Surgical treatment of adolescent idiopathic scoliosis in the United States from 1997 to 2012: an analysis of 20,346 patients

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OBJECT Adolescent idiopathic scoliosis (AIS) can cause substantial morbidity and may require surgical intervention. In this study, the authors aimed to evaluate US trends in operative AIS as well as patient comorbidities, operative approach, in-hospital complications, hospital length of stay (LOS), and hospital charges in the US for the period from 1997 to 2012.

METHODS Patients with AIS (ICD-9-CM diagnosis codes 737.30) who had undergone spinal fusion (ICD-9-CM procedure codes 81.xx) from 1997 to 2012 were identified from the Kids' Inpatient Database. Parameters of interest included patient comorbidities, operative approach (posterior, anterior, or combined anteroposterior), in-hospital complications, hospital LOS, and hospital charges.

RESULTS The authors identified 20,346 patients in the age range of 0–21 years who had been admitted for AIS surgery in the defined study period. Posterior fusions composed 63.4% of procedures in 1997 and 94.1% in 2012 ($r = 0.95$, $p < 0.01$). The mean number of comorbidities among all fusion groups increased from 3.0 in 1997 to 4.2 in 2012 ($r = 0.92$, $p = 0.01$). The percentage of patients with complications increased from 15.6% in 1997 to 22.3% in 2012 ($r = 0.78$, $p = 0.07$). The average hospital LOS decreased from 6.5 days in 1997 to 5.6 days in 2012 ($r = -0.86$, $p = 0.03$). From 1997 to 2012, the mean hospital charges (adjusted to 2012 US dollars) for surgical treatment of AIS more than tripled from \$55,495 in 1997 to \$177,176 in 2012 ($r = 0.99$, $p < 0.01$).

CONCLUSIONS Over the 15-year period considered in this study, there was an increasing trend toward using posterior-based techniques for AIS corrective surgery. The number of comorbid conditions per patient and thus the medical complexity of patients treated for AIS have increased. The mean charges for the treatment of AIS have increased, with a national bill over \$1.1 billion per year in 2012.

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KEY WORDS scoliosis; pediatric spinal surgery; pedicle screw; hospital charge; complications; spine

ADOLESCENT idiopathic scoliosis (AIS) can cause substantial morbidity in patients and may require surgical intervention.^{1,6,12,14–17,19,21,22,24,25,28,30,31,33} If the condition is left untreated or undertreated, curve progression,¹⁹ pulmonary dysfunction,³³ back pain,²⁵ and negative impacts on self image can occur.²⁶ Providing appropriate treatment for AIS is critical in optimizing long-term clinical outcomes.^{15,17,23,29,31,32}

The surgical care of AIS has been revolutionized by the advent of pedicle screw technology,^{1,3,11,20} surgical navigation,¹⁶ derotation techniques,²¹ arthrodesis enhancement,¹³ and various growing-rod technologies.^{4,6} While long-term health-related quality of life studies are needed to fully understand the effects of operative intervention, outcomes in children following spinal deformity surgery are generally positive.^{1,10,14,15,17,22}

ABBREVIATIONS AHRQ = Agency for Healthcare Research and Quality; AIS = adolescent idiopathic scoliosis; HCUP = Healthcare Cost and Utilization Project; KID = Kids' Inpatient Database; LOS = length of stay.

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Surgical techniques are well described for both the anterior and posterior approach to spinal instrumentation and arthrodesis. Anterior procedures gained popularity in the 1990s and 2000s.^{12,28} In recent years, instrumented posterior fusion has been performed with greater regularity for the treatment of AIS.^{1,14,16,17,20–22} The relative proportion of anterior versus posterior procedures for patients with AIS was previously investigated by Martin et al.,¹⁸ who described the rising use of posterior-based techniques as well as the increasing charges associated with inpatient surgical care, although they did not report comorbidity or complication data.

In the present study, we aimed to evaluate US trends in operative AIS as well as patient comorbidities, operative approach, in-hospital complications, hospital length of stay (LOS), and hospital charges in the US for the period from 1997 to 2012. We hypothesized that the rate of posterior-based surgery would be increasing compared with the rates for anterior-based surgery or a combined approach and that the hospital LOS, charges, and in-hospital complications would be lower in patients who underwent posterior surgery than in those who underwent anterior surgery.

