A COMPARISON OF COSTS AND EFFECTIVENESS OF THE BACTEC NR-730 SYSTEM AND A CONVENTIONAL METHOD OF BLOOD CULTURE.

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Abstract. Results and costs of the first six months experience with BACTEC NR-730 were compared with a series of blood cultures performed by the conventional method previously used. The newer technology detected the growth of 14.1% of significant isolates on the day of receipt of the specimens. The previous method lacked blind subcultures on the day of receipt and therefore detected growth only after overnight incubation. No direct comparison of the sensitivities of the methods was possible, but the percentages of cultures yielding significant isolates were similar for the two methods. With the new method, technicians needed less time for daily screening of blood cultures, fewer subcultures were required and less contamination was observed.The method used to calculate the directly-related variable costs of the two methods is set out. In the particular situation reported, workload and labor costs were such that introduction of BACTEC NR-730 resulted in a saving on variable costs.

INTRODUCTION

The recognition of bacterial growth in blood culture by detection of CO_2 production is a well established principle. Both radiometric (BACTEC 460, Johnston Laboratories, Towson, MD, USA) and infrared spectrophotometric methods (BACTEC NR-660, NR-730) have been adopted widely, but the necessity of costly, dedicated equipment is a constraint for many laboratories. Published reports include an evaluation of the infrared method in routine use (Courcol *et al,* 1986) and a comparison of the two methods (Jungkind *et al,* 1986). The extensive recent literature on blood culture, including these and alternative methods, has been reviewed by Washington and Ilstrup (1986) Bryan (1989) and Freeman (1990).

We report the introduction of BACTEC NR-730 into a 700-bed general and teaching hospital in Singapore. The results of 3,214 consecutive blood cultures examined between September 19, 1989 and March 31, 1990 are analyzed. It was not considered practicable to compare this method with the previous one directly on the same series of clinical specimens, but data from a series of 1,662 blood cultures tested by conventional methods are given for comparison, these having been tested in the three month period immediately prior to the introduction of BACTEC NR-730. The methods are compared in terms of both effectiveness and cost.

MATERIALS AND METHODS

BACTEC NR-730

Enriched tryptic soy broth media NR 6A and NR 7A (BACTEC) were used for aerobic and anaerobic cultures respectively. Antimicrobial removal devices (ARD) NR 16A and NR 17A were used when indicated. Cultures were incubated at 37°C, aerobic cultures being agitated at that temperature for the first 24 hours. Readings were taken at 4 pm on the day of receipt (Day 0), with morning readings on days 1 to 5 thereafter. The settings used for flagging positive cultures were 30 or greater for aerobic and 25 or greater for anaerobic cultures. Vials giving such readings were subcultured onto aerobic and anaerobic blood agar plates and onto "chocolate" agar incubated in 5% CO_2. Subcultures were made on day 7 of all vials which had not previously yielded positive cultures.

Conventional method

Aerobic blood culture medium was prepared from brain-heart infusion broth (Oxoid, Basingstoke, UK) with the addition of 0.05% "liquoid" (Roche, Montclair, NJ, USA). Brewer's thioglycolate medium (Oxoid CM23) was used for anaerobic blood cultures. Antimicrobial removal was attempted when indicated, using ARD (Becton Dickinson, Cockeysville, MD, USA), subculturing as above after 15 minutes rotation. Cultures were examined macroscopically on the day after receipt and daily thereafter. Subcultures were made routinely from all bottles after one, two and seven days incubation, and from any bottle showing turbidity on daily inspection, onto blood agar and "chocolate" agar as above. In either method, incubation for 14 days and subculture on additional media were used when indicated, but the isolates reported here were obtained as described above.

Identification of isolates

Rapid identification methods included microscopy, co-agglutination and latex agglutination tests on heated and filtered preparations of positive blood cultures. On subculture, isolates were identified by conventional biochemical and serological tests, supplemented when necessary by the use of API20C, API20S, API20NE or API20E (Analytab Products, Plainview, NY, USA).

