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CLINICAL ARTICLE

Cost analysis of awake versus asleep deep brain stimulation: a single academic health center experience

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OBJECT The objective of this study was to compare the cost of deep brain stimulation (DBS) performed awake versus asleep at a single US academic health center and to compare costs across the University HealthSystem Consortium (UHC) Clinical Database.

METHODS Inpatient and outpatient demographic and hospital financial data for patients receiving a neurostimulator lead implant (from the first quarter of 2009 to the second quarter of 2014) were collected and analyzed. Inpatient charges included those associated with *International Classification of Diseases, Ninth Revision* (ICD-9) procedure code 0293 (implantation or replacement of intracranial neurostimulator lead). Outpatient charges included all preoperative charges ≤ 30 days prior to implant and all postoperative charges ≤ 30 days after implant. The cost of care based on reported charges and a cost-to-charge ratio was estimated. The UHC database was queried (January 2011 to March 2014) with the same ICD-9 code. Procedure cost data across like hospitals (27 UHC hospitals) conducting similar DBS procedures were compared.

RESULTS Two hundred eleven DBS procedures (53 awake and 158 asleep) were performed at a single US academic health center during the study period. The average patient age (± SD) was 65 ± 9 years old and 39% of patients were female. The most common primary diagnosis was Parkinson's disease (61.1%) followed by essential and other forms of tremor (36%). Overall average DBS procedure cost was $39,152 ± $5340. Asleep DBS cost $38,850 ± $4830, which was not significantly different than the awake DBS cost of $40,052 ± $6604. The standard deviation for asleep DBS was significantly lower ($p \leq 0.05$). In 2013, the median cost for a neurostimulator implant lead was $34,052 at UHC-affiliated hospitals that performed at least 5 procedures a year. At Oregon Health & Science University, the median cost was $17,150 and the observed single academic health center cost for a neurostimulator lead implant was less than the expected cost (ratio 0.97).

CONCLUSIONS In this single academic medical center cost analysis, DBS performed asleep was associated with a lower cost variation relative to the awake procedure. Furthermore, costs compared favorably to UHC-affiliated hospitals. While asleep DBS is not yet standard practice, this center exclusively performs asleep DBS at a lower cost than comparable institutions.

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KEY WORDS deep brain stimulation; cost; awake; asleep; functional neurosurgery

Deep brain stimulation (DBS) has been clearly demonstrated to be more effective than best medical therapy for patients with medically intractable Parkinson's disease.[5,19] While high-quality clinical outcomes are important, the value of a procedure is also inversely related to cost. Studies of the cost of DBS for Parkinson's disease, and other disease entities, have been performed with increasing frequency over the past decade.[1,6–8,13,16] A number of studies have been published recently that suggest that DBS is cost-effective after the first year or two of therapy, even considering the relatively high cost of the initial implant.[2–4,9–12,14,17,20]

ABBREVIATIONS DBS = deep brain stimulation; ICD-9 = *International Classification of Diseases, Ninth Revision*; ICU = intensive care unit; IPG = internal pulse generator; LOS = length of stay; OHSU = Oregon Health & Science University; OR = operating room; UHC = University HealthSystem Consortium.

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In our center, we have recently adopted a new method of implanting DBS electrodes, portable CT (CereTom). We were interested in how this new methodology would affect the cost of DBS electrode implantation, and the utilization of operating room (OR) resources. In this study, we compared the historical costs of electrode implantation at our institution in patients under local anesthesia, utilizing microelectrode recording to locate targets ("Awake DBS"), to a newer method in which DBS electrodes were implanted under general anesthesia, using only image guidance ("Asleep DBS"). This cost analysis was then benchmarked to the University HealthSystem Consortium (UHC) database for 26 "high-volume" UHC Clinical Database principle member hospitals for DBS electrode and internal pulse generator (IPG) implantation procedures.