Methods

Data Source

The Healthcare Cost and Utilization Project (HCUP) Kids' Inpatient Database (KID) for the years 1997 to 2012 was used for this study. This database was developed by the US Agency for Healthcare Research and Quality (AHRQ) as part of a partnership among industry, federal, and state agencies to help track and analyze trends in health care utilization, cost, quality, and outcomes. The KID contains national estimates of hospital inpatient stays for patients younger than 21 years of age and includes discharges from over 4000 US hospitals annually. The KID data are available every 3 years from 1997 to 2012 and comprises up to 7 million patients annually from 44 states. Procedure and diagnostic codes are classified according to the ICD-9-CM. Patient-specific demographic data and hospitalization information coded by synthetic identifiers are also available.

Patient Selection

We performed a retrospective analysis using hospital discharge data from the KID for the period from 1997 to 2012. Using IBM SPSS statistics software and the ICD-9-CM diagnosis codes, we identified children with a diagnosis of idiopathic scoliosis (737.30). Patients with any of the following ICD-9-CM procedure codes were included in the study: cervical level, 81.02, 81.03, 81.32, 81.33; thoracolumbar level, 81.04, 81.05, 81.34, 81.35; and lumbosacral level, 81.06, 81.07, 81.08, 81.36, 81.37, 81.38. Patients were also separated into those who underwent anterior spinal fusion (81.02, 81.04, 81.06, 81.08, 81.32, 81.34, 81.36, 81.38) and those who underwent posterior fusion (81.03, 81.05, 81.07, 81.33, 81.35, 81.37). Those who underwent both an anterior and posterior fusion were included in a separate cohort.

Patient Demographics

We examined patient mortality, number of assigned discharge diagnoses, hospital LOS, expected primary payer (Medicare, Medicaid, private insurance, self-pay, or no charge), and total hospital charge in US dollars. Dollar figures were adjusted to 2012 values utilizing the US Department of Labor Bureau of Labor Statistics Inflation Calculator (http://www.bls.gov/data/inflation_calculator.htm).

Complications were noted if any of the following diagnoses were made during a patient's hospitalization: accidental puncture or laceration of the dura mater during a procedure (749.31), nervous system complication (997.01, 997.02, 997.09), operative field and wound management complication (998.11, 998.12, 998.13, 998.30), deep venous thrombosis or pulmonary embolus complication (415.11, 415.12, 415.13, 415.19, 453.40, 453.41, 453.42, 453.81, 453.82, 453.83), infectious complication (998.51, 998.59, 486, 599.0; which was further divided into wound infection, pneumonia, and urinary tract infection), and any complication or blood loss that required transfusion of packed cells (99.04).³⁴

Data Analysis

Patients in the cohort who were 18 years or younger were used to determine the incidence of spinal deformity surgery per year. Using a weighted KID population calculation determined by the AHRQ, we figured national estimates for children younger than 18 years who had undergone AIS fusion surgery. The US population 18 years and under was determined from the US Census Bureau. Other than incidence calculations, the research protocol included patients 21 years and younger because we determined that the majority of patients undergoing these operations were most likely to have AIS before the age of 18 years.

Patients who underwent anterior column fusion, posterior column fusion, and combined anteroposterior column fusion were separated within each year and compared in terms of mortality, number of discharge diagnoses, LOS, in-hospital complications, and hospital charges. Mean total charges for each year were adjusted for inflation according to year 2012 values. The proportion of predicted primary payer type was also analyzed. A linear regression of mean hospital charges for all inpatient admissions in the KID, regardless of diagnosis, was trended to examine health care "inflation" over time. This group represented any child admitted to the hospital and served as a control to compare charges for undergoing fusions in a temporal relationship.

A statistical analysis of continuous and categorical outcome variables was performed using unpaired t-tests and chi-square tests with Yates' correction. Linear regression analysis was completed using Pearson correlation coefficients with 2-sided p values with a statistical cutoff of $p < 0.05$, set a priori. Crude odds ratios with 95% confidence intervals and z statistics were determined where appropriate with a statistical cutoff of $p < 0.05$, set a priori. Statistical analysis was performed using SPSS version 22 (IBM Corp.).

