MAJOR ARTICLE

Infectious Disease Consultation and Microbiologic Surveillance for Intensive Care Unit Trauma Patients: A Pilot Study

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Infection remains a major cause of posttrauma morbidity. We retrospectively reviewed 2 cohorts of trauma patients admitted to a regional trauma center before and after a policy change integrating prospective microbiologic surveillance and infectious disease (ID) consultation into management of trauma admissions. Primary interests were effects of this policy change on antimicrobial use and diagnostic precision (particularly differentiation of infection from colonization). Associated costs, microflora, survival, and disability were also compared. Patients were stratified for risk of infection. ID consultation was associated with a 49% increased odds that an infection diagnosis was microbiologically based ($P = .006$) and 57% reduction of antibiotics costs per hospitalized day ($P = .0008$). Costs of consultation and an 86% increase ($P < 10^{-6}$) in total cultures combined to minimally exceed that financial saving. The observed improvements in diagnostic precision and antimicrobial usage, however, suggest consideration of prospective microbiologic surveillance and multidisciplinary physician teams including ID physicians for high-risk trauma patients.

Nosocomial infections frequently complicate the course of trauma patients admitted to the intensive care unit (ICU). Infection is second to severe head injury as a cause of death in trauma patients surviving >3 days [1]. One-fifth of trauma deaths occur well after the accident, largely from sepsis or multiple organ system failure [2]. Trauma predisposes to infection by numerous direct mechanisms, whereas intravascular catheters, endotracheal tubes, and urinary catheters create opportune environments for nosocomial infection during treatment. Prompt recognition of infection in trauma patients is thus a cornerstone of management [3]. More generally, ICU mortality is substantial and elevated in patients with nosocomial infections [4, 5], and nosocomial infection risk increases with severity of trauma illness [6]. Earlier diagnosis and treatment and/or reduction of nosocomial infection in the ICU should thus benefit trauma patients.

Routine microbiologic surveillance and early consultation with infectious disease (ID) physicians might contribute to these goals but could also increase cost of care. Few researchers have examined the impact of ID physician consultation on care of hospitalized patients. Two recent studies [7, 8] suggest increased costs and length of stay associated with involvement of ID physicians, but substantial selection biases make these studies difficult to interpret. To our knowledge, the value of ID physicians working proactively within a multidisciplinary ICU team has never been assessed by

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either case-control or prospective investigation in a defined population. Prospective microbiological surveillance could aid early diagnosis and treatment of infections, but it is also of unproven value.

To explore whether proactive ID consultation and microbiologic surveillance of febrile ICU trauma patients leads to more precise diagnoses of infections and more judicious use of antimicrobials, we retrospectively reviewed charts of patients treated immediately before and after introduction of such an ID management approach. Patterns of observed microflora, costs of care, and ultimate survival and disability were also examined.

MATERIALS AND METHODS

This study compared charts of cohorts of trauma patients admitted to a regional trauma center in consecutive years, before and after a change in routine ID management. Cohorts I and II include, respectively, all trauma patients admitted from March through August of 1990 and 1991. The same months were reviewed in consecutive years to ensure similar distributions of trauma causes.

Patients in both cohorts were admitted and treated by the same 2 trauma physicians. For cohort I patients, consultation from ID physicians was obtained only for circumstances deemed beyond the knowledge base of the treating trauma physicians. Cultures were obtained, and antibiotics administered, without specific protocols. In contrast, ID physicians performed consultative services, usually within the first 72 h, for febrile cohort II patients expected to spend >48 h in the ICU. Microbiologic surveillance and antibiotic protocols were initiated for these cohort II patients, and the ID consultants participated in multidisciplinary patient management teams.

Microbiologic surveillance. Nursing staff were trained to implement a surveillance protocol similar to that previously used at the University of Maryland Emergency Medical Services (Baltimore) [1, 5]: sputum Gram stains obtained Mondays, Wednesdays, and Fridays; sputum cultures obtained Monday and Friday; urinalyses performed Monday and Thursday; and urine cultures performed on Monday. Results of laboratory tests were generally available for late morning multidisciplinary rounds. Blood cultures were obtained for fever ⩾38.5°C or when clinical status suggested onset of systemic inflammatory response syndrome (SIRS). In general, no more than 2 sets of blood cultures were obtained per 24-h febrile period, and the protocol allowed no more than 2 sets/24 h after initiation of antibiotics unless new SIRS was suspected. The microbiology laboratory did not repeat sensitivity testing of the same isolates within 7 days of culture, unless additional sensitivity testing was requested by the ID physicians. ID consultants personally reviewed Gram stains and culture results before multidisciplinary rounds, during which the patient's fever curve, vital signs, physiologic parameters, and chest x-ray were also used to distinguish between colonization and infection and to advise on appropriate management.