Methods

At Oregon Health & Science University (OHSU), preoperative MRI is performed just prior to inpatient hospitalization. DBS electrodes are implanted during an initial overnight hospital stay (Phase 1), and IPGs are implanted from 4 to 9 days later in an ambulatory surgery center (Phase 2). Inpatient care, coded by *International Classification of Diseases, Ninth Revision* (ICD-9) procedure code 0293, includes implantation of an intracranial neurostimulator lead. Outpatient care consists of the preoperative imaging and eventual implantation of an IPG. In an effort to capture all costs associated with DBS, all outpatient and inpatient charge data from patients receiving a DBS implant at a single academic health center (OHSU) were collected. Included outpatient charges were any preoperative charges recorded within 30 days prior to the implant and any postoperative charges recorded up to 30 days after the implant. Charges that were unrelated to DBS were excluded, such as charges for emergency department visits. Inpatient charges that were included were those associated with the ICD-9 code 0293 intracranial implant encounter.

Costs were calculated using a cost-to-charge ratio, which was calculated from the ratio of total direct cost to total charge by item type. The cost-to-charge ratio was then applied to each line-item charge to approximate costs for the respective fiscal year. Cost-to-charge ratios from fiscal year 2013 were applied to charges of fiscal year 2014.

Asleep DBS was compared with awake DBS (performed before year 2011). Top cost contributors by revenue category for each method and total cost, length of stay (LOS), and readmissions were compared. Surgical procedures were performed by 1 surgeon (K.J.B.); therefore, provider comparisons are not included.

For benchmarking purposes, OHSU's implantation of intracranial neurostimulator leads were compared with 26 "high-volume" UHC Clinical Database principle member hospitals. Benchmarking analysis was limited to the inpatient procedure associated with DBS: ICD-9 procedure code 0293, "implantation or replacement of intracranial neurostimulator lead." High volume was defined as greater than or equal to 5 procedures per year. Direct cost indices, total cost, volume, and average total cost per discharge between OHSU and UHC institutions were compared. UHC benchmarking data, mean total cost, mean observed di-

TABLE 1. OHSU DBS patient demographics (July 2009–March 2014)

Patient Characteristics	Awake DBS	Asleep DBS	Total
No. of patients (%)	53 (25)	158 (75)	211 (100)
Mean age in yrs (range)	66 (50–82)	64 (27–82)	65 (27–82)
Female (%)	30	42	39
3M Severity of Illness (%)			
Minor	75	81	80
Moderate	25	18	20
Major	0	1	0
Patient status (%)			
Home or self-care	98.1	96.8	97.2
Transferred to home health	1.9	0	0.5
Transferred to skilled nursing facility	0	2.5	1.9
Transferred to a Medicare-certified long-term care hospital	0	0.6	0.5
Primary diagnosis (%)			
Parkinson's disease	71.7	57.6	61.1
Essential and other specified forms of tremor	28.3	38.6	36
Abnormal involuntary movements	0	1.3	0.9
Other*	0	2.5	2
Insurance status (%)			
Medicare	69.8	67.7	68.2
Contracts (private insurance)	30.2	31.6	31.3
Medicaid—Oregon	0	0.6	0.5

* Includes headache, other acquired torsion dystonia, temporal sclerosis, and unspecified drug or medicinal substance causing adverse effect in therapeutic use.

TABLE 2. OHSU DBS cost by all revenue categories (July 2009–March 2014)

Revenue Category	Mean Cost ± SD per Patient ($)	% Utilization*	Mean Cost ± SD per Utilizer ($)†
Medical/surgical supplies	24,011 ± 3492	100	24,136 ± 3087
OR services	7307 ± 1563	100	7307 ± 1563
ICU	2562 ± 1319	84	3037 ± 784
Recovery room	1594 ± 645	100	1602 ± 637
Anesthesia	631 ± 185	100	631 ± 185
Drugs requiring specific identification	544 ± 287	100	510 ± 285
Room & board (semiprivate, 2 beds)	415 ± 1595	13	3245 ± 3317
MRI	380 ± 226	95	401 ± 213
Coronary care	379 ± 979	13	2854 ± 359
Pharmacy	278 ± 126	100	302 ± 142
CT	197 ± 133	78	252 ± 93
Laboratory	192 ± 255	100	192 ± 255
Physical therapy	131 ± 94	91	166 ± 129
Radiology—diagnostic	129 ± 338	30	433 ± 504
Professional fees	92 ± 94	85	108 ± 94
Clinic	72 ± 70	88	82 ± 68
Occupational therapy	69 ± 119	28	173 ± 97
Electroencephalogram	28 ± 295	1	1953 ± 1870
Electrocardiogram	27 ± 17	82	33 ± 13
Respiratory services	21 ± 121	12	172 ± 311
Treatment or observation room	21 ± 177	2	1089 ± 808
Emergency room	16 ± 104	3	485 ± 331
Cardiology	14 ± 60	6	235 ± 80
Pulmonary function	14 ± 9	81	17 ± 7
Speech-language pathology	14 ± 117	3	437 ± 512
Other diagnostic services	9 ± 44	32	29 ± 75
Other imaging services	2 ± 21	1	213 ± 7
Other therapeutic services	1 ± 9	0	137
Laboratory pathological	0 ± 3	1	33 ± 14
Psychiatric/psychological services	0 ± 3	2	17 ± 11
Psychiatric/psychological treatments	0 ± 1	2	7 ± 5
Total	39,152 ± 5340		