Determination of significance of isolates

In the series examined by BACTEC NR-730, significance was assessed on the basis of clinical data obtained from request forms, patient records or discussion with the clinicians, as necessary. Similar assessment was made in the earlier series, but consistency between the two series has not been established.

Method of comparison of costs

No estimate has been made of the total costs of the tests: overheads, and labor costs of senior staff have been excluded from the calculations. Only variable costs directly related to blood culture have been considered. These include laboratory consumables, equipment and labor costs. The purchase price, maintenance and depreciation of the BACTEC NR-730 equipment were consolidated by a contract in which a surcharge on each vial of medium was the only payment made. Labor costs were calculated from local salaries and conditions. Calculation of cost per minute of technician's time was based on direct timing of procedures and comparison with the Canadian Schedule of Unit Values for Clinical Laboratory Procedures. Only 60% of the technicians' working time is spent in hands-on technical work at the laboratory bench, but we have regarded all work relevant to the running of the laboratory as of equal value. We have therefore divided the mean annual salary by the number of minutes spent at productive work in the laboratory during one year, this being taken as 90% of the stipulated working time.

The main difference in labor costs between the two methods arises from the numbers of subcultures required. To simplify comparison of costs, these are calculated for negative cultures examined for 7 days. The great majority of cultures fall into this category. The methods of detection of growth have relatively little effect on costs arising from positive cultures, or from the use of ARDs, longer incubation times or additional media. The frequency with which such costs are incurred will depend on the particular series of specimens being examined rather than on the method used to detect growth.

RESULTS

There were 354 positive cultures, from 302 patients, from the 3,214 pair of vials examined by the BACTEC NR-730. Sixteen mixed cultures were observed, leading to differences between the total numbers of isolates and total numbers of positive cultures shown in Tables 1 and 2. Table 1 shows the organisms isolated and the days on which positive cultures were observed. Also shown are the percentages of positive cultures appearing on each day, and the cumulative percentages. Table 2 shows significant isolates, as assessed on the basis of clinical data.

Table 3 shows all isolates and significant isolates obtained from 1,662 consecutive blood cultures examined by conventional means in the period immediately prior to the installation of BACTEC NR-730. This Table also shows percentages and cumulative percentages of significant isolates, by

Table 1

Organisms detected from Sept 19, 1989 to March 31, 1990 by BACTEC NR-730, by day of detection.

	DOR*	Day 1	Day 2	Day 3	Day 4	Day 5	Day 7	Total positive
Salmonella typhi		10	4				1	15
S. paratyphi A		8	1					9
other salmonellas	2	2						4
Klebsiella spp.	9	33	1	3	1	1	1	49
Escherichia coli	12	35	3		2	1		53
Enterobacter spp.	2	4						6
Proteus mirabilis	3							3
Citrobacter spp.		3						3
Flavobacter spp.		1	1	1				3
Acinetobacter spp.	1	10						11
Pseudomonas spp.		10	2	2				14
Aeromonas hydrophila		1						1
Haemophilus influenzae			3	3				6
Campylobacter fetus				1	1			2
Bacteroides fragilis		1						1
Neisseria sp.		1						1
Veillonella parvula			1					1
Staph. aureus	4	20	2	2	1			29
Staph. epidermidis	3	28	13	9	3	2	1	59
Micrococcus spp.					2			2
alpha-haemolytic streptococci	1	23	2	1				27
Group B streptococci		6						6
Group G streptococci		2						2
Group D streptococci	1	11	1		1			14
Streptococcus pneumoniae	3	4	1					8
Gemella hemolysans					1			1
Peptococcus sp.				1				1
Bacillus spp.		7	2		1			10
Corynebacterium spp.				1			1	2
Propionibacterium acnes							1	1
Clostridium sporogenes		1						1
Candida spp.		4	5					9
Total isolates	41	225	42	24	13	4	5	354
Total positive cultures	41	210	38	24	13	4	5	335

Percentage of isolates	DOR*	day 1	day 2	day 3	day 4	day 5	day 7
by day of detection	11.6	63.5	11.9	6.8	3.7	1.1	1.4
Cumulative percentage	11.6	75.1	87.0	93.8	97.5	98.6	100

Number of blood cultures = 3,214 Number positive = 335 (10.4%)

*DOR = day of receipt

Table 2

Significant isolates detected by BACTEC NR-730, by day of detection.