Antibiotic use. No specific guidelines for antibiotic prophylaxis were in effect for cohort I patients. Cohort II received antibiotic prophylaxis, generally for ⩽48 h, following standard recommendations [9, 10] according to the patient's severity of illness. Antibiotics for this cohort were generally managed by the ID physician working within the multidisciplinary team. Antibiotic prophylaxis was defined as antibiotic administration for prevention of primary infection. Empiric antibiotic therapy for suspected sepsis was considered therapeutic use.

Baseline data. Patient age, gender, injury type, injury severity score (ISS), Glasgow coma scale score (GCS), and probability of survival (PS, using the trauma and injury severity score [TRISS] methodology) were routinely determined. The GCS, and consequently the PS, was not available for some patients (10 cohort I, 7 cohort II) who received sedation prior to arrival at the hospital without prehospital GCS.

Outcomes. For each patient, days in the ICU, total days hospitalized, days on mechanical ventilation, days with fever (>38.5°C), antibiotic days (24-h periods when ⩾1 antibiotic was administered), numbers of cultures performed, and microbiologic information were reviewed. Infecting and colonizing organisms were distinguished, as were therapeutic from prophylactic antibiotic courses. Laboratory costs, pharmacy costs, and consultation charges for each cohort were used to assess economic impact. The latter were obtained from the business office using current procedural terminology (CPT) codes 90600–90630 and 90640–90643.

Infections were defined and classified as follows: "nosocomial," infection with onset ⩾48 h postarrival that was not incubating at the time of admission; "wound," positive culture with intent to treat with antibiotics; "urinary tract infection (UTI)," ⩾10 WBCs per high power field, or ⩾50 WBCs/μL, associated with a positive urine culture of ⩾10,000 organisms/mL; "central catheter," ⩾15 colonies per plate of a semiquantitative culture, as defined by the method of Maki [11]; "abscess," positive Gram stain or culture from a normally sterile body site, or radiographic evidence of a positive finding not normally expected postoperatively, with the intent to treat with antimicrobials. Pneumonia was defined clinically as purulent sputum with a Gram stain with WBCs and bacteria, new chest infiltrate, and associated fever. Quantitative bronchoscopic microbiologic cultures were used to assist diagnosis of ventilator-associated pneumonia for many cohort II cases [12]. Sepsis and multiple organ system dysfunction were determined following the method of the American College of Chest Physicians/Society

of Critical Care Medicine Consensus Conference Committee [13].

Data Analysis

Baseline comparisons. Distributions of demographic factors and risk indices were examined and compared between cohorts. For hypothesis testing, Pearson's χ^2 test or a generalized Fisher's exact test was used for categorical variables, depending on the magnitudes of estimated cell expected values. Linear rank tests, employing Wilcoxon (rank) or Savage (logrank) scores, depending on the degree of skewing in the data, were used for continuous variables.

Risk stratification. To control for possible confounding of between-cohort comparisons by infection risk, patients were retrospectively separated into 4 strata. Minimal-infection-risk patients were those admitted with GCS >13 but not requiring ventilation and who spent <2 days in the ICU. Patients admitted with GCS <6 and/or requiring >3 days mechanical ventilation were classified at high or highest risk according to whether ISS was <30 or ⩾30 at admission. Others were classified as at moderate infection risk. The distribution of patients into risk strata was compared across cohorts using Pearson's χ^2 test; demographic factors and risk indices were also compared across cohorts within each stratum.