* Percentage of patients with costs in the revenue category.
† Mean cost per patient among the patients utilizing the revenue category.

TABLE 3. OHSU DBS outcomes (July 2009–March 2014)

Outcome	Awake + Asleep DBS	Awake DBS	Asleep DBS
No. of patients (%)	211	53 (25)	158 (75)
Mean cost ± SD ($)	39,152 ± 5340	40,052 ± 6604*	38,850 ± 4830*
Mean LOS in days ± SD	1.18 ± 0.76	1.23 ± 0.87	1.16 ± 0.72
No. of readmissions (%)	9 (4.3)	2 (3.8)	7 (4.4)
Mean ICU LOS in days ± SD	0.9 ± 0.5	1 ± 0.5	0.9 ± 0.5
Mean OR time in minutes ± SD	285.85 ± 57.83	282.55 ± 58.55	286.97 ± 57.72
In-hospital deaths (%)	0	0	0
30-day postoperative deaths (%)	0	0	0
30-day postdischarge deaths (%)	0	0	0

* Significant difference between DBS procedures at $p = 0.05$ when adjusted by 3M Severity of Illness. Two-sample variance comparison test, $p = 0.0034$.

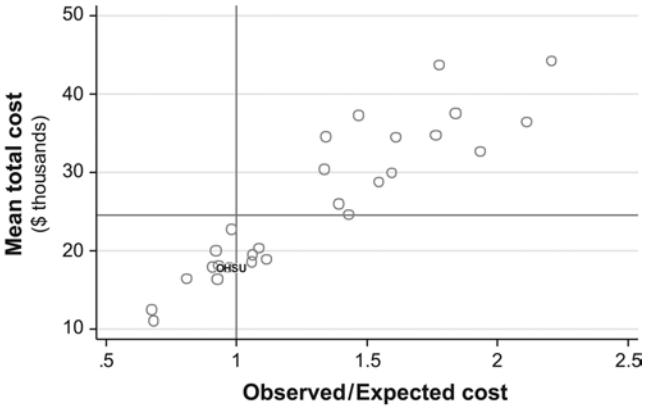

FIG. 1. Scatterplot of cost benchmarking of the ICD-9 code 0293 (neurostimulator implant lead) and adult inpatient cost data from 27 UHC hospitals from January 2011 to March 2014. Data source: UHC.

rect cost, mean expected direct cost, and direct cost index were queried from January 2011 to March 2014. Queries of mean total cost and direct cost index were compared. In these queries, total cost was defined as the sum of direct and indirect costs. Direct costs are costs specifically associated with providing the service or procedure of interest. Indirect costs are those that are related to support services necessary to the procedures and services specified, but not directly related to delivering care. The direct cost index is the observed direct cost over the expected direct cost. Expected direct costs were generated using the UHC 2013 risk adjustment model. Total DBS cost over time was compared with the upper control limit and lower control limit determined by data from the period prior to January 5, 2011, when OHSU still performed awake DBS procedures.

Results

Demographics

Two hundred eleven DBS cases were included in the study period of July 2009 to March 2014. The average patient age was 65 ± 9 years and 39% were women. Overall primary patient diagnosis was Parkinson's disease (61.1%) and "essential and other specified forms of tremor" (36%). The majority of patients (80%) had minor 3M Severity of Illness, and 97.2% were ultimately discharged home or to self-care; 68.2% of patients were covered by Medicare and 31.3% had private insurance coverage (Table 1).

