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EXAMINING THE INFLUENCE OF PICTURE ARCHIVING COMMUNICATION SYSTEMS AND OTHER FACTORS UPON THE LENGTH OF STAY FOR PATIENTS WITH TOTAL HIP AND TOTAL KNEE REPLACEMENTS

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Abstract

Objectives: To examine the influence of a picture archiving and communication system (PACS) on the length of stay (LOS) for patients receiving total hip replacement (THR) or total knee replacement (TKR) procedures.
Methods: A before-and-after design was used. Data were collected on all THR and TKR procedures at Hammersmith Hospital from 1993–96. A regression approach was used to examine the influence of PACS on LOS. Factors such as patient age, sex, and physician were controlled for.
Results: Type of admission and discharge, month of procedure, complications, and number of procedures all significantly influenced LOS for patients undergoing THR. For patients receiving TKR, age, sex, admission, prosthetic complications, number of procedures, and PACS significantly influenced LOS.
Conclusions: While this study shows an apparent reduction of 25% in the average LOS for TKR patients at the time PACS was introduced, this is unlikely to be a true PACS effect and no similar reduction in LOS was shown for THR patients.

Keywords: Radiology information systems, Length of stay, Arthroplasty, Replacement, Hip, Knee

Picture archiving and communication systems (PACS) are designed to replace conventional analog x-ray systems with a completely digitized system. X-rays are

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acquired either digitally or using traditional analog methods and then digitized, which enables the process of image handling to be automated and images to be transported via networks. Clinicians and radiologists can call up images they wish to view on special networked computers (workstations), thus eliminating the requirement for the traditional physical x-ray packet.

A large, independent, economic evaluation was commissioned by the Department of Health to evaluate the implementation of a hospitalwide PACS at Hammersmith Hospital in west London. Hammersmith Hospital is a National Health Service (NHS) teaching hospital and tertiary referral center that forms a part of the Hammersmith Hospitals NHS Trust. Other aspects of the study have already been reported (5;6;24). This study is one element of the evaluation and aims to assess the impact of PACS on inpatient length of stay (LOS).

In attempting to justify the additional capital expenditures associated with the introduction of PACS, it has been argued that some of the principal benefits such systems will bring are improvements in the efficiency of the organization and operation of a hospital (1;11), such as inpatient LOS. In particular, the claim has been made that inpatient hospital stays are likely to be shortened due to the more rapid availability of diagnostic information (14;19). However, there is little empirical evidence to assess the impact of PACS on LOS, principally because very few large-scale PACS have yet been implemented. Warburton (23) investigated the theoretical impact of delays in obtaining medical imaging information on LOS by questioning the admitting physicians at a hospital without a PACS. She concluded that it is premature to assume that the PACS technology would significantly reduce stays for most patients. However, Straub and Gur (21) also asked clinicians working in a hospital without PACS to estimate the impact of delayed access to diagnostic information on hospital stay. They found that in 43% of unsuccessful visits to locate images, physicians felt the lack of access would result in delays in diagnosis and/or therapy, and in 17% of unsuccessful visits would probably increase patient LOS.

METHODS

The first step was to identify patient groups for whom a PACS-induced change in LOS was thought to be most likely. In a survey of all clinical directors (13), only the orthopedic surgeons were able to identify specific patient groups of reasonable size for which a PACS-induced reduction in LOS was thought likely to occur, namely those who underwent total hip replacement (THR) surgery or total knee replacement (TKR) surgery. It was hypothesized that if immediate access to images offered by PACS could move up the decision on when to begin patient mobilization, then a decision on discharge could be made sooner, thus reducing inpatient LOS.

Data were collected on all patients who were admitted to Hammersmith Hospital for THR or TKR as their primary procedure during the period 1993–96. It was not possible to randomly allocate patients to being cared for in a PACS-based setting or a film-based setting, because a hospitalwide PACS was implemented and the time during which the two radiology systems ran in parallel was minimized. Thus, it was necessary to compare a historical cohort of patients treated in a film-based situation with a cohort treated once the PACS was fully operational. The principal problem with such a before-and-after comparison is that the two patient populations may be different in one or more important aspects, or there may be other changes taking place that are independent of the introduction of PACS.