Outcomes. Generalized linear models (GLMs), a collection of regression models suitable for analyses of data on different measurement scales from both symmetric and skewed probability distributions, were used to compare outcome variables across cohorts, after adjustments for measures of exposure time and differences in the distribution of infection-risk strata [14]. We adjusted for the above strata, rather than simply restricting to subjects for which the infection surveillance protocol was intended, (1) to give finer control for injury severity and (2) because introduction of the formal consultation and surveillance protocol for some patients was likely to have indirectly influenced the treatment of other patients as well. Subjects in the minimal-risk stratum were excluded from these analyses, as the surveillance protocol should not have affected these subjects appreciably; however, notable observations in this minimal-risk group are mentioned separately.

Depending on the specific model, maximum likelihood or quasi-likelihood was used for estimation. Likelihood or quasi-likelihood ratio tests, with a standard correction for under- or overdispersion [14], were used to check whether cohort effects differed across risk strata. We used main effect parameters to estimate consistent and systematic differences between cohorts I and II and checked for statistical significance of such differences using Wald statistics [14].

More specifically, infection rates and culture count were modeled by Poisson regression of rates relative to either days in hospital (culture count, all infections, blood, central line, wound, other infections), days on mechanical ventilation (pneumonia) or, for UTIs, days in intensive care as a surrogate for catheter days. In such a model, the main effect parameter represents (on the log scale) a common within-stratum relative risk of cohort II to cohort I.

The proportion of patients treated with antibiotics and the proportion of infections diagnosed using microbiologic in contrast to purely clinical evidence were modeled by logistic regression analysis. The main effect parameter in each of these models represents a (log-scale) common within-stratum OR between cohort II and cohort I. Culture costs and days on antibiotics were analogously treated by quasi-likelihood analysis of a GLM with log link function and variance proportional to the mean; for antibiotic costs, we used maximum likelihood analysis of a GLM with these characteristics and an underlying gamma probability distribution. The estimated parameters in these latter models represent how the ratio of an outcome count or other accumulation to a measure of exposure duration (e.g., number of diagnosed infections, cultures, or mean antibiotic costs, per 1000 days) varies on the log scale with risk stratum and cohort. The logarithm of the appropriate exposure denominator was used as "offset" in each model equation to enable this interpretation [14].

To summarize an outcome measure within a cohort, we directly adjusted model-predicted values from each cohort and risk stratum combination, using as weights the proportions of patients or exposure time within each risk stratum of the pooled cohorts [15]. The resulting comparisons remove effects of differences between the aggregate risk distributions of patients in cohorts I and II. Where it was necessary to choose a specific duration of exposure, we used the median duration in the pooled cohorts. The standard of statistical significance for hypothesis tests was $\alpha = .05$ throughout.

The frequencies with which common pathogenic microorganisms were observed in cultures, and major pharmacological classes of antibiotics were prescribed, were tabulated and descriptively compared across cohorts. Mean daily consulting charges (excluding microbiological surveillance costs) were calculated for each infection-risk stratum and compared across cohorts.

RESULTS

Comparison of Cohorts at Admission

A total of 154 patients (0.84 cases per day) with 271 coded injuries were observed in cohort I, and 141 patients (0.77 patients per day) with 261 coded injuries in cohort II. Mean

patient ages ± SD were 33.7 ± 20.4 and 31.7 ± 23.2 years in cohorts I and II, respectively, with males comprising 70% and 66% of cases. The cohorts were generally similar with respect to causes and types of injury. On the basis of the ICD9-CM supplementary classification E-codes [16], 193 cases (65%) resulted from various motor vehicle collisions, 54 cases (18%) from falls, 20 cases (7%) from other accidents, 22 (7%) from assault, and 6 (2%) were self-inflicted. Among all patients, 76 (25.7%) experienced skull fractures (58 [19.7%] closed; 18 [6.1%] open), 72 (24.4%) concussion, 91 (34.9%) other intracranial injury, 33 (11.2%) vertebral fractures, 85 (28.8%) chest and 49 (16.6%) abdominal injuries, and 72 closed fractures (24.4%) and 42 open fractures (14.2%) of the extremities.

Mean recorded ISS, GCS, and PS (±SD) in cohort I were 19.0 ± 12 ($n = 153$), 12.5 ± 4 ($n = 144$), and 89.2 ± 21% ($n = 139$) compared, respectively, to 20.7 ± 11 ($n = 141$), 11.9 ± 4 ($n = 134$), and 86.7 ± 24% ($n = 131$) in cohort II. The between-cohort differences were not statistically significant.

