The higher costs associated with teaching hospitals have received some attention in the literature. The objective of the current study was to determine the increase in resource consumption associated with resident education in knee arthroplasty surgery. Seventy-four patients who underwent primary total knee arthroplasty in the same hospital were studied (50 private practice and 24 teaching practice). Time in the operating room and medical severity of illness were noted. Hospital charges were used as a measure of resource consumption. In addition, length of stay and in-hospital consultations and complications were observed. Kruskall-Wallis, chi square, and stepwise multiple regression analysis were performed. The mean age of the patients was 68 years. Patients who underwent surgery at the teaching service had higher charges ($30,311 versus $23,116) and longer times in the operating room (190 minutes versus 145 minutes). These patients also had a trend toward more associated comorbid medical conditions (0.71 versus 0.42). Stepwise multiple regression analysis showed that teaching was the most important predictor of charges and operating room time. The results show a 22% increase in perioperative resource consumption for patients who underwent surgery at a teaching service. The measured increase in cost is significantly lower than what has been reported in other series (82%). At the teaching institution, the anesthesia and orthopaedic surgery residents work together on all cases and perform a significant percent of the procedures under direct supervision. The increased resource consumption observed in a teaching service is most likely attributable to the hands-on approach taken to train residents.

The cost of training medical students has received much attention in the literature. It has been estimated that on the average, society pays between $50,000 and $90,000 to train a medical student. For the most part, these funds are obtained through a combination of tuition and federal funds. The cost of training residents also has received some attention. The direct costs of training residents has been estimated to be approximately between $7500 and $185,000 per resident per year.4

The total amount of money spent in the United States on direct graduate medical education costs for 1997 exceeded 18 billion dollars. These dollars currently are obtained from Medicare, Medicaid, the Department of Defense, and the Department of Veterans’ Af-
The majority of the funds, however, come from Medicare. These funds get paid to the health system through two basic mechanisms: direct and indirect graduate medical education payments. Direct payments for graduate medical education generally are calculated on a per resident amount determined on a formula stipulated in 1984 as reported by Asplin and Schafermeyer in 1998. These funds are paid directly to the hospital and are based on a percent of the hospital inpatients they accounted for by Medicare beneficiaries. Direct costs generally cover residents’ monthly salaries, administrative expenses, and institutional overhead. In 1997, these payments totaled 2.2 billion dollars. Indirect medical education dollars are based strictly on the number of full time equivalent residents trained at that particular teaching institution. The total number of dollars paid to teaching hospitals in indirect medical education adjustments totaled 4.6 billion dollars in 1997. In most orthopaedic surgery programs, the professor who does the training, receives no money for teaching.

Total knee replacement is a procedure that is widely performed throughout the world. It was estimated that in 1998, more than 500,000 total knee replacements were performed. Although most surgeons teaching arthroplasty of the knee have little to no formal training in education, the United States continues to produce some of the best knee surgeons in the world.

The cost of training a resident has been estimated in several disciplines. The calculation of these costs usually involves a significant amount of assumptions. These studies are the subject of much controversy. After a thorough search of the literature the authors were unable to find a study in which the resource consumption of teaching elective orthopaedic procedures was reported. The objective of the current study was to assess resource consumption in resident education in total knee arthroplasty surgery.

MATERIALS AND METHODS

Seventy-four consecutive patients admitted to the authors’ hospital for elective unilateral knee arthroplasty were included in this study. All surgeries were performed between January 1, 1997 and December 31, 1997 in one of two services (50 private services and 24 teaching services). The mean age of the patients was 68.6 years ± 1.3 (± standard error) (range, 31–90 years; median, 70 years), and 47 of these patients were women (63.5%). Preoperative diagnoses included osteoarthritis in 68 patients (92%) and rheumatoid arthritis in six (8%). Three board certified orthopaedic surgeons (two private practitioners and a full-time faculty member at the authors’ institution) performed all the surgeries.

Data were collected prospectively using a standard questionnaire before admission for surgery for patients undergoing surgery in the academic service or from medical charts for those patients in the private service.

Standard preoperative laboratory tests were performed on all patients. For each patient, medical severity of illness was assessed using the Charlson Comorbidity Index. This index takes into account the number and the severity of medical diseases that patients presented at the time of surgery. Each disease is given a weight score, and the total score for the index is obtained by adding the individual scores. Resulting data collected from the comorbidity index were grouped into three categories depending on the total score (0, 1, and 2 or more), and analyzed as an ordinal variable.

