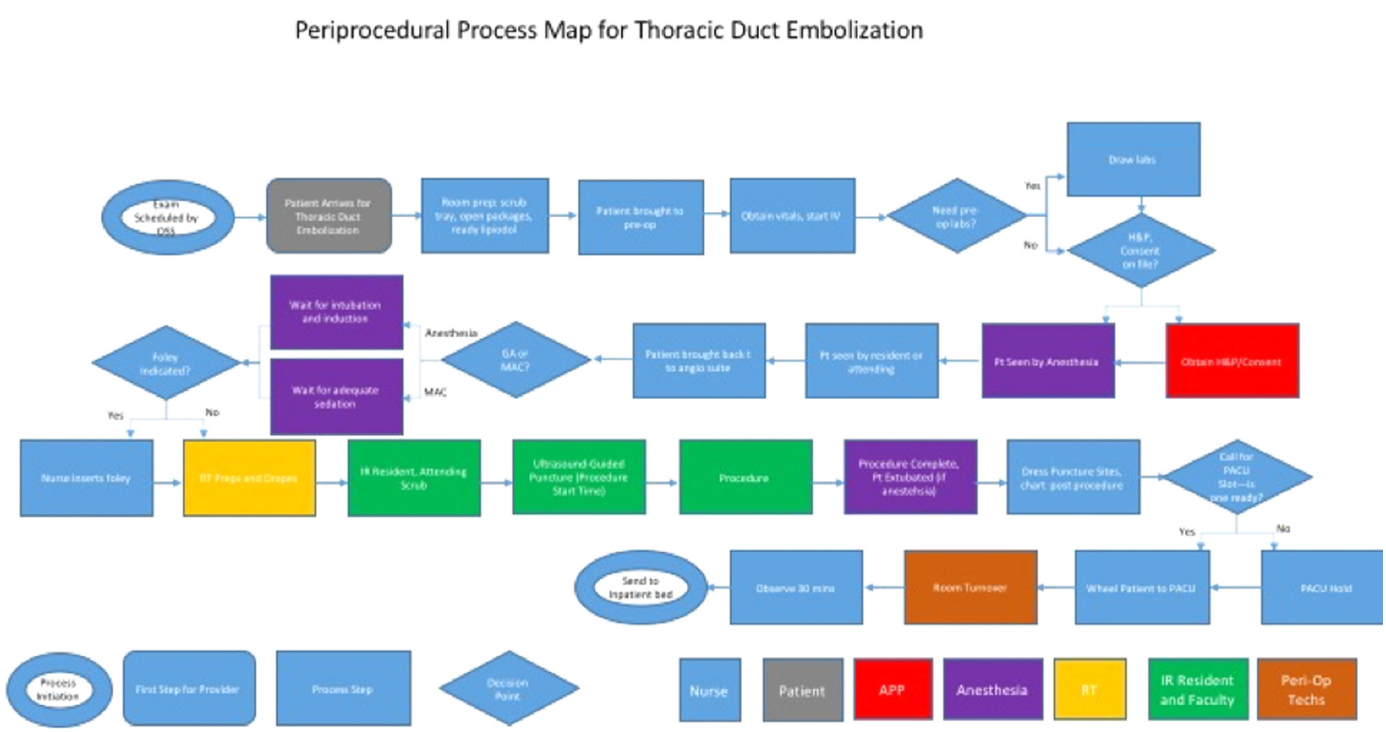

FIG 1. Process map showing all decision points, staff, and resources involved in thoracic duct embolization. This analysis focuses on costs incurred between the time the patient enters the procedure room and the time the patient exists the procedure room.

radiology suites is approximately 948 hours per week for 12 rooms, or 79 hours per week per room. Again assuming a practical capacity equal to 85% of full capacity, this yields a cost rate of $129 per hour per room per hour. Nondisposable multipurpose products and fixed angiography suite material (such as hospital bed, angiography table, and electronic medical record) are not included in the analysis due to multiple confounding uses of these items and relatively small per-patient impact when factoring depreciation.

A formal detailed capital analysis is out of the scope of this paper, and detailed analyses of equipment costs at our own institution are precluded by the proprietary nature of institutional equipment costs.