Infection Risk and Fever

The distribution of subjects across the infection-risk strata differed significantly between the cohorts (table 1; $P = .02$ by χ^2 test), because of an excess of high-risk subjects in cohort II relative to cohort I. Within each stratum, demographic and admission status variables were similar for the 2 cohorts, except that 6 (38%) of 16 highest-risk patients in cohort II were males, as compared to 16 (80%) of 20 in cohort I. Table 1 also shows percentages of patients who became febrile and the mean days of fever among febrile patients. The elevated mean days febrile for cohort II patients in the highest-risk group is largely due to a patient ventilated for 103 days and febrile for 57 days. Neither the proportions of patients with fever nor durations of fever among them differed significantly between cohorts. Because ID consultation was not intended for patients at minimal infection risk, unless otherwise noted, we henceforth report only on the 88 cohort I and 87 cohort II patients at moderate or higher infection risk.

Treatment Durations

Days on ventilator. Mechanical ventilation was required for 60 (68.2%) of 88 patients in cohort I and 63 (72.4%) of 87 cohort II patients, and 15% (9 of 60 patients) and 17% (11 of 63 patients) of these for >2 weeks. Ventilated cohort I patients averaged 7.3 ± 9.8 days of support, compared to 9.3 ± 16.6 days for ventilated cohort II patients. The increased mean and SD in cohort II were entirely attributable to 2 patients with exceptionally long ventilation periods (65 and 103 days).

Days in ICU/length of stay. Cohort I patients averaged 6.9 ± 8.5 days and 13.7 ± 12.7 days in the ICU and hospital, respectively, versus 7.6 ± 9.9 and 16.9 ± 17.5 days for cohort II patients. High- and highest-risk cohort I patients averaged 23.3 ± 15.7 hospital days compared to 22.9 ± 21.9 for cohort II. Differences between cohorts were not statistically significant.

Infections

Infection rates. In each cohort, only 2 infections were diagnosed in the minimal-risk stratum. Among those at significant risk, 41 infections were diagnosed among 88 cohort I patients, hospitalized in aggregate for 1204 days, or 34.1 infections per 1000 days. One year later, 80 infections were diagnosed in 87 patients in cohort II over 1471 days, or 54.4 infections per 1000 days, an overall 60% increase. We directly adjusted these rates for infection risk by use of additive Poisson regression models and the distributions of exposure times pooled across cohorts. Because there were no statistically significant differences between the stratum-specific ratios, the ratios of these directly adjusted rates *(RR)* are used to describe

Table 1. Distribution of subjects and fever across infection risk strata, by cohort.

	Infection risk stratum				
Variable	Minimal	Moderate	High	Highest	Total
Subjects (% of cohort)					
Cohort I	66 (42.9)	56 (36.4)	12 (7.8)	20 (13.0)	154 (100.0)
Cohort II	54 (38.3)	42 (29.8)	29 (20.6)	16 (11.4)	141 (100.0)
% febrile (mean fever-days for febrile patients)					
Cohort I	22.7 (2.1)	41.1 (2.9)	83.3 (8.7)	90.0 (8.4)	42.8 (5.1)
Cohort II	20.4 (2.1)	54.8 (1.9)	72.4 (9.1)	75.0 (13.9)	47.5 (6.3)

Table 2. Diagnosed infection rates, by infection type and cohort, directly adjusted for risk strata using Poisson regression and pooled risk-days.

Denominator and infection type	Cohort I rate (SE)	Cohort II rate (SE)	Rate ratio	*P*
Per 1000 days mechanical ventilation				
Pneumonia[a]	29.4 (6.1)	30.6 (6.0)	1.04	0.90
Per 1000 days in ICU				
Urine	7.8 (2.3)	25.8 (5.5)	3.29	.009
Per 1000 hospitalized days				
Blood	0.8 (0.4)	8.1 (1.9)	9.75	.01
Central line	1.5 (0.7)	3.7 (1.2)	2.38	.20
Wound	7.7 (3.2)	3.4 (1.4)	0.44	.19
Other	9.5 (1.8)	13.1 (2.1)	1.38	.31
All infections	35.5 (3.4)	51.3 (4.1)	1.49	.011

NOTE. ICU, intensive care unit; SE, standard error.