Hospital charges were provided by the authors’ institutions chief financial officer and were used as a measure of resource consumption. Length of stay, number of inhospital consults, and the presence of complications during the patient’s stay in the hospital also were collected from hospital charts. Complications were defined as events that occurred during surgery and in-hospital recovery that could increase resource consumption, lead to a specialist in-hospital consult, or increase length of stay. Length of stay was divided into four categories: 0 to 3, 4 to 6, 7 to 9 and greater than 10 days. Likewise, three categories were used for the number of in-hospital consults: 0, 1, and 2 or more.

Statistical Methodology

Statistical analysis was performed using SPSS 9.0 software (SPSS Inc, Chicago, IL). The normality of the distribution of the continuous variables was assessed before any analysis and, if necessary, the data were transformed or nonparametric methods.
were used. Independent groups were compared using either the t test or analysis of variance (ANOVA) or the nonparametric counterparts of these tests, the Mann-Whitney or the Kruskall-Wallis test. To assess associations between discrete variables, chi square analyses were used. Multiple linear regression was used to assess, after adjusting for relevant covariates, the effect of the collected variables on resource consumption and surgical and anesthesia time. A p < 0.05 was considered statistically significant.

RESULTS

Seventy-four consecutive patients who underwent unilateral total knee replacement at the senior authors’ institution were included in the current study. Thirty patients (40.5%) had their right knee replaced and 44 patients (59.5%) had their left knee replaced. Twenty-three patients (31.1%) had general anesthesia and 51 (68.9%) had regional anesthesia.

The average charge for all patients was $25,450 ± $551 standard error (range, $18,985–$37,722; median, $23,723), with an average length of hospital stay of 4.6 days ± 0.16 standard error, mean number of inpatient consults of 0.47 ± 0.06 standard error, and average anesthesia and surgical times of 160.4 minutes ± 3.9 standard error and 87 minutes ± 3.9 standard error, respectively. For the 74 patients, the overall rate of complications directly related to the surgical procedure was 8.1%. These included two episodes of confusion, one arthrofibrosis, and one fracture in the patients treated in the academic service and one excessive bleeding episode and one patellar dislocation in the patients treated in the private service. The average number of comorbid diseases present in the groups was 0.46, and the average comorbidity index score was 0.51.

Table 1 shows the age and short-term outcome parameters for each of the patients undergoing surgery for each service. There were statistically significant differences with respect to operating room time (p < 0.001) and hospital charges (p < 0.001) (Figs 1,2). Patients treated in the academic service had approximately 40% more comorbid medical conditions when compared with patients treated in the private service. However, this was not statistically significant (p = 0.3). The lack of statistical significance in this comparison and some of the other variables may be attributable to the small sample size in both groups.

Multiple stepwise regression analysis was performed using charges and an operating room time as the dependent variable and age, gender, body mass index, preoperative diagnosis, service (academic or private), procedure, comorbid medical conditions, length of stay, and number of inhospital consults as independent variables. Variables that fit the model in order, were service (β coefficient = −474.5 ± 683 standard error, p < 0.001), length of stay (β coefficient = 137.2 ± 191 standard error, p < 0.001), operating room time (β coefficient =

<table>
<thead>
<tr>
<th>TABLE 1. Age and Short-Term Outcome Parameters For all Patients and For Patients Per Surgical Service</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable</strong></td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Charges</td>
</tr>
<tr>
<td>Number of consults</td>
</tr>
<tr>
<td>Length of stay (days)</td>
</tr>
<tr>
<td>Time in operating room</td>
</tr>
<tr>
<td>Comorbid index</td>
</tr>
<tr>
<td>Complications</td>
</tr>
</tbody>
</table>

*p value by chi square of dichotomized variables; (mean ± standard error).
5.4 ± 9.7 standard error, p < 0.001), age (β coefficient = −5.5 ± 22.4 standard error, p = 0.017), and number of inpatient consults (β coefficient = 1047.7 ± 468 standard error, p = 0.029) when charges was the dependent variable. Service was the most important predictor of operating room time when this variable was used as the dependent variable (β coefficient = −5.6 ± 4.5 standard error, p < 0.001).