Table 1. List of the Independent Variables

Set	Variable	Explanation
Patient demographic characteristics	Age	Quantitative variables measured as the number of years from the date of birth to the date of procedure
	Sex	Dummy variable taking the value 1 if male and 0 if female
	Status on admission	Dummy variable taking the value 1 if elective and 0 if nonelective admission
	Discharge	Dummy variable taking the value of 1 if the patient went home or 0 if the patient did not go home
Patient medical characteristics	Additional procedures	Variable measuring the number of additional procedures performed within the same inpatient episode
	Diagnoses	Dummy variables created for the diagnostic groups: arthritis, arthrosis, fractures, complications, and others
	Complications	Dummy variable entered as a discrete group, taking the value of 1 if the diagnosis was "complications due to internal prosthetics of previous knee or hip replacement procedure"
	Procedure	Dummy variable taking the value of 1 if cement was used for the procedure, 0 if no cement was used.
Physician variables	Consultant	Dummy variables created for the consultant surgeon caring for the patient
Hospital variables	Day of the week of admission	Dummy variable taking the value 1 if admitted during the weekend, and 0 if admitted during the week
	Time of admission	Dummy taking the value of 1 if admitted between 3:00 PM and 10:00 PM on day of admission (evening hours)
Others	Month/year of procedure	Continuous variable with a value for each month of each year
	PACS	Dummy variable taking the value 1 for the PACS phase and 0 for the pre-PACS phase

In order to overcome this problem, multiple regression using ordinary least squares (OLS) was employed. A literature review was undertaken, to identify variables that other researchers have found to be significant in explaining variations in hospital LOS. Five categories of such variables were identified: a) patient demographic variables; b) patient medical variables; c) physician variables; d) hospital variables; and e) other variables. Table 1 lists and defines those parameters for which data were collected for our analysis.

There were several reasons for the selection of variables collected. First, we included only one physician variable out of a wide range that has been described by Burns and Wholey (7). The reason for omitting factors such as physician's age and medical school attended was that only five consultant orthopedic surgeons were responsible throughout the period for all THRs and TKRs at Hammersmith Hospital, so it was feasible to include a variable to account for each specific consultant in charge of the THR or TKR. Second, there are two kinds of hospital variables

Table 2. Descriptive Length of Stay Statistics for Patients Undergoing Total Hip Replacement

	1993	1994	1995	1996	1993–96
Mean	17.0	17.6	18.5	16.3	17.6
Median	16	14	14	13	14
Standard deviation	7.8	11.7	15.6	9.9	12.4
IQ range	11–21	11–18	10–21	10–17	11–18

(9;10): those seeking to explain variation in average LOS between hospitals, such as hospital size and teaching status, and those seeking to explain variation in individual patients' LOS, such as day of the week of admission and time of admission. As the data relate to a single U.K. NHS hospital (Hammersmith), this study included only hospital variables of the second type. Melfi et al. (16) also included factors such as availability of community health care resources and region, which would be similar for all patients treated at Hammersmith Hospital.

Regression coefficients for both THR and TKR were initially calculated from the full models, which meant that all variables that could *theoretically* influence LOS were included in the analysis (Table 1). However, the true effect of some variables can be concealed by other variables if the model is overspecified (4) (i.e., too many variables are included), so a more concise model was designed for both procedures, using a stepwise model selection and validation process. Thus, variables were not included if they did not explain a significant level of variation in LOS.

The natural logarithm (LOG) of LOS was used as the dependent variable in the model because this increased the model's robustness. As a result, the coefficients of the independent variables measure an estimated percentage change in LOS. For independent variables that are dummy variables (i.e., having a value of either one or zero), the percentage LOS is given by $e^{\beta} - 1$ (where β is the coefficient of the dummy variable) because in natural logarithms the base is e (2). From the regression model it was possible to identify the variables that were associated with variation in LOS and the statistical nature of their relationship with LOS. The statistical analysis software SAS was used for all the analyses (20).