Inpatient and Outpatient Costs Associated With DBS

All revenue categories were sorted by average per patient cost and the percentage of patients who were billed for the revenue category (% utilization). For revenue categories, the amount of variance and mean cost per patient were as expected based on OHSU clinical practice. However, more utilization was expected in certain categories, such as CT. Expected CT utilization was 100%, but actual utilization was 78% (Table 2). Overall, mean DBS cost for both awake and asleep approaches was $39,152 ± $5340. Mean LOS was 1.18 days and readmission rate was 4.3%. The mean OR time was 285.85 ± 57.83 minutes. There were no deaths (Table 3).

Awake Versus Asleep DBS

There were no significant differences in readmissions, LOS, intensive care unit (ICU) LOS, OR time, and cost. Costs included ICD-9 inpatient procedure code 0293 and outpatient costs closely associated with DBS, such as implantation of an IPG (Table 3). The mean cost of asleep DBS ($38,850 ± $4830) was lower than that of awake DBS ($40,052 ± $6604), which was not significant. However, there was a significant difference in the standard deviation ($p = 0.0034$).

Benchmarking DBS: ICD-9 Procedure Code 0293

OHSU's observed cost for implanting a neurostimulator lead was less than the expected cost (ratio 0.97; Fig. 1). In 2013, the average cost of implanting neurostimulator leads at OHSU was $17,150, less than the group median of $34,052 (Table 4). OHSU's cost for these procedures also appeared to be lower than the median among institutions that performed at least 5 of these procedures a year (Fig. 2, Table 4).

Total DBS costs over time were compared, as indicated in Fig. 3 by the awake DBS mean (Fig. 3, grey line) and asleep DBS mean (Fig. 3, black line). One observation (1.85%) is above the upper control limit in the awake period. Three observations (1.88%) exceed 3 times the standard deviation in the asleep period. The mean cost during the period of asleep DBS procedures was lower than that during the period of awake DBS procedures, but was not statistically significant. After adjusting for severity, varia-

TABLE 4. DBS UHC benchmark and OHSU costs*

Variable	Total Cost ($)			
	2010	2011	2012	2013
25th percentile	20,569	22,614	25,129	23,755
Median	26,921	29,153	33,335	34,052
75th percentile	34,692	43,725	43,411	44,930
95th percentile	61,775	66,051	67,613	56,643
OHSU cost	**18,680**	**23,268**	**19,515**	**17,150**
Mean UHC volume (n)	20	36	37	42
Mean OHSU volume (n)	**20**	**57**	**57**	**74**

* Costs are average costs per discharge. Data source: UHC Financial Database 2010–2013; 27 UHC principle members.

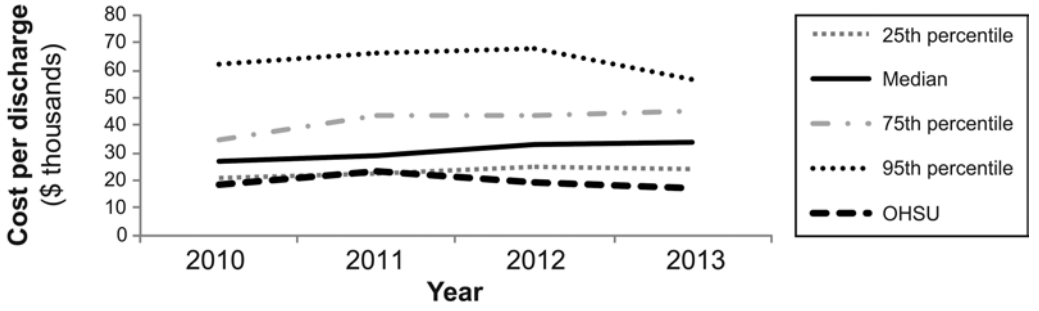

FIG. 2. Percentile average total cost per discharge for ICD-9 code 0293, using adult inpatient cost data from 27 UHC hospitals (2010–2013). Data source: UHC.

tion in cost was lower for asleep DBS when compared with awake DBS, and this difference was statistically significant (Table 3).

Costs by revenue category and DBS procedure were compared in Table 5. The column in the table labeled "Total Cost (%)" indicates the percentage of total cost that is accounted for by the revenue category. After adjusting for severity of illness, the revenue categories indicated a significant difference in average costs by DBS procedure. For example, the per-patient costs of medical or surgical supplies were $26,515 ± $2914 and $23,172 ± $3266 for awake and asleep DBS procedures, respectively. Medical or surgical supplies account for 61.3% of the total cost of DBS procedures. Other revenue categories that were significantly lower for asleep DBS included anesthesia and MRI. Costs of OR services, recovery room, and CT increased with asleep DBS.