[a] Diagnosed throughout full period of hospitalization.

the changes from cohort I to cohort II. The rate of diagnosed infections (table 2) of any type increased by 49% ($RR = 1.49$; $P = .011$) after adjustment for infection-risk strata. Diagnosis rates for UTIs and blood infections in cohort II were substantially and statistically significantly higher than in cohort I, with respective rate ratios of 3.3 ($P = .011$) and 9.8 ($P = .01$). On the other hand, pneumonia was diagnosed at virtually identical rates in cohorts I and II. Observed increases in diagnosis rates for central line and "other" infections in cohort II, and a decrease for wound infections, were compatible with chance variation.

In the combined cohorts, all (20 [100%]) diagnosed blood and central line infections, 10 (91%) of 11 diagnosed wound infections, 20 (95%) of 21 diagnosed UTIs, 28 (78%) of 36 diagnosed pneumonias, and 19 (61%) of 31 other infections diagnosed had ≥ 1 pathogen that established a microbiologic diagnosis. Surveillance increased the observed proportion of infections that were microbially diagnosed from 68.3% for cohort I to 88.8% for cohort II (OR 1.49; $P = .006$). When analyses were confined to microbiologically diagnosed infections, results of comparisons between cohorts were substantively similar to those above.

Recovered organisms. The distributions of infecting and colonizing organisms are similar to one another across, and within, cohorts (table 3). *Pseudomonas* species and yeast infections were found more frequently in cohort I patients, and *Staphylococcus aureus* in cohort II infections, but these differences were not statistically significant. No analysis was conducted on specific antimicrobial susceptibilities.

Usage and Costs

Microbiological cultures. Risk-adjusted total culture rates for cohorts I and II were 447.6 and 834.6 cultures per 1000 days, respectively, an increase of 86% ($P < 10^{-6}$). Cost data reflect this, with risk-adjusted daily costs of $16.53 and $32.92 for cohorts I and II, a 90.4% increase in constant dollars (after inflation adjustment of 4.6%, the mean of the 1990 and 1991 percentage increases in the Consumer Price Index; figure 1). Culture use also increased from 93.3 to 110.4 cultures per 1000 days for minimal-risk patients, with mean cost per hospital day of $2.64 increasing by 52.5% after inflation adjustment.

Antibiotics. The proportion of patients treated with 1 or more antibiotics, adjusted by infection-risk strata and to the median 11-day length-of-stay, exhibited a nonsignificant increase from 79.5% in cohort I to 88.2% in cohort II ($P = .12$); however, among all patients the risk-adjusted mean days of prophylactic antibiotics per 100 days declined 45% from 256.0 to 140.5 ($P = .0016$). Cephalosporins and simple penicillins were used for roughly 90% of prophylactic courses, with respective mean durations of 4.2 days in cohort I and 2.4 days in cohort II. Among patients with documented infections, we observed an 18% decline in risk-adjusted mean days on therapeutic antibiotics from 16.5 to 13.5 days, consistent with clinical expectation although statistically nonsignificant ($P = .27$). Cephalosporins, penicillins, aminoglycosides, and vancomycin accounted for ~85% of all therapeutic antimicrobial courses. Noticeable reductions in mean treatment duration were seen

Table 3. Distribution of recovered microorganisms, by cohort (% of microbiologically diagnosed infections/% of all organisms recovered).

Organism	Cohort I (n = 47/133)	Cohort II (n = 92/284)
All gram-negative organisms	44.7/38.1	45.7/38.7
Enterobacter species	4.3/7.5	4.3/5.6
Escherichia coli	8.5/3.7	10.9/4.9
Haemophilus influenzae	8.5/6.7	9.8/6.7
Klebsiella species	6.3/3.0	7.6/4.9
Pseudomonas species	12.8/11.2	5.4/7.8
Other gram-negative organisms	4.3/6.0	7.6/8.8
All gram-positive organisms	29.8/41.0	40.2/34.5
Staphylococcus aureus	10.6/11.9	26.1/15.5
S. epidermidis	0.0/3.7	2.2/3.5
Other gram-positive cocci	19.1/25.4	12.0/15.5
Other gram-positive organisms	4.3/1.5	4.3/4.2
Anaerobes	8.5/3.0	0.0/0.0
MURF	6.3/11.2	7.6/13.0
Yeast	6.3/5.2	2.2/8.1

NOTE. MURF, mixed upper respiratory flora.

in all categories of these agents except vancomycin and second-generation cephalosporins (table 4). Simple penicillins often replaced extended spectrum penicillins. Use of vancomycin and third-generation cephalosporins increased in cohort II relative to other antimicrobials, whereas aminoglycoside use declined somewhat (table 4).