Disposable Equipment Costs

Unit prices were obtained from the institution's charge master and compared to data obtained through market analysis and published data to obtain cost estimates.[14,15] Materials selected for sensitivity analysis include guidewires, needles, catheters, embolization coils, cyanoacrylate glue, and vascular plugs.

Cost Sensitivity Analyses

The input parameters for the base case analysis are summarized in Table 1. Following development of the base case, univariate sensitivity analyses were performed to determine the cost contribution of each variable.[16] Two classes of variables were analyzed: labor costs and disposable materials costs. The range and rationale for values studied are summarized in Table 2. The lower and upper bounds for salary were the 10th and 90th percentiles of nationally reported data obtained from the *Bureau of Labor Statistics* occupational employment statistics database or from other publicly available databases.[9-12,17] Task time was varied from 50% to 200% of the mean procedure logs, from retrospectively obtained institutional data. Disposable material cost variations were estimated based on published online market values, discussions with vendors, and the institutional central supply department.

True institutional salary data and materials costs are proprietary and not individually reported, but are incorporated into an overall cost comparison, as a multivariate secondary analysis. Additional multivariate sensitivity analyses were performed by varying the minimum and maximum values for all model variables, in order to generate a base case cost range. Cost range of additional embolic materials, not utilized in the base case, was determined by adding supplemental agent costs and quantities to base case values in a multivariate fashion.

Results

The average procedure duration, from entering to exiting the angiography suite, for thoracic duct embolization was 4.29 hours (range: 2.15-7.16 hours). The base case cost, per case, of thoracic duct embolization is $7466.67 (Table 1). Inclusion of institution-specific capital equipment costs increased total cost by 6.9%. Multivariate sensitivity analyses performed with all minimum and maximum values for cost input variables yields a cost range of $1001.95 (minimum) to $89,503.50 (maximum, including all studied occlusive agents). Using local salary information and negotiated prices for materials as cost parameters, the true cost per case of thoracic duct embolization at the study institution was $8038.94.

Sensitivity analysis of labor factors related to thoracic duct embolization is summarized in Table 2 and Figure 2. Per univariate sensitivity analysis, the largest labor factor contributing to cost was the time an anesthesiologist was required to be present for the procedure (minimum total cost of $6772; maximum total cost of $8766). Additional substantial labor cost drivers were the interventional radiology attending time (minimum total cost of $7048; maximum total cost of $8033), and certified registered nurse anesthetist time (minimum total cost of $7206; maximum total cost of $7987). Wage variation across the considered ranges produced a consistently smaller variation in total cost than the impact of time.

Univariate sensitivity analyses of disposable materials costs are summarized on Table 2 and Figure 3. Disposable materials had a greater impact on total cost than labor factors (ie, wages or labor time required). The quantity of cyanoacrylate glue used was the single largest driver of cost, responsible for a price increase of $5000 over the examined range of glue volume (minimum total cost of $4467; maximum total cost of $12,467). Glue quantity was a stronger driver of total cost than glue price (minimum total cost of $5217; maximum total cost of $10,467). Cost of selected embolic coils were another strong cost driver (minimum total cost of $7377; maximum total cost of $10,920), although selected coil cost was a stronger driver of total

TABLE 1
Base case cost model, per case, for thoracic duct embolization. The table presents model variables grouped by labor costs and equipment costs. Associated data sources are provided for reference