Results

Study Cohort

We identified a total of 20,346 patients in the age range of 0–21 years who had been admitted for inpatient surgery for AIS from 1997 to 2012 (Table 1). Within this cohort, a subpopulation of 18,649 patients was 18 years or younger. The incidence of pediatric surgery for AIS increased from 0.58 admissions/10,000 individuals in 1997 to 0.74 admissions/10,000 individuals per year in 2012 ($r = 0.91$, $p = 0.01$). The mortality rate was under 0.3% for all years examined. The mean number of discharge diagnoses increased from 3.0 in 1997 to 4.2 in 2012 ($r = 0.92$, $p = 0.01$). The average hospital LOS decreased from 6.5 days in 1997 to 5.6 days in 2012 ($r = -0.86$, $p = 0.03$).

Expected Payer and Hospital Charges

Private insurers were the expected payer in 75% of admissions in 1997, a rate that decreased to 63% in 2012 ($r = -0.96$, $p < 0.01$; Fig. 1). Medicaid was the next most common expected payer, covering 17.7% of admissions in 1997 and increasing to 29.9% in 2012 ($r = 0.99$, $p < 0.01$).

In the 15-year study period, the mean hospital charges

for the surgical treatment of AIS, adjusted to 2012 US dollars, more than tripled from \$55,495 in 1997 to \$177,176 in 2012 ($r = 0.99$, $p < 0.01$; Fig. 2). In comparison, in the control group of all admissions in the KID database, there was a lower increase of just 2-fold from \$13,416 in 1997 to \$31,159 in 2012.

The estimated national aggregate of inpatient charges for all pediatric patients undergoing surgery for AIS was \$228 million in 1997 compared with \$1.132 billion in 2012, a more than 4-fold increase in national charges.

AIS Corrective Surgery Complications and Mortality

The complication rate increased from 15.6% in 1997 to 22.3% in 2012 ($r = 0.78$, $p = 0.07$). The primary etiology for inpatient complications after the correction of AIS was transfusion of cells, which occurred at an incidence of 11.1% in 1997 and increased to 19.5% in 2012 ($r = 0.70$, $p = 0.12$). An infectious complication, which included pneumonia, urinary tract infection, or wound infection, was the second most likely complication. The rate of patients with infectious complications ranged from 2.8% in 1997 to 2.1% in 2012 ($r = 0.75$, $p = 0.09$). Operative field and wound management complications (such as excessive

TABLE 1. Patients with AIS undergoing surgical fusions*

Parameter	Year					
	1997	2000	2003	2006	2009	2012
No. of patients w/ surgical correction	1783	2383	3069	3550	4333	5228
Mean LOS in days†	6.5 (±5.2)	6.2 (±3.9)	6.6 (±6.2)	6.0 (±5.1)	5.7 (±4.9)	5.6 (±5.7)
Mean no. of discharge diagnoses‡	3.0 (±2.3)	2.9 (±2.4)	3.1 (±2.4)	3.3 (±2.9)	3.6 (±3.2)	4.2 (±3.7)
Patients w/ complications (no.)	15.65% (279)	19.22% (458)	23.13% (710)	24.03% (853)	27.03% (1171)	22.32% (1167)
Mortality (no.)	0.22% (4)	0.17% (4)	0.13% (4)	0.09% (3)	0.02% (1)	0.10% (5)
Anterior fusion						
Patients (no.)§	21.8% (388)	23.6% (562)	19.0% (584)	13.6% (484)	8.8% (383)	3.3% (171)
Mean LOS in days	6.4 (±4.7)	6.3 (±4.4)	6.4 (±5.3)	5.8 (±3.4)	5.6 (±7.4)	6.5 (±8.5)
Mean no. of discharge diagnoses¶	3.0 (±2.1)	2.8 (±2.1)	3.2 (±2.4)	3.4 (±2.7)	3.6 (±2.8)	4.7 (±4.0)
Patients w/ complications (no.)**	15.2% (59)	12.6% (71)	18.8% (110)	19.4% (94)	19.3% (74)	20.5% (35)
Posterior fusion						
Patients (no.)††	63.4% (1130)	62.1% (1480)	65.6% (2013)	76.7% (2722)	85.4% (3700)	94.1% (4917)
Mean LOS in days	5.8 (±3.0)	5.6 (±2.7)	5.9 (±4.2)	5.8 (±5.0)	5.5 (±3.9)	5.4 (±5.0)
Mean no. of discharge diagnoses‡	2.8 (±2.1)	2.7 (±2.2)	2.9 (±2.2)	3.1 (±2.7)	3.5 (±3.1)	4.1 (±3.6)
Patients w/ complications (no.)	14.5% (164)	18.8% (278)	21.7% (436)	23.2% (633)	27.3% (1010)	22.0% (1080)
Anteroposterior fusion						
Patients (no.)‡‡	14.9% (265)	14.3% (341)	15.4% (472)	9.7% (344)	5.8% (250)	2.7% (140)
Mean LOS in days	9.8 (±10.1)	8.4 (±6.2)	10.1 (±11.2)	8.3 (±6.9)	9.0 (±9.7)	10.2 (±15.7)
Mean no. of discharge diagnoses§§	4.3 (±3.3)	4.2 (±3.1)	4.1 (±3.0)	5.1 (±3.7)	5.9 (±4.3)	6.4 (±4.4)
Patients w/ complications (no.)¶¶	21.1% (56)	32.0% (109)	34.8% (164)	36.6% (126)	34.8% (87)	37.1% (52)