Antibiotic costs dropped at least commensurately with use. Without statistical modeling, risk-adjusted daily costs were $21.89 for cohort I versus $10.77 for cohort II patients, an adjusted reduction of 54.2% after 7.5% inflation adjustment (the mean of the 8% 1990 and 7% 1991 inflation adjustments to hospital pharmacy charges). A statistical model based on the gamma distribution, to diminish the effect of high outliers, yielded lower estimated daily costs of $16.84 for cohort I and $9.16 for cohort II but a similar 49.4% reduction after the inflation adjustment ($P = .0008$; figure 1). Changes of a similar character were also seen in minimal-infection-risk patients. Thus, 38.9% of the minimal-risk patients in cohort II received prophylactic antibiotics versus 54.5% in cohort I; days of prophylactic antibiotics per 1000 hospital days among minimal-risk patients were 265.0 for cohort II versus 469.3 for cohort I; mean days on antibiotics for the small number of minimal-risk patients who nevertheless became infected were 6.0 for cohort II versus 13.0 for cohort I; and mean antibiotic costs per hospital day for minimal-risk patients were $3.52 for cohort II versus $6.87 for cohort I.

Consulting charges. For cohort I, ID consulting charges ranged from $0.03 per day for the minimal-infection-risk stratum to $2.90 per day for the highest-infection-risk stratum. The surveillance protocol increased daily ID consulting charges commensurately with infection risk, respectively, to $1.41 for the minimal-risk stratum and to $9.39, $33.34, and $31.06 per day for the 3 strata of patients at risk.

Table 4. Therapeutic courses of antimicrobials prescribed, by cohort.

	% of therapeutic courses (mean days/course)	
Antimicrobial class	Cohort I ($n = 90$)	Cohort II ($n = 149$)
Cephalosporins		
First generation	5.5 (7.4)	4.7 (3.6)
Second generation	14.4 (6.9)	11.6 (6.8)
Third generation	3.3 (12.0)	8.8 (3.9)
Penicillins		
Simple	10.0 (7.0)	21.8 (5.4)
Extended spectrum	16.7 (8.1)	2.7 (5.8)
Aminoglycosides	30.0 (5.8)	23.8 (4.6)
Vancomycin	3.3 (4.0)	14.9 (4.7)
Antifungals	3.3 (5.7)	4.1 (8.0)
Fluoroquinolones	3.3 (7.3)	1.4 (2.0)
Other[a]	10.0 (13.2)	6.1 (6.4)
Total	100 (7.5)	100 (5.2)

[a] Includes trimethoprim-sulfamethoxazole, clindamycin, erthyromycin, and rifampin.

Patient Outcomes

There were 13 deaths in cohort I (1 because of multiple organ system failure due to sepsis) and 14 deaths (none due to multiple organ failures) in cohort II. In each cohort, the observed number of deaths was (27; 13 in cohort I, 14 in cohort II) 80% of that expected ($n = 34$) based on the PS data at patient entry (which were available for all but 1 fatality). No statistically significant differences were seen in distributions of discharge levels of feeding, locomotion, or expression (data not shown).

DISCUSSION

Introduction of prospective microbiologic surveillance and ID consultation was followed by a statistically significant 49% increase in the diagnosed infection rate per 1000 days, including clinically and statistically significant increases in rates of documented bloodstream infection and UTIs. These likely reflect improved surveillance and documentation of bacteremias and true UTIs, in contrast to empiric treatment of SIRS or urinary colonization with microorganisms. On the other hand, nosocomial pneumonia was not diagnosed more frequently in cohort II after adjustment for severity, possibly because of adoption of quantitative bronchoscopic cultures for the diagnosis; however, the 36 total pneumonia diagnoses are too few for firm conclusions from this observation.