Variable	Base cost values	Source
Labor		
IR nurse		
Adjusted hourly wage ($/h)	$51.86/h	BLS OES data, median national salary
Time required/case (min)	352.00 min	Institutional retrospective data
IR tech		
Adjusted hourly wage ($/h)	$43.52/h	BLS OES data, median national salary
Time required/case (min)	438.60 min	Institutional retrospective data
Fellow		
Adjusted hourly wage ($/h)	$36.24/h	Institutional data and publicly available academic hospital data[13]
Time required/case (min)	257.00 min	Institutional retrospective data
IR attending		
Adjusted hourly wage ($/h)	$196.41/h	Institutional data and publicly available salary data[10]
Time required/case (min)	257.00 min	Institutional retrospective data
Attending anesthesiologist		
Adjusted hourly wage ($/h)	$218.33/h	Institutional data and publicly available salary data[11]
Time required/case (min)	209.00 min	Institutional retrospective data
CRNA		
Adjusted hourly wage ($/h)	$121.42/h	BLS OES
Time required/case (min)	265.00 min	Institutional retrospective data
Materials cost		
Guidewire (represents average of most commonly used guidewires at our institution)		
Cost (per unit)	$49.00/unit	Combined market analysis and institutional data
Quantity	5.00	Institutional retrospective data
Needles (22 G, 20 cm)		
Cost	$44.00/unit	Combined market analysis and institutional data
Quantity	2.50	Institutional retrospective data
Microcatheter (represents average of most commonly used microcatheters at our institution)		
Cost	$495.00/unit	Combined market analysis and institutional data
Quantity	2.00	Institutional retrospective data
Glue		
Cost ($/mL)	$2000.00/mL	Estimated from institutional data[14]
Quantity	1.50 mL	Institutional retrospective data
Coils		
Cost ($/unit)	$49.00/unit	Combined market analysis and institutional data
Quantity	3.00	Institutional retrospective data
Coil delivery system		
Cost ($/unit)	$59.00/unit	Combined market analysis and institutional data
Quantity	1.00	Institutional retrospective data
Total cost of TDE	**$7466.67**	

BLS OES, Bureau of Labor Statistics, Occupational Employment Statistics (citation 9); CRNA, certified registered nurse anesthetist; TDE, thoracic duct embolization.

TABLE 2
Univariate sensitivity analysis range of values and total costs. The table presents the minimum and maximum values over which each variable was investigated. Rationale for range is provided for reference. Total cost refers to the model output cost with all other variables held static to the base case. The base case cost is $7466.67/case

Cost parameter	Value	Total cost of TDE	Basis for values
Labor			
IR nurse hourly wage ($/h)			
Minimum	$35.70/h	$7371.89	10th percentile national data (BLS OES)
Maximum	$78.02/h	$7620.17	90th percentile national data (BLS OES)
IR nurse time required/case			
Minimum	136.00 min	$7279.99	Minimum time based on institutional data
Maximum	656.00 min	$7729.41	Maximum time based on institutional data
IR tech hourly wage ($/h)			
Minimum	$29.29/h	$7362.63	10th percentile national data (BLS OES)