* Values expressed as the mean (standard deviation), unless indicated otherwise.

† $r = -0.86$, $p = 0.03$.

‡ $r = 0.92$, $p = 0.01$.

§ $r = -0.96$, $p < 0.01$.

¶ $r = 0.88$, $p = 0.02$.

** $r = 0.82$, $p = 0.04$.

†† $r = 0.95$, $p < 0.01$.

‡‡ $r = -0.92$, $p = 0.01$.

§§ $r = 0.91$, $p = 0.01$.

¶¶ $r = 0.81$, $p = 0.05$.

FIG. 1. Primary payer of inpatient admission charges for surgical care of patients with AIS treated using spinal fusion. Figure is available in color online only.

hemorrhage, hematoma, or seroma within the operative field) or wound disruption occurred at an incidence of 2.4% in 1997 but decreased to 1.7% in 2012 ($r = -0.81$, $p < 0.05$). Other complications such as iatrogenic dural tear and/or CSF leakage, neurological injury, deep vein thrombosis, or pulmonary embolus all occurred at incidences $< 1.0\%$ for all years studied.

In the 15-year study period, 21 patients died during hospitalization after surgical treatment for AIS. The mortality rate decreased from 0.22% in 1997 to 0.10% in 2012 ($r = -0.86$, $p = 0.03$). In comparison with the surviving cohort, the OR of death after transfusion was 2.51 (95% CI 1.03–6.05, $p = 0.04$); after infection, 6.95 (95% CI 2.04–23.67, p

< 0.01); and after an operative field or wound management complication, 11.63 (95% CI 3.90–34.72, $p < 0.01$).

Anterior Versus Posterior Spinal Fusions

The rate of anterior fusions decreased from 21.8% of procedures in 1997 to 3.3% in 2012 ($r = -0.96$, $p < 0.01$; Table 1). Conversely, posterior fusions increased from 63.4% of procedures in 1997 to 94.1% in 2012 ($r = 0.95$, $p < 0.01$; Fig. 3).

Hospital LOS in patients who underwent anterior fusion ranged from 6.4 days in 1997 to 6.5 days in 2012 ($r = -0.32$, $p = 0.54$). In patients who underwent posterior fusions, the LOS ranged from 5.8 days in 1997 to 5.4 in 2012

FIG. 2. Mean hospital charges for each child undergoing surgery for AIS. All charges were adjusted for inflation according to year 2012 values. "Any inpatient admission" refers to the control group. Figure is available in color online only.

FIG. 3. Adolescent idiopathic scoliosis treated with anterior fusion, posterior fusion, or anteroposterior fusion, 1997–2012. Figure is available in color online only.

($r = -0.65$, $p = 0.16$; unpaired t-test with $p < 0.01$; Table 1). The mean number of discharge diagnoses for patients who underwent an anterior fusion ranged from 3.0 in 1997 to 4.7 in 2012 ($r = 0.88$, $p = 0.02$). The mean number of discharge diagnoses for patients who underwent posterior fusions ranged from 2.8 in 1997 to 4.1 in 2012 ($r = 0.92$, $p = 0.01$; unpaired t-test with $p = 0.03$).