	DOR*	Day 1	Day 2	Day 3	Day 4	Day 5	Day 7	Total positive
S. typhi		10	4				1	15
S. paratyphi A		8	1					9
other salmonellas	2	2						4
Klebsiella spp.	9	29	1	1		1	1	42
Escherichia coli	12	32	3		2			49
Enterobacter spp.	2	1						3
Proteus spp.	2							2
Citrobacter spp.		3						3
Flavobacterium spp.		1	1					2
Acinetobacter spp.		9						9
Pseudomonas spp.		7	1	1				9
Haemophilus influenzae			3	3				6
Campylobacter fetus				1	1			2
Bacteroides sp.		1						1
Clostridium sp.		1						1
Staph. aureus	4	20		1	1			26
Staph. epidermidis	2	12	5	5				24
alpha-haemolytic streptococci	1	20	2	1				24
Group B streptococci		6						6
Group G streptococci		2						2
Group D streptococci	1	10	1		1			13
Streptococcus pneumoniae	3	4	1					8
Peptococcus sp.				1				1
Candida spp.		4	5					9
Total isolates	38	182	28	14	5	1	2	270
Total positive cultures	38	176	27	14	5	1	2	263
8.2% of blood cultures yielded significant isolates								

*DOR = day of receipt

day of detection. Table 4 compares rapidity of detection of growth by the two methods: only significant isolates are considered. Numbers, percentages and cumulative percentages of isolates are given for the day of receipt, for 1 and 2 days of incubation and, as combined figures, for days 3 to 7 inclusive.

Table 5 compares the cost per thousand negative blood cultures examined by BACTEC NR-730 with the cost per thousand examined by the conventional method.

DISCUSSION

No accurate comparison of the sensitivities of the two methods can be made because different series of specimens were examined. There is no obvious overall difference. The BACTEC method we employed is not the most sensitive blood culture method available: the lysis-centrifugation method (Isolator system: EI du Pont de Nemours, Wilmington, DEL, USA) is reported to be more sensitive than the radiometric BACTEC system (Kellogg *et al,* 1984), but Kelly *et al* (1990) report the non-radiometric BACTEC using resin media NR-16A and 17A to be more sensitive than the Isolator system.

When compared with the conventional method that was used, the more obvious advantages of the BACTEC system were earlier detection of positive

Table 3

Organism isolated by conventional blood culture, by day of detection.

	Day 1	Day 2	Day 3-7	Total
S. typhi	11			11
S. paratyphi A	3			3
other salmonellas	3			3
Klebsiella spp.	18	1	1	20
Escherichia coli	21	1		22
Enterobacter spp.	2			2
Proteus spp.	4			4
Pseudomonas spp.	7			7
Acinetobacter sp.	1			1
Haemophilus influenzae		1		1
Bacteroides sp.	1			1
Moraxella sp.		1	1	2
Staph. aureus	18	2	1	21
Staph. epidermidis	12	23	8	43
Micrococcus spp.	1		3	4
Group A streptococcus	4			4
Group B streptococcus	1	1		2
Group D streptococcus	10	1		11
Streptococcus pneumoniae	2			2
other streptococci		1		1
Bacillus spp.	11	35	14	60
Corynebacterium sp.		1		1
Propionibacterium acnes	1			1
Candida spp.	1		3	4
Total isolates	132	68	31	231
Isolates considered significant	113	15	7	135
Percentage of total significant isolates	83.7	11.1	5.2	
cumulative percentages	83.7	94.8	100	

8.1% of 1,662 blood cultures yielded significant isolates

cultures, reduced frequency of contamination, and saving of technicians' time. The earlier detection of positive cultures with the BACTEC system was shown by the detection of 38 out of 270 (14.1%) significant positive cultures on the day of receipt of the samples, whereas none was detected by the conventional method until the day after the sample was received. The BACTEC method's advantage of earlier positive results might be matched by subculture of all conventional blood cultures after 6 to 17 hours incubation, as recommended by Sliva and Washington (1980), but additional cost and risk of contamination would be involved.