Maximum	$62.57/h	$7605.91	90th percentile national data (BLS OES)
IR tech time required/case			
Minimum	136.00 min	$7247.17	Minimum time based on institutional data
Maximum	656.00 min	$7690.38	Maximum time based on institutional data
Fellow hourly wage ($/h)			
Minimum	$28.18/h	$7434.85	Lowest salary estimated obtained through national data[13]
Maximum	$39.79/h	$7481.88	Highest salary estimated obtained through national data[12]
Fellow time required/case			
Minimum	129.00 min	$7389.36	Minimum time based on institutional data
Maximum	430.00 min	$7571.17	Maximum time based on institutional data
IR attending hourly wage ($/h)			
Minimum	$72.73/h	$6936.92	Lowest salary estimated obtained through national data[13]
Maximum	$246.97/h	$7683.25	Highest salary estimated obtained through national data[12]
IR attending time required/case			
Minimum	129.00 min	$7047.67	Minimum time based on institutional data
Maximum	430.00 min	$8032.99	Maximum time based on institutional data
Attending anesthesiologist hourly wage ($/h)			
Minimum	$156.57/h	$7251.53	Lowest salary estimated obtained through national data[13]
Maximum	$272.22/h	$7654.37	Highest salary estimated obtained through national data[12]
Attending anesthesiologist time required/case			
Minimum	18.00 min	$6771.64	Minimum time based on institutional data
Maximum	566.00 min	$8765.77	Maximum time based on institutional data
CRNA hourly wage ($/h)			
Minimum	$81.79/h	$7291.66	10th percentile national data (BLS OES)
Maximum	$157.58/h	$7626.40	90th percentile national data (BLS OES)
CRNA time required/case			
Minimum	136.00 min	$7205.63	Minimum time based on institutional data
Maximum	522.00 min	$7986.74	Maximum time based on institutional data
Materials cost			
Guidewire cost (per unit)			
Minimum	$19.00	$7316.67	Market analysis
Maximum	$560.00	$10,021.67	Market analysis
Guidewire quantity			
Minimum	1.00	$7270.67	Institutional data
Maximum	23.00	$8348.67	Institutional data
Needles cost (per unit)			
Minimum	$10.00	$7381.67	Market analysis
Maximum	$99.00	$7604.17	Market analysis
Needles quantity			
Minimum	1.00	$6971.67	Institutional data
Maximum	11.00	$11,921.67	Institutional data
Microcatheter cost (per unit)			
Minimum	$375.00	$7226.67	Market analysis
Maximum	$1,070.00	$8616.67	Market analysis
Microcatheter quantity			
Minimum	1.00	$6971.67	Institutional data
Maximum	6.00	$9445.67	Institutional data
Glue cost (per mL)			
Minimum	$500.00/mL	$5216.67	25% of base case, market analysis
Maximum	$4000.00/mL	$10,466.67	200% of base case, market analysis
Glue quantity			
Minimum	0.00 mL	$4466.67	Institutional data
Maximum	4.00 mL	$12,466.67	Institutional data
Coils cost (per unit)			
Minimum	$19.00	$7376.67	Market analysis
Maximum	$1,200.00	$10,919.67	Market analysis
Coils quantity			
Minimum	0.00	$7319.67	Institutional data
Maximum	32.00	$8887.67	Institutional data
Coil delivery system (per unit)			
Minimum	$11.80	$7419.47	Market analysis
Maximum	$88.50	$7496.17	Market analysis
Coil delivery system (per unit)			
Minimum	0.00	$7407.67	Institutional data
Maximum	1.00	$7466.67	Institutional data