The difference in use of cultures between cohorts reflected the trauma physicians' initial philosophy of treating fevers or early clinical indications of SIRS with antibiotics, often empirically and without a complete microbiologic evaluation. With an ID consultant involved daily, patients were cultured in accordance with the microbiologic surveillance protocol, with additional cultures obtained only in response to clinical changes suggestive of SIRS or infection. This alteration in practice was reflected in an increased ratio of microbiologically to clinically diagnosed infections in cohort II.

Though potentially explainable by chance, some differences in species distributions between cohorts (table 3) warrant comment. *Pseudomonas* species and yeast were more common in cohort I, perhaps reflecting higher antibiotic use and broader spectrum of drugs selected for these patients. Also, as in Baker et al. [17], increased awareness of early onset pneumonia and prompt diagnostic evaluation of cohort II patients may have increased diagnoses of gram-positive and mixed respiratory

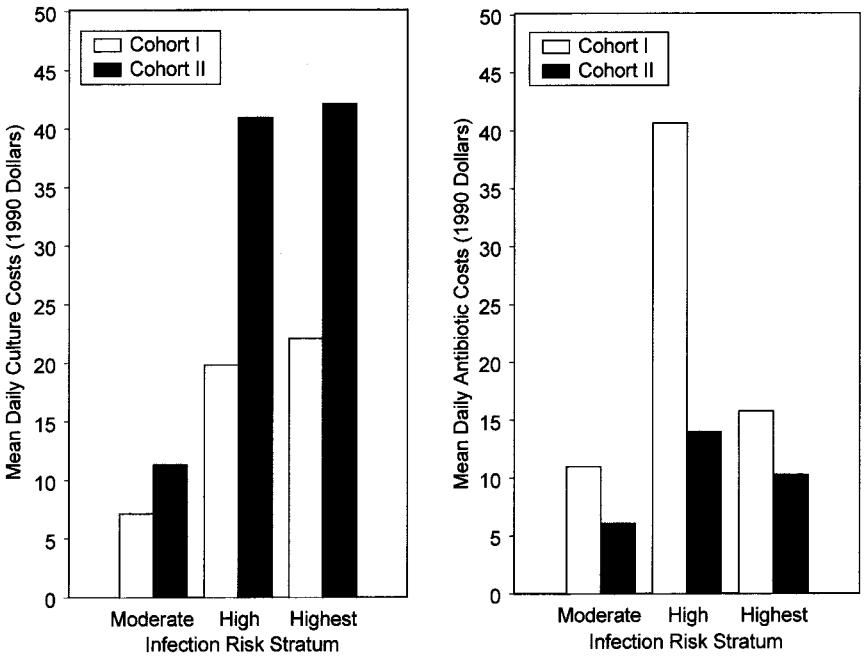

Figure 1. Inflation-adjusted costs of laboratory cultures and antibiotic therapy prior (cohort I) and subsequent to (cohort II) initiation of systematic microbiological surveillance and infectious disease consultation, stratified by infection risk.

flora infections. *Staphylococcus aureus* was less common in cohort I than in cohort II patients, but their frequency was compatible with other trauma surveillance studies [18]. Mixed upper respiratory tract flora (MURF) was commonly found in conjunction with pneumonia in cohort II patients, probably reflecting more restricted antibiotic use in this cohort. With 1 exception, bacteremias were found only in cohort II patients.

Microbiologic surveillance of high-risk patients may facilitate not only earlier diagnosis of infection, but also more appropriate choice and timing of antimicrobial agents. Others have studied prospective microbiologic surveillance in trauma patients. For patient surveillance in the Maryland Emergency Medical System, Caplan and Hoyt [1, 5] used a slightly more intensive approach than ours: alternate weekday sputum Gram stains and cultures, and alternate day urine cultures. Several authors [17, 19] have argued that quantitative respiratory tract cultures can assist in diagnosis and prudent treatment of ventilator-associated nosocomial pneumonia.