Mean charges for patients admitted for anterior and posterior fusions were \$53,453 and \$49,424, respectively, in 1997 (unpaired t-test with $p < 0.0001$; Fig. 2). In 2012, the mean charges for patients admitted for anterior and posterior fusions were \$167,130 and \$175,570, respectively (unpaired t-test with $p = 0.291$).

In 1997, anterior fusions were associated with a complication rate of 15.2% compared with 14.5% for posterior fusions ($p = 0.80$). In 2012, the complication rates were 20.5% and 22.0%, respectively ($p = 0.71$). Blood transfusions were the most commonly reported complication for patients in both the anterior and posterior fusion groups. In 1997, anterior fusions were associated with a transfusion rate of 11.3%; posterior fusions, with a transfusion rate of 17.5% ($p = 0.01$). In 2012, transfusion rates for anterior and posterior fusions were 15.8% and 19.3%, respectively ($p = 0.30$). Infection was the second most common complication in the 2 groups. In 1997, anterior and posterior fusions were associated with infection rates of 2.6% and 4.4%, respectively ($p = 0.14$); in 2012, the infection rates were 4.7% and 2.0%, respectively ($p = 0.03$). The mortality rate associated for the 2 groups was 0.08% and 0.06%, respectively, over the 15-year study period ($r = -0.19$, $p = 0.71$).

Combination Anteroposterior Spinal Fusions

Patients who underwent combined anteroposterior spinal fusions composed 14.9% of those with spinal deformity in 1997, compared with only 2.7% in 2012 ($r = -0.92$, $p = 0.01$; Fig. 3). These patients were also found to have a longer LOS, more diagnosed conditions, and higher hospital charges, which were all significant when comparing within the anterior and posterior fusion subgroups ($p = 0.0001$ for all). Hospital LOS for patients undergoing the combination fusion ranged from 9.8 in 1997 to 10.2 in 2012 ($r = 0.13$, $p = 0.81$; Table 1). The number of comorbid

conditions in patients who underwent anteroposterior fusion increased from 4.3 in 1997 to 6.4 in 2012 ($r = 0.91$, $p = 0.01$). Hospital charges for patients who underwent an anteroposterior fusion were \$84,376 in 1997 and \$246,298 in 2012 (Fig. 2). In terms of complications, 21.1% of patients in 1997 had at least one complication; when compared with aggregate anterior and aggregate posterior fusions, there was a significant difference (unpaired t-test with $p = 0.01$). In 2012, the complication rate in those who underwent anteroposterior fusion was 37.1% ($p < 0.0001$). Over time, the percentage of patients with a complication from this combination surgery increased significantly ($r = 0.81$, $p = 0.05$). The mortality rate for patients who underwent anteroposterior fusion was 0.5%, which was significantly higher than the rate for those who underwent isolated anterior or posterior fusion (0.06%; $p < 0.0001$).

Discussion

In this study we evaluated US trends in the surgical treatment of AIS from 1997 to 2012. The study revealed an increased rate of surgery for AIS as well as an increase in the use of posterior-based surgical techniques, the number of patient comorbidities, and the inflation-corrected mean hospital charges over time.

A previous study by Martin et al. examined patients with AIS and reported findings that support our conclusions that posterior-based techniques are increasing compared with anterior and anteroposterior techniques and that surgical care of AIS is becoming more costly.¹⁸ We also examined comorbid conditions in this population and found an increasing trend toward more comorbid conditions in all patients with AIS who underwent corrective surgery. Throughout the 15-year study period, patients who underwent anteroposterior fusion had the greatest number of comorbid conditions, whereas patients who underwent posterior fusions had the fewest such conditions. Patients who underwent anteroposterior fusion may have had more severe spinal curves, which could lead to comorbid conditions, although this assertion cannot be proven with billing (HCUP KID) data alone.