BLS OES, Bureau of Labor Statistics, Occupational Employment Statistics (citation 9); CRNA, certified registered nurse anesthetist; TDE, thoracic duct embolization.

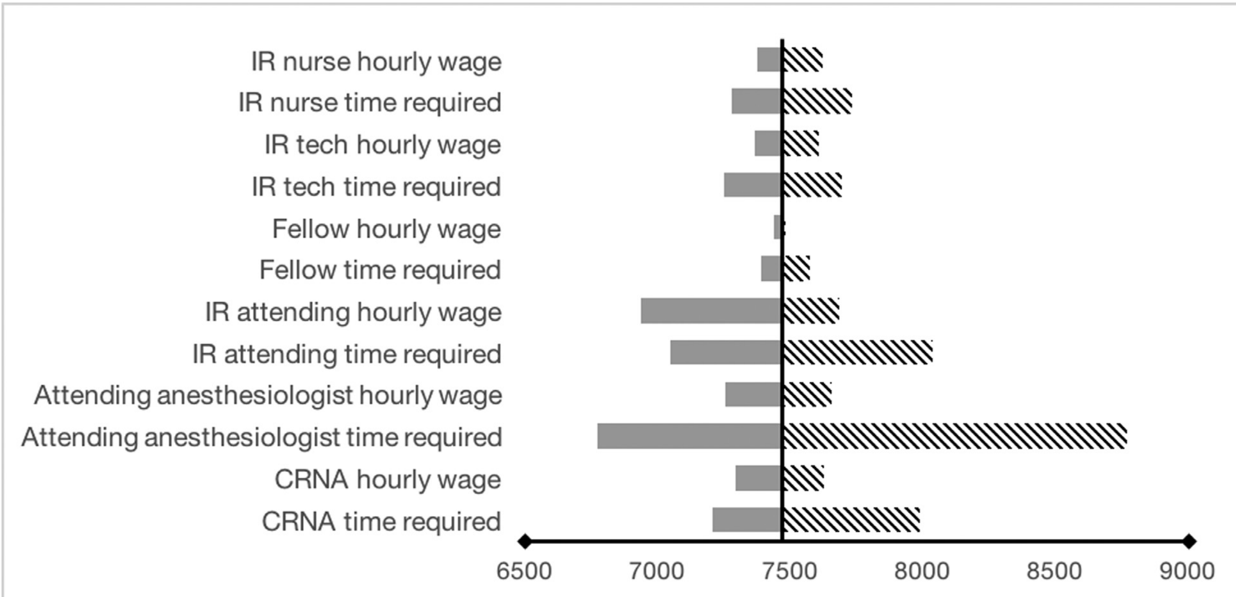

FIG 2. Univariate sensitivity analysis of labor factors related to cost of thoracic duct embolization, per case. The base case is indicated by the central vertical line and corresponds to a cost of $7466.67. Each variable is modeled as an uncertain variable, from minimum to maximum studied values around the base case value, with all other variables held static. Gray bars to the left of the vertical line represent the degree of total cost reduction and the striped bars to the right of the vertical line represent the degree of total cost increase.

cost than the number of coils used (minimum total cost $7320; maximum total cost $8889).

With cyanoacrylate glue being both widely used at our institution and a strong driver of total cost, an additional univariate analysis was performed to assess the cost savings of 2 alternative tissue adhesives: Histoacryl (*n*-butyl-2-cyanoacrylate) and Glubran-2 (*n*-butyl-2-cyanoacrylate and methacryloxysulfolane co-monomer) (GEM SRL; Viareggio, Italy). These agents are marketed at a substantially lower price than *n*-BCA and may offer similar functionality in many applications.[18-20] Using Glubran-2 in place of *n*-BCA with all other costs held equal results in a cost savings of $2735.06 per case (total cost $4731.61), whereas using Histoacryl results in a cost savings of $2948.24 per case (total cost $4518.43).

Discussion

TDABC has been used to evaluate the cost drivers of procedures in numerous specialties including neurosurgery[7] and otorhinolaryngology.[8] Almost universally, personnel wages and benefits are the dominant driver of procedural costs. This analysis, however, demonstrates that procedural disposable devices and material expenses dominate the cost of thoracic duct embolization. Furthermore, these costs are tremendously variable between cases, depending on both the techniques employed and the technical complexity of the case.

The most expensive line item disposable was cyanoacrylate glue, at a base cost of $2000 per mL/vial. Indeed, each vial of glue used contributes an expense equal to 68% of the total personnel cost for the