DISCUSSION

The data clearly show that resource consumption as measured by hospital charges (Fig 1) was significantly higher in patients treated in the academic services when compared with patients treated in the private services. The academic service consumed an average of $30,311 per admission whereas $23,116 (22% increase, p < 0.001) was consumed per admission in the private service. The increase in charges observed in the cohort is mostly attributable to the increased time spent in the operating room. The total time spent in the operating room was higher for patients treated in the academic service by approximately 50 minutes (statistically significant p < 0.001). This period is a combination of the operative and anesthesia times.
There are significant costs associated with having a trainee perform the actual procedure. In addition, the attending surgeon tends to spend more time explaining the procedure when a resident is observing. It has been reported that anterior cruciate ligament reconstruction takes up to twice the amount of time when a resident is in the room. At the authors’ institution, the participation of the anesthesia teaching service in all procedures probably accounts for part of the large discrepancies observed in the operating room time between the cohorts (Fig 2). This is shown by an increased anesthesia time when comparing perioperative times between the two groups (p < 0.004). Orthopaedic residents in the authors’ program perform a significant percent of all procedures. Anesthesia residents attempt most of the spinal procedures and perform a significant number of the intubations.

The increase in resource consumption reported excludes the value of the surgeon’s time. This is an important undervalued resource consumed in the training process that is neglected in most of the studies that estimate the cost of graduate medical education. The same attending surgeon without a resident probably would be able to perform twice as many procedures in the amount of time devoted to teaching a resident how to do the procedure.

Increase in the severity of illness often has been reported as the main reason to justify the increase in costs observed in teaching institutions. The comorbid index measured within patients treated in the academic service showed a trend to higher values when compared with patients treated in the private service (0.71 versus 0.42; p = 0.3). However, this figure was not statistically significant (Fig 3). The number of patients involved in the study is too small to make any conclusive statements regarding medical severity of illness between the cohorts.

The complication rate observed was also apparently higher in the patients treated in the academic service but this figure was not statistically significant. Defining complication rates in joint replacement remains controversial. Episodes of confusion are relatively common in the elderly and seldom have any long-term sequelae. According to the authors’ definition of a complication, if the period of confusion led to a laboratory work up or a neurologic or psychiatric consultation, it increased the resource consumption.

In addition, the teaching service had an apparent increase in the average of hospital consultations, 0.54 versus 0.44 (Fig 4, p > 0.05). Some of the patients operated on by the teaching service had received little medical care in the past. Some conditions such as diabetes were

**Fig 3.** The mean comorbidity index score for patients treated in the private and academic services is shown (p = 0.3).
identified during the patient’s stay in the hospital. Most of the perioperative treatment of patients is done by the residents with moderate supervision. On occasion, a problem that is resolved without difficulty by a private attending orthopaedic surgeon is consulted to a specialty team before the attending surgeon on the teaching service is notified. It is not uncommon in certain teaching services within all orthopaedic departments to have the resident reprimanded for not consulting a specialty team when a specific symptom occurs.

Taylor et al. reported on 802 patients who were admitted to the hospital for hip fractures. They determined that teaching hospitals cost the government 17% more than nonteaching hospitals. The reasons for the increased costs were attributed to various factors. Physicians in training have been shown to order more tests and contribute to the increased costs reported in teaching facilities. A junior medical resident asked to clear a patient for surgery is more likely to order unnecessary tests than an experienced internist. The mortality rate on the patients reported by Taylor et al. showed a significant advantage associated with treatment in the teaching hospital. The hazard ratio reported for patients treated in the teaching hospital was .54 when compared with .37 to .79 for patients treated in the nonteaching service.

Implant selection also has been reported to affect total costs and resource consumption in elective procedures. (Lavernia CJ, Lyons R: Economic implications of prosthetic selection in hemiarthroplasty of the hip. Presented at the American Academy of Orthopaedic Surgery, New Orleans, LA, 1991). At the authors’ institution, a contract with implant vendors exists. The contract is structured in such a way that the effects of implant selection in resource consumption are neutralized through volume discounts and per case capitation.

Length of hospital stay has been reported to be the most important determinant of resource consumption. The overall length of stay in the authors’ institution was not different for both services (Fig 5). Most of the patients undergoing arthroplasty at the authors’ institution are transferred to a rehabilitation unit. These practice patterns were similar in both cohorts studied.

The specific techniques used to teach residents how to perform a procedure vary widely from institution to institution. Surgical simulators have been used in the medical and the surgical specialties. In orthopaedic surgery the use of saw bones in joint replacement is widespread. However, in the day to day functioning of most academic programs very little simulation actually occurs before the performance of surgical procedures. The common

![Fig 4. The mean inpatient consults for patients treated in the academic and private services is shown (p = 0.24).](image-url)
saying of watch one, do one, and then teach one is widespread in most teaching hospitals. This is particularly true in most public hospitals in which the amount of work exceeds the time available. The senior author recalls a time in his training in which a procedure was done at night with no supervision and the manual for “the gizmo du Jour” was open in the back table of the operating room.