A systematic review³⁰ by Weiss and Goodall revealed a complication rate from scoliosis surgery ranging from 0% to 89%. Potential explanations for the wide range of reported rates include heterogeneity in the patient populations, the lack of a standard definition of complication, and variable follow-ups. Their investigation revealed in-hospital complication rates of 6.3%–17.8%, depending on the year examined and the surgical approach. Patients who had undergone the anteroposterior fusion had the highest complication rates. These data further suggest that patients who undergo anteroposterior fusion represent a more medically complex group. In 1997, patients with AIS who had undergone anterior fusions had more complications than those who had undergone posterior fusions. In each successive year studied, however, a higher complication rate was reported for patients who underwent posterior fusion. This result is probably explained by the higher transfusion rate associated with posterior fusions.

Hospital inpatient charges for AIS admissions increased from 1997 to 2012, even after adjusting for inflation. It is

estimated that the inpatient hospital charges for surgical treatment of AIS nationwide was more than \$1.1 billion in 2012 alone. Anteroposterior fusions were associated with the highest hospital charges over the 15-year study period. This may be attributable to a higher complication rate, longer LOS, and larger patient population. Posterior fusions were associated with the second highest hospital charges, and anterior fusions were the least costly. Posterior fusions for AIS corrective surgery generally employ more instrumentation as they include longer segments of fixation than anterior fusions,¹² which probably plays a role in the higher cost of these procedures.

The 2.8-fold increase in the mean hospital charges for AIS surgery is alarming but may be explained by general health care inflation. To examine this possibility, we investigated all patients within the KID, regardless of admission diagnosis. We identified a 1.9-fold increase in hospital charges for all-comers, compared with the 2.8-fold increase for AIS surgery. Furthermore, the increase in charges for patients with AIS appears to be greater than that for patients undergoing other spine procedures.⁷ For example, in a review of patients with C-2 fracture who had undergone surgical procedures, Daniels et al. found that mean charges increased from \$70,781 in 2000 to \$133,064 in 2010, a 1.9-fold increase over 11 years. This finding is in contrast to the nearly 3-fold increase in charges for patients with AIS. These rises in charges may be caused, at least in part, by the increased use of advanced technology such as dense pedicle screw constructs, surgical navigation, and recombinant human bone morphogenetic protein utilization.^{1,13,16,17,20}

The trend toward posterior-based surgical techniques may be attributed to a number of different factors, including a perception of fewer complications^{2,5} and decreased LOS⁹ associated with segmental posterior instrumentation procedures. Furthermore, ongoing advances in posterior instrumentation technology have increased the ability to correct severe deformity through posterior techniques with 3-column osteotomies such as vertebral column resection. And because posterior surgical approaches for spine deformity surgery have become more popular, future spine surgeons may receive less training in anterior or anteroposterior techniques, which will further propagate this phenomenon.

This study has several potential limitations. The HCUP KID is based on billing data. An examination of curve severity or a detailed analysis of patient complexity was not possible. Care should be taken when comparing the cost and complications of posterior versus anterior surgery, as the posterior fusion group may represent a healthier population with less severe spinal deformity. Additional inherent limitations of the HCUP database include a lack of outpatient data, a probable underestimation of inpatient complications, and a lack of complete granularity regarding the severity of illness and the surgical techniques performed.^{8,27,34} Furthermore, hospital charge data do not equate to hospital cost data; hospital charges have been increasing more rapidly than costs.⁷ Despite these limitations, the data remain important as a basis for further investigation into trends in the surgical treatment of AIS and the rising charges associated with these procedures.

Conclusions

In summary, over the course of a 15-year study period, the proportion of posterior fusions performed for AIS increased compared with anterior and anteroposterior procedures. Mean charges for the treatment of AIS increased, with a national bill of more than \$1.1 billion per year in 2012. The number of comorbid conditions per patient and thus the medical complexity of patients treated for AIS have increased. Further studies are needed to evaluate the implications, both financial and clinical, of the trend toward posterior-only fusions for AIS corrective surgery.

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Conception and design: Vigneswaran, Grabel, Eberson, Daniels. Acquisition of data: Vigneswaran. Analysis and interpretation of data: Vigneswaran, Grabel, Daniels. Drafting the article: Vigneswaran, Grabel, Daniels. 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: Vigneswaran. Statistical analysis: Vigneswaran. Administrative/technical/material support: Daniels. Study supervision: Daniels.

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