Total OR time for implantation of neurostimulator leads was calculated and upper and lower control limits were determined by data from the period prior to January 5, 2011, when awake DBS was performed at OHSU (Fig. 4). The mean OR times of awake DBS versus asleep DBS were compared, as indicated in Fig. 4 by the mean awake (Fig. 4, grey line) and mean asleep (Fig. 4, black line). One observation (1.8%) is above the upper control limit in the awake period. Four observations (2.5%) exceed 3 times the standard deviation in the asleep period. The mean OR time during the asleep period appears to be higher than that during the awake period (Table 3). However, in a severity-adjusted model, this difference was not statistically significant. The difference in variance of OR time by awake versus asleep DBS, after adjusting for severity, remained not significant.

Discussion

There is a growing interest in the use of image guidance[18,21] as an alternative to microelectrode mapping[15] for DBS electrode implantation. We have presented a detailed analysis of the costs of DBS implantation performed under general anesthesia with image guidance at OHSU. We have compared this result to a historical group of patients at OHSU who underwent DBS implantation under local anesthesia with microelectrode guidance. Costs included ICD-9 inpatient procedure code 0293 and outpatient costs closely associated with DBS, such as implantation of an IPG. The results show that there were no differences in readmissions, LOS, ICU LOS, OR time, and cost when these two types of procedures were compared within the same institution.

A more comprehensive understanding of costs associated with DBS requires outpatient and inpatient data. However, for the purposes of this study, obtaining outpatient data from other UHC institutions was not feasible. Despite this limitation, OHSU's cost for these procedures was lower than the median among comparable UHC institutions. We suggest that a comprehensive assessment of costs at high-volume UHC hospitals for these procedures would be interesting and add a higher level of confidence to future cost-effectiveness analyses. We are confident that

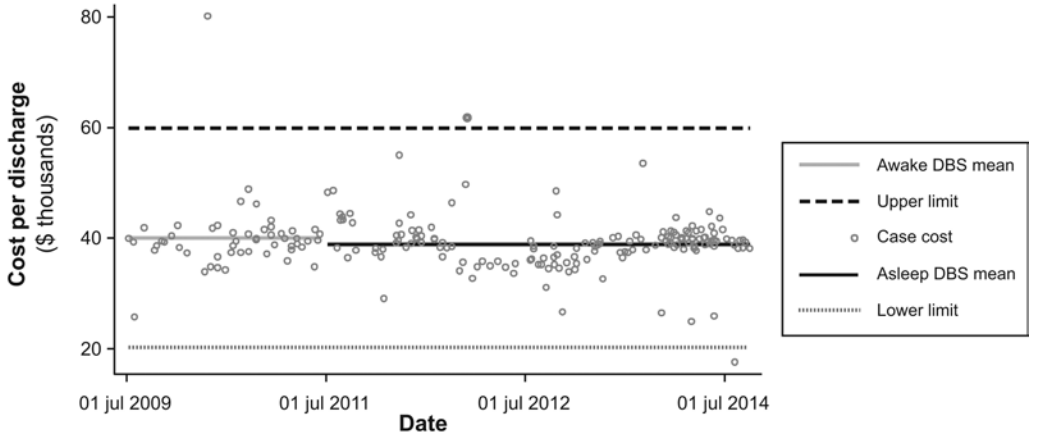

FIG. 3. Total OHSU DBS cost over time with upper and lower 3 standard deviations (July 2009–March 2014). Data source: OHSU.