RESULTS

Data were collected on patients admitted to Hammersmith Hospital for THR or TKR from April 1, 1993 until December 31, 1995 in the pre-PACS period (160 THR cases and 164 TKR cases). Data were then collected on patients admitted for THR or TKR from January 1996, after the "filmless" operation of inpatient orthopedics, until September 1996, when the Orthopedics Department moved to a different site without access to PACS, with only two nominal inpatient beds remaining on other wards at Hammersmith Hospital. This move brought to a premature end the post-PACS period of data collection, with data collected on 40 THR cases and 41 TKR cases. Descriptive LOS statistics for the study data are shown in Tables 2 and 3.

Patient Demographic Characteristics

Prior to the multiple regression analysis, the variables for inclusion in the model were examined individually in order to highlight any clear differences between the pre-PACS and post-PACS periods of data collection. Of the patient demographic

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Table 3. Descriptive Length of Stay Statistics for Patients Undergoing Total Knee Replacement

	1993	1994	1995	1996	1993–96
Mean	15.2	18.9	19.8	16.2	18.7
Median	16	15	14	13.5	15
Standard deviation	4.5	14.8	18.7	16.1	16.4
IQ range	11–20	11–19	10–21	11–17	11–20

variables, no significant differences in age or gender were found between the pre- and post-PACS periods. The mean age was 67 years for the THR group and 69 years for the TKR group. Approximately two-thirds of the patients receiving THR or TKR were women.

More than one-third of admissions (38% of THR and 36% of TKR) were nonelective, in that the patients were not booked for the procedure, and the majority were taken from THR and TKR waiting lists. Only 9% of THR and 5% of TKR nonelective admissions were patients admitted as emergency cases. In the post-PACS period, significantly more patients undergoing TKR (p = .02) were taken from the waiting list.

There were no significant differences between pre-and post-PACS groups in terms of their discharge destination. Nearly all patients undergoing THR or TKR returned home after being discharged, and there were no patients from either group who went to a nursing home or residential home. Four patients undergoing THR in the pre-PACS implementation period died during their inpatient episode.

Patient Medical Characteristics

For both the THR and TKR groups, in both the pre and post-PACS periods, the majority of patients had more than one procedure carried out during their inpatient stay. The most common procedures undertaken in addition to THR or TKR were catherization and endoscopy. Most THR procedures were performed using cement; only 22 (14%) patients in the pre-PACS period and three (7%) patients in the post-PACS period underwent procedures not using cement.

The two most frequent primary diagnoses for both THR and TKR patients were "arthrosis" and "complications of an internal prosthesis." As shown in Table 4, there were no significant differences found between the pre-PACS and post-PACS diagnostic groups for either THR or TKR patients.

Table 4. Diagnostic Categories for Patients Undergoing Total Hip Replacement and Total Knee Replacement

	THR			TKR		
Diagnosis	Pre-PACS	Post-PACS	p-value	Pre-PACS	Post-PACS	p-value
Arthritis	7 (4%)	0 (0%)	0.2[a]	21 (13%)	2 (6%)	0.3[a]
Arthrosis	86 (54%)	22 (55%)	0.9	81 (49%)	11 (35%)	0.2
Fractures	8 (5%)	5 (12.5%)	0.9[a]	34 (20%)	10 (32%)	0.1
Complications	52 (33%)	8 (20%)	0.1	26 (16%)	8 (26%)	0.2
Other	7 (4%)	5 (12.5%)	0.9[a]	4 (2%)	0 (0%)	0.5[a]

[a] Fisher exact test.

Table 5. Ordinary Least Squares Regression Model (LOG Length of Stay) for Hip Replacements[a]

Variable	Coefficient estimate	Standard error	*p*-value
Intercept	4.0627	0.3141	<.01
Status on admission	−0.5878	0.0991	<.01
Month of procedure	−0.0097	0.0031	<.01
Prosthetic complications	0.2012	0.0657	<.01
Went home after discharge	−0.9590	0.2586	<.01
Number of additional procedures	0.1777	0.0469	<.01

[a] $R^2 = 0.35$; adjusted $R^2 = 0.33$.