At the authors’ institution, the residents are instructed to read orthopaedic textbooks delineating the specific steps of the procedure. These books are made available to them and include general orthopaedic operative textbooks and subspecialty joint replacement textbooks. Subsequent to this, videos and compact disc technology are provided to review the procedure. Residents observe the attending surgeon doing three to four cases with gradual assumption of responsibility during the surgical intervention. At the end of the eighth week on the joint replacement rotation, most of the senior residents are doing all the primary procedures. The attending surgeon is present when every implant is inserted.

In some well known large joint replacement services, the residents observe at all times. In some institutions, the attending surgeons even close the incisions. In other teaching programs the attending surgeon is not in the room when the implants are placed. Whether observation with little participation or solo participation is the best technique to train surgeons remains to be determined. As surgical educators, professors should assess the effectiveness of various methodologies. Evaluation of teaching modalities is extremely difficult. One of the main criteria used by the American Board of Orthopedic Surgery to evaluate training programs is the pass rate in the National Orthopedic Boards and the Orthopedic in Training Examination scores. With the advent of mass data storage and virtual reality simulators it soon will be possible to objectively assess the effectiveness of surgical training methodology. However, the skill of academic surgeons is variable. Evaluation of the teachers also is an extremely important and often neglected factor in training programs.

The authors think that the teaching institutions in the United States are among the finest in the world. Numerous government and business world leaders from very wealthy countries routinely come to the United States for medical evaluations and highly specialized surgical and medical interventions. These interventions are done for the most part at major teaching institutions throughout the United States. The University of Pennsylvania, Stanford and the University of California, San Francisco and numerous other teaching hospitals reported losses of tens of millions of dollars in 1998.\textsuperscript{22} Stanford and the University of

\textbf{Fig 5.} The mean length of stay for patients treated in the academic and private services is shown ($p = 0.16$).
California, San Francisco reported an operating loss of 86 million dollars and net losses of 73 million dollars in fiscal year 1998 to 1999. The University of Pennsylvania and Georgetown University Medical Center also reported losses of 198 million and 75 million, respectively. These institutions are renowned for producing world-class research and for educating some of the best doctors in the system. In 1997, the Balanced Budget Act was passed, which mandated a total budget reduction of 64 billion dollars. Sixty-six percent of the required reductions are to come from Medicare. In particular 5.6 billion dollars are to be taken off from Medicare in direct teaching payments during the next 5 years. The budget cuts that are stated to happen during the next 5 years already have started to take a toll on very prestigious medical institutions in the United States. The direct effect to the orthopaedic surgery specialty remains to be seen.

The need to maintain adequate funding levels for graduate medical education has captured the interest of the senate and congress. The Medical Education Trust Fund Act of 1999 was reintroduced in the senate on January 19, 1999. This legislation would establish a fund that would receive moneys from three sources: a 1.5% tax on health insurance premiums (private sector) and Medicare and Medicaid (public sector) to average payments of approximately $17 billion in the 5 years after enactment.

Orthopaedic surgical teachers have a duty to guide the process of surgical instruction through the next millennium. The surgical costs are going to be scrutinized during the next 10 years. Orthopaedic surgeons who are academically inclined must develop ways to assess the effectiveness and costs of teaching methodologies and also must strive to get the dollars that are needed for graduate medical education. Getting involved with the Payment Assessment Commission is a good vehicle to effect change. Lecturing to peers and in particular speaking with patients to increase the awareness and the importance of graduate medical education is a must. Everyone must know the impact that surgical training will have on our children and grandchildren.

Significant drawbacks of the current study include the limited number of patients and surgeons and the lack of long-term outcome. In addition, the orthopaedic severity of illness is not accounted for. Physician charges also are not included in the calculations, but such charges probably would strengthen the conclusions.

Teaching knee arthroplasty surgery is an expensive process. Most of the increase in resource consumption occurs in the operating suite. There is a trend that shows increased patient severity of illness in the teaching cohort. Methodology to treat surgical skill has been neglected in the orthopaedic literature.

References
11. Dripps RD, Lamont A, Eckenhoff JE: The role of