TABLE 5. OHSU DBS cost per patient by top revenue categories (July 2009–March 2014)

Revenue Category	Mean Awake DBS Cost ± SD ($)	Mean Asleep DBS Cost ± SD ($)	Total Cost (%)	Difference ($)	p Value
Medical/surgical supplies	26,515 ± 2914	23,172 ± 3266	61.3	−3343	<0.001
OR services	6254 ± 1576	7660 ± 1394	18.7	1406	<0.001
ICU	2410 ± 1293	2612 ± 1328	6.5	202	0.582
Recovery room	981 ± 441	1800 ± 568	4.1	819	<0.001
Anesthesia	702 ± 175	608 ± 182	1.6	−94	0.001
Drugs requiring specific identification	511 ± 316	555 ± 277	1.4	44	0.532
Room & board (semiprivate, 2 beds)	470 ± 1806	397 ± 1523	1.1	−73	0.514
Coronary care	214 ± 673	434 ± 1058	1	220	0.099
MRI	602 ± 172	305 ± 190	1	−297	<0.001
Pharmacy	304 ± 144	270 ± 118	0.7	−34	0.116
CT	30 ± 92	253 ± 91	0.5	223	<0.001
Laboratory	182 ± 283	195 ± 246	0.5	13	0.913

cost analysis for DBS will become increasingly important as health care expenditures come under increasing pressure, and as these procedures are more in demand in an aging population.

This study may have limited generalizability, as it shows the experience of a single center; however, the performing surgeon at the center has set the standard for asleep DBS procedure methodology. Furthermore, the effects we show are the effects of the single surgeon performing first awake DBS, then asleep DBS. The differences we see in cost variation may be due to either secular trends or the change in practice from awake to asleep DBS. While we adjust for patient characteristics, it is possible that unmeasured factors may be causing the decrease in cost variation. Another potential bias for this study may include unobserved changes in practice style that could have occurred during the study period; however, this limitation may have been mitigated by the fact that the procedures were performed by the same physician. Practice patterns beyond the change from the awake to the asleep method are unlikely to have varied significantly.

One outcome of this study is that using the asleep DBS strategy, OR time and the cost variation of the procedure appear to be decreasing over time, presumably as the procedure becomes more routine and predictable from the standpoint of imaging and intraoperative workflow. Of course, outcome is the most important aspect of any surgical innovation. The outcome in this particular analysis was cost. We are compiling our clinical outcome statistics, with long-term follow-up, in a subsequent report.

Conclusions

In this single academic medical center cost analysis, DBS performed while the patient was asleep was associated with a lower cost variation relative to the awake procedure. Furthermore, costs for asleep DBS compared favorably to those of high-volume UHC-affiliated institutions.

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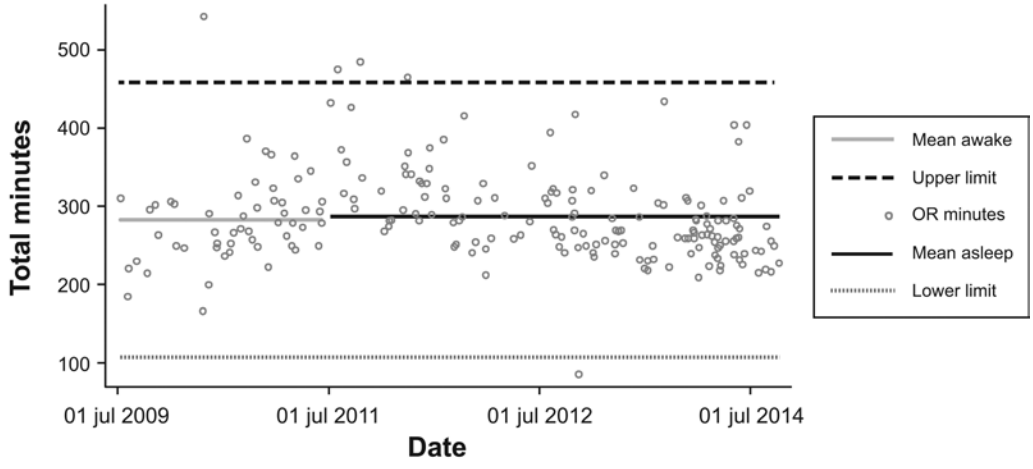

FIG. 4. OHSU OR minutes over time with upper and lower 3 standard deviations (July 2009–March 2014). Data source: OHSU.

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Disclosures

Dr. Burchiel is Founder and President of CereMod, Inc., a medical device company.

Author Contributions

Conception and design: Burchiel. Acquisition of data: Burchiel, Jacob, Geddes. Analysis and interpretation of data: Burchiel, Jacob, Geddes. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Burchiel. Statistical analysis: Jacob, Geddes. Administrative/technical/material support: Burchiel, McCartney. Study supervision: Burchiel.

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