Hospital Characteristics

Most THR and TKR patients were admitted on a weekday, although a larger percentage of patients undergoing TKR were admitted during the weekend (36% TKR compared with 9% THR). Of the THR group, 64 (40%) admissions took place during evening hours (i.e., between 3 p.m. and 10 p.m.) in the pre-PACS period while 20 (50%) of the post-PACS period admissions took place between these times. A smaller proportion of patients undergoing TKR were admitted during evening hours. For such characteristics, there were no significant differences found within the THR and TKR groups.

Regression Models

The model specifications that resulted from the regression procedure are shown in Tables 5 and 6. An indication of how well the model fits the data, or predicts the dependent variable, is given by the adjusted R^2 statistic. The adjusted R^2 (0.33) in Table 5 implies that 33% of the variation in the LOG LOS for THR patients is explained by the model. The adjusted R^2 (0.29) for the TKR patients in Table 6 shows that 29% of the variation is explained by the model.

The following variables in the THR model were significant: status on admission, the month of admission, prosthetic complications, discharge home, and the number of procedures in addition to THR. The coefficient estimate for the variable status on admission (−0.59), indicated that elective admissions were associated with hospital stays that were about 44% shorter than nonelective admissions. In addition, the month of the admission (i.e., change over time) also had a significant impact

Table 6. Ordinary Least Squares Regression Model (LOG Length of Stay) for Knee Replacements[a]

Variable	Coefficient estimate	Standard error	*p*-value
Intercept	3.2036	0.8769	<.01
Age	−0.0140	0.0114	.02
Sex	−0.2112	0.0977	.03
Additional procedures performed	0.3406	0.0730	<.01
Prosthetic complications	−0.2141	0.6372	<.01
Interaction term age* complications	0.0269	0.0092	<.01
After hours admission	0.1990	0.0937	.03
PACS	−0.2903	0.1239	.02

[a] $R^2 = 0.32$; adjusted $R^2 = 0.29$.

on LOS, in that LOS was reduced by nearly 1% each month, thus approximately 12% each year. The model also indicated that if the primary diagnosis was that the patient had a complication and/or infection associated with an internal prosthetic, LOS increased by 22%. For each additional procedure carried out on the patient during the same inpatient episode, one could expect a 19% increase in his or her LOS on average.

The different consultants that cared for patients undergoing THR appeared to have had standardized policies with regard to the LOS of their patients and so did not improve the specification of the model. Similarly, the day of the week and time of admission did not appear to have a significant impact upon the LOS of the THR group and, importantly, neither did the implementation of PACS.

In the TKR regression model the following variables explained a significant amount of variation in the LOG LOS: age, sex, additional procedures performed, time of admission, prosthetic complications, admission during evening hours, and PACS. A significant difference in the age of patients undergoing TKR during the post-PACS implementation procedure was found, in that patients in the post-PACS group with a diagnosis of prosthetic complications were significantly younger than those patients with alternative diagnoses. Therefore, an additional interaction term was included in the model to adjust for this.

The coefficient estimate was negative for the variable age and indicated that the LOS increased by approximately 1% with each year of increasing age. If the patient was male, this was associated with a 19% shorter LOS. The discharge destinations of patients in the THR and TKR groups were shown to differ, in that all but three patients in the THR group went home while the patients in the TKR group were discharged to a greater variety of destinations. This difference was further demonstrated by the coefficients in the two regression models, in that the LOS in patients undergoing THR tended to be shorter if the patient was returning home. Additional procedures to TKR were shown to increase the LOS by 40%. For patients with complications of the internal prosthesis, LOS tended to be shorter by 19% on average. The significant interaction between the age of these patients and their diagnoses formed an explanation of this unusual finding, in that they were significantly younger than the patients without prosthetic complications. The time of admission also explained a significant amount of variation in the LOS of TKR patients, in that if a patient was admitted after 3:00 PM, the LOS was increased, on average, by 22%. In line with the THR model, the consultant, day or month of admission, and discharge did not explain a significant amount of variation in LOS among the TKR group. Finally, according to the regression coefficient for PACS (−0.29), the LOS for TKR patients after the implementation of PACS was 25% shorter (around 4 days shorter) than before the implementation of PACS.