Antibiotics were used less frequently for cohort II than for cohort I patients (table 4). In the highest infection-risk stratum, however, antibiotic costs declined but days on antibiotics did not. SIRS was common in these patients, for whom most antibiotic use was therapeutic and the potential consequences of withholding antibiotics most serious. Through the surveillance process in cohort II, colonizing microorganisms were generally known at the time of multidisciplinary rounds. This promoted more refined decision making on starting or stopping antibiotics in lower-risk patients, and avoided "pancultures" for fever in ICU patients. The mean duration of therapeutic antimicrobials was substantially reduced in cohort II, where extended spectrum penicillins were used only rarely (table 4).

Classen et al. [7] linked ID physician consultation to higher mortality, increased use and costs of antibiotics, and longer hospital stays. In a study of survivors of intensive care requiring mechanical ventilation, Jacques [8] found length of stay to be directly associated with the adherence of interdisciplinary treatment teams to recommendations of ID physicians. Selection bias, in which ID physician activity increases in response to severity of illness, may have distorted the outcomes of both these studies. To combat such bias, Classen et al. [7] recommended matching patients according to severity of illness scores, exact sites of infection, and possibly exact pathogens. A critical care multidisciplinary team was successful in reducing the rates of ventilator-associated pneumonia [20]. Byl et al. [21] found that when empiric antibiotic therapy for bacteremia was guided by ID specialists, treatment was significantly more appropriate, and this was linked to a lower patient mortality rate. Finally, in a study not restricted to trauma patients, a program to improve antimicrobial use was associated with decreased costs of antimicrobials and decreased rates of selected nosocomial infections by resistant organisms [22].

Our study design and statistical analyses substantially reduce problems such as those encountered by Classen et al. [7], and our findings differ. Cohorts I and II were comparable with

respect to univariate distributions of gender, causes and types of injuries, age, ISS, GCS, and PS by TRISS. Mean days of mechanical ventilation and mean fever days showed noticeable differences between cohorts that did not, however, attain statistical significance, and were largely attributable to outliers; however, examinations of combinations of variables gave some suggestions of increased injury severity in cohort II. We thus controlled for clinical differences in infection risk by analytic adjustment, using strata defined by criteria clinically antecedent to infection. Although our specific risk stratification has not been prospectively validated, studies have clearly associated nosocomial pneumonia with days on mechanical ventilation, GCS, and ISS, of which TRISS is a refinement [23–26]. The fourth component of stratification, ICU stay, is included because vascular devices and urinary catheters, ubiquitous in ICU trauma management, are long-accepted infection-risk factors. After adjustment for differences in the distribution of these strata between cohorts, mean ICU stay was 8% lower, whereas mean hospital stay was 10% higher in cohort II, with neither difference statistically significant.

There are several cost implications of prospective microbiologic surveillance and clinical ID guidance for trauma patients. Costs of consultation and frequent cultures must be balanced against potential benefits of treating known pathogens over reliance on empiric therapy, potential savings in antimicrobial use, and other potential improvements in quality of care from including ID specialists within multidisciplinary teams. In the high- and highest–infection-risk strata, costs of culture and ID consultation rose respectively $20 and $30 per day in cohort II, increases partially offset by a decline of roughly $15 per day in antibiotic costs. Our experience suggests that microbiologic surveillance costs could be safely lowered further by reducing sputum sampling.

Whether prospective microbiologic surveillance and ID consultation affect length of stay or result in improvements in disability and/or mortality are open questions that can be resolved only by a large clinical trial. The present study was neither randomized nor planned with sufficient power to detect differences in those endpoints. Our results, however, do suggest that benefits are achievable. Standardization of microbiologic surveillance, antibiotic prophylaxis, and involvement of ID physicians with the trauma team was followed by increased diagnosis of infections, greater awareness of the infecting organisms, refinement in antibiotic use and reduction in antibiotic costs. These effects were most clinically significant in the group of patients with high infection risk but with ISS <30. Such effects would be expected to benefit patient outcomes, but additional data are needed to establish the cost-benefit ratio. In principle, input from ID physicians on selection of antimicrobial agents should become increasingly important, because of the rapid emergence of resistant microorganisms in the ICU. Until more extensive data become available, the minimal overall additional daily cost of ID consultative services in this pilot study, in the context of the total cost of patient hospitalization and the value of multidisciplinary team care, suggests that prospective microbiologic surveillance and multidisciplinary physician teams be considered for high-risk trauma patients.

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