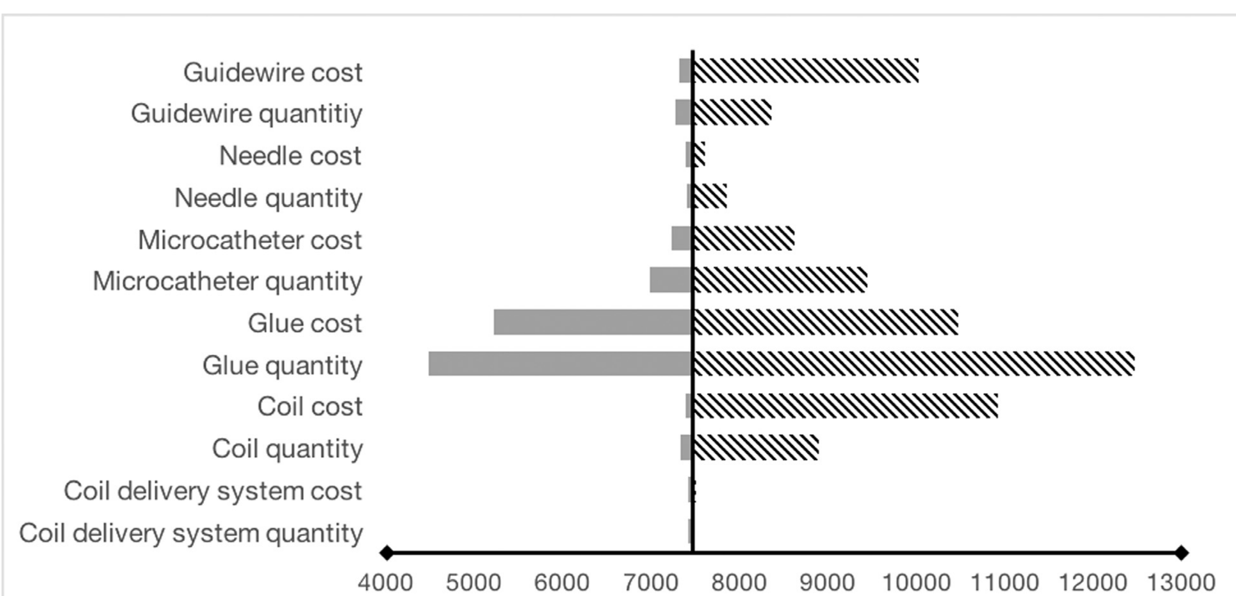

FIG 3. Univariate sensitivity analysis of material factors related to cost of thoracic duct embolization per case. The base case is indicated by the central vertical line and corresponds to a cost of $7466. Each variable is modeled as an uncertain variable, from minimum to maximum studied values around the base case value, with all other variables held static. Gray bars to the left of the vertical line represent the degree of total cost reduction and the striped bars to the right of the vertical line represent the degree of total cost increase.

procedure. Likewise, minimization of glue volume was shown to be the single greatest cost saving measure in the univariate analysis. It should also be noted that the ratio of cyanoacrylate glue to ethiodol oil dilution used during the embolization will directly affect the volume of glue required and subsequently the cost contribution of this material. There is no established standard dilution used for of cyanoacrylate glue embolization within the thoracic duct but ratios of glue to ethiodol oil range from 1:1 to 1:3, however much of this decision making is operator dependent.

Use of an alternative tissue adhesive provides an even greater opportunity for cost savings. Substituting Histoacryl glue for *n*-BCA resulted in a predicted cost savings of 60% relative to the base case. While no trials have been conducted to date to assess the efficacy of Histoacryl (or Glubran-2) in thoracic duct embolization, studies have shown that Histoacryl can be used off-label as an endovascular embolic agent in several applications, including obliteration of gastric varices[21] and portal vein embolization prior to partial hepatectomy.[22] Additional studies are necessary to determine whether Histoacryl or Glubran-2 could offer these cost savings in thoracic duct embolization without compromising patient outcomes or indirectly increasing costs by increasing operative time or increasing complication risks.

While embolic materials largely drive cost in thoracic duct embolization, staffing costs offer a substantial opportunity for cost savings as well. While nearly all thoracic duct embolizations are performed under general anesthesia, the length of time the attending anesthesiologist is present is highly variable. Utilizing certified nurse anesthetists to minimize the length of time the attending anesthesiologist is present is associated with a substantial cost savings over having an attending present the entire case. However, overall, variation in wages produced a comparatively small effect on total cost—importantly, embolic material selection has a substantially greater impact on total expense than staffing. It remains to be seen whether this is a pattern across interventions or is specific to thoracic duct embolization, and further studies are necessary to determine the impact of materials selection in cost reduction across interventional radiology.

The base case cost of a thoracic duct embolization in the present analysis was $7466.67. While significant variability exists, the costs of this minimally invasive treatment would likely be more cost-effective than the surgical ligation of the thoracic duct in the management of chyle leaks. The costs related to operating room time and extended hospital stays for recovery following the operation would appear to exceed the costs related to thoracic duct embolization given the expedited recovery and decreased complication profile.

There are limitations. This evaluation is a cost analysis and not a cost-benefit or cost-effectiveness analysis. Further, a patient's underlying disease and specific anatomy may be more conducive to one line of treatment over another, independent of cost. It should be noted that there is significant national variability in not only the technique used during thoracic duct embolizations but also staff efficiency, workflows, compensation structures, and industry contracts that could all potentially affect the significant cost drivers. At present; however, interventional radiologists are choosing between these materials with little information on total cost.

This study used a TDABC method to investigate primary cost drivers in thoracic duct embolization. This study demonstrates that anesthesia staffing costs cyanoacrylate glue, and coils are large, potentially modifiable drivers of overall cost. Additional studies will be necessary to define thoracic duct embolization protocols that deliver cost savings on materials without compromising outcomes.

Ethical Statement

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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