DISCUSSION

An overall change in LOS for the whole hospital that could be directly attributed to the implementation of PACS would be difficult to establish, given the limited availability of research resources. Our research effort, therefore, concentrated on two patient groups where there was the greatest expectation of such a change with the move to a "filmless" environment. If a change in LOS was to be observed and could be attributed to PACS in this study, it would not necessarily be possible to generalize the findings to other patient groups treated at Hammersmith Hospital. However, if no PACS-induced change in LOS was observed in these selected patient groups, then it would be unlikely that such a change would have occurred for other groups. The THR and TKR regression models, developed to introduce statistical control, were found to account for a significant proportion of variance in patient LOS and can therefore go some way toward explaining the variation in LOS of patients undergoing THR and TKR. The use of regression models partially overcomes potential biases inherent in simpler before-and-after comparisons.

In both patient groups, the most significant variables appeared to be the patient's medical characteristics, particularly the primary diagnosis and the number of procedures undergone. The patient demographic characteristics, such as sex, whether the admission was elective or nonelective, and the discharge destination, have also been shown to have an impact on LOS. However, it appeared that the five orthopedic consultants within the hospital had a consistent discharge policy in terms of the discharge of patients after both THR and TKR procedures; in neither model did the variable "consultant surgeon" explain any variation in LOS. In terms of hospital characteristics, while there was a significant impact due to the patient's time of admission (during evening hours) in the TKR model, there was no such impact shown in the THR model. In the "other' "category, both the month/year of admission in the THR group, and PACS in the TKR group, were shown to have an impact on LOS.

In the regression model for THR, PACS, the dummy variable, was not significant, but for TKR it indicated that PACS was associated with a 25% reduction in LOS. The median LOS prior to PACS was 15 days. Therefore, the model would predict that the use of PACS could reduce the average TKR inpatient stay by nearly 4 days, all other things being equal. If this association were in fact a causal relationship, this would have important economic implications, in that the cost of the implementation of PACS could be set against considerable savings over time from a reduction in LOS (15;17). However, no plausible mechanism by which PACS might bring about a reduction of this magnitude can be hypothesized. Data gathered elsewhere in the evaluation of PACS (for example, on image and report turnaround times) do not support the magnitude of change in LOS found here (5). There were a number of confounding factors occurring around the same time as the implementation of PACS that also could have affected the LOS of patients undergoing TKR, but which were not measured in this study.

In April 1995, the Hammersmith Hospital merged with another hospital, and this merger may have had an impact simultaneously with the introduction of PACS. Additionally, in September 1996, the Orthopedic Department was moved to the other hospital so that all orthopedic services were on one site. Unfortunately, the move of the orthopedic surgery from the Hammersmith site meant that it was not possible to extend the period following the implementation of PACS beyond September 1996 in order to observe a longer post-PACS period. Thus, the small PACS sample may not be representative, and a cautious approach to the interpretation of the results is required.

In summary, while this study appears to show a reduction of 25% in the average LOS for patients undergoing TKR at the time PACS was introduced, this is unlikely to be a true PACS effect. No PACS-related reduction in LOS was shown for patients undergoing THR. These findings leave significant doubt as to the true effects of PACS alone. Longer observational studies of the effect of the introduction of PACS on LOS, free from other major institutional changes, are required to provide convincing evidence.

REFERENCES

1. Andriessen, J. H. T. H., Ter Haar Romeny, B. M., Barneveld Binkhuysen, F. H., & Van der Horst-Bruinsma, I. E. Savings and costs of a picture archiving and communication system in the University Hospital Utrecht. *SPIE*, 1989, 1093, 578–84.

2. Armitage, P., & Berry G. *Statistical methods in medical research*. Oxford: Blackwell Scientific Publications, 1994.
3. Barbaro, D., Shuman, L. J., & Swinkola, R. B. An evaluation of various pre-surgical testing procedures. *Inquiry*, 1977, 14, 369–83.
4. Belsey, D. A., Kuh, E., & Welsch, R. E. *Regression diagnostics*. New York: John Wiley & Sons, 1980.
5. Bryan, S., Weatherburn, G., Watkins, J., et al. *Costs and benefits of hospital-wide PACS networks: An overview of a comprehensive evaluation exercise, 1998*. Paper presented at SPIE, Medical Imaging: PACS Design and Evaluation, California, 1998.
6. Bryan, S., Weatherburn, G., Watkins, J., et al. Radiology report times: The impact of picture archiving and communication systems. *American Journal of Roentgenology*, in press.
7. Burns, L. R., & Wholey, D. R. The effects of patient, hospital, and physician characteristics on LoS and mortality. *Medical Care*, 1991, 29, 251–71.
8. Cairns, J. A., & Munro, J. Why does LOS vary for orthopaedic surgery? *Health Policy*, 1992, 22, 297–306.
9. Cannoodt, L. J., & Knickman, J. R. The effect of hospital characteristics and organisational factors on pre- and postoperative lengths of hospital stay. *Health Services Research*, 1984, 19, 561–85.
10. Eastaugh, S. R. Organizational determinants of surgical lengths of stay. *Inquiry*, 1980, 17, 85–96.
11. Glass, H.I. Economic model of a whole hospital picture archiving and communication system installation. *Journal of Digital Imaging*, 1991, 4 (4), 71–74.
12. Goldfarb, M.G., Hornbrook, M.C., & Higgins, C.S. Determinants of hospital use: A cross-diagnostic analysis. *Medical Care*, 1983, 21, 48–66.
13. Keen, J., Bryan, S., & Weatherburn, G. Evaluation of PACS at Hammersmith Hospital: Instrument for the assessment of the subjective views of clinical staff. *SPIE*, 1993, 1899, 463–74.
14. Langlotz, C. P., Even-Shashan, O., Seshadri, S. S., et al. A methodology for the economic assessment of PACS. *Journal of Digital Imaging*, 1995, 8, 95–102.
15. Lave, J. R., & Leinhardt, S. The cost and length of a hospital stay. *Inquiry*, 1976, 13, 327–43.
16. Melfi, C., Coyte, P., Joyce, D., et al. Determinants of length of hospital stay following total knee replacement surgery in the United States and Canada. Discussion paper, 1993.
17. Metz C. M., & Freiberg A. A. An international comparative study of total hip arthroplasty cost and practice patterns. *Journal of Arthroplasty*, 1998, 13(3), 296–98.
18. Morgan, M., & Beech, R. Variations in lengths of stay and rates of day case surgery: Implications for the efficiency of surgical management. *Journal of Epidemiology and Community Health,* 1990, 44, 90–105.
19. Mosser, H., & Hruby, W. Experience of PACS in the clinical environment: Filmless for 16 months. *EuroPACS '93 Proceedings,* 1993, 31–32.
20. SAS/STAT©Software. Cary, NC: SAS Institute Inc.
21. Straub, W. H., & Gur, D. The hidden costs of delayed access to diagnostic imaging information: Impact on PACS implementation. *American Journal of Roentgenology,* 1990, 155, 613–16.
22. Studenmund, A. H. *Using econometrics: A practical guide*. New York: HarperCollins Publishers Inc., 1992.
23. Warburton, R. N. Digital imaging at a community hospital: Implications for hospital stays and teleradiology. *International Journal of Biomedical Computing*, 1991, 28, 169–80.
24. Weatherburn, G., Watkins, J., Bryan, S., et al. The effect of PACS on the visualization of the lateral cervical spine and the management of patients presenting with trauma. *Medical Informatics*, 1997, 22, 359–68.