Of the 38 organisms detected early by BACTEC, 27 (71%) were members of the Enterobacteriaceae. The remaining 11 were Gram-positive cocci, and included 4 isolates of *Staphylococcus aureus* and 3 of *Streptococcus pneumoniae*. The value of earlier detection was enhanced by earlier availability of antimicrobial sensitivity and final identification of the organisms. On subsequent days the cumulative percentages of significant isolates were very similar for the two methods.

The use of BACTEC NR-730 was expected to reduce laboratory contamination, but our figures gave an exaggerated impression of this advantage

Table 4

Numbers, percentages and cumulative percentages of significant isolates, by method and day of detection.

Method	Day of receipt	Day 1	Day 2	Days 3-7
BACTEC NE-730				
significant isolates	38 (14.1%)	182 (67.4%)	28 (10.4%)	22 (8.2%)
cumulative percentages	14.1	81.5	91.9	100.1
Conventional method				
significant isolates	nil*	113 (83.7%)	15 (11.1%)	7 (5.2%)
cumulative percentages	nil	83.7	94.8	100.0

* method did not include subcultures on day of receipt.

because of an unusually high rate of contamination, mainly with *Bacillus* species, in the series examined by the conventional method.

The newer method clearly makes more economical use of technicians' time, both in the time taken to examine cultures and in the number of subcultures required. Out of 5 isolates obtained by subculture on day 7, only 2 were considered significant, this being 0.7% of the significant isolates in the series. However, these were isolates of *Salmonella typhi* and a *Klebsiella* species and of evident clinical importance, although such delayed reports were of diminished value. Our results from day 7 subcultures are comparable with those of Campbell and Washington (1980) and Gill (1981). The value and cost-effectiveness of routine subculture on day 7 have been questioned both by Gill (1981) and by Masterson and McGowan (1988).

In our series examined by BACTEC NR-730, the cost of obtaining the two final significant cultures was US$5492, this being the cost in labor and materials of subculturing the 2,865 pairs of blood culture bottles that gave negative readings on the fifth day. Thus, 89% of the cost of examining the 3,214 blood cultures (excluding costs of identification and sensitivity testing) was spent in obtaining the last 0.7% of the significant isolates. There would be a great saving if final subcultures could be limited to selected cases.

In retrospect, it is unfortunate that BACTEC NR-730 readings were not taken routinely on the seventh day, prior to subculture. Growth from bottles with negative readings would raise more serious questions regarding the method than delayed growth coinciding with positive readings. Currently, seventh-day readings, visual inspections and routine subcultures are being compared: as these can be carried out on the same vials, the yield from subcultures made in the absence of other evidence of growth can be measured.

If the adoption of the non-rediometric BACTEC system is considered on the basis of cost only, expected savings in labor and materials must be put against purchase price, maintenance and operating costs plus depreciation, or any contractual arrangements to cover these costs. In the instance reported, a contract served to consolidate the costs of equipment, maintenance, supplies and depreciation into a surcharge on media, and the calculation became a simple one. The size of the surcharge was clearly determined by the expected workload, according to which we note that the price of the equipment would be covered by the surcharge within 3 years. Workload is a vital figure in any decision to buy new technology because it affects every cost item except depreciation. Labor cost is the other factor determining whether savings can be expected or not. If in our case, all other costs had been equal but salaries lower by one third, no reduction in the cost of blood culture

Table 5

Comparison of directly-related variable costs of BACTEC and conventional methods applied to cultures remaining negative after 7 days incubation.

Note: calculation of costs in US$ is based on the exchange rate at the time of writing, Singapore 1.75S$ = 1.0 US$.

	Costs (US$)
Technicians' mean annual salary	= 11657.14
Working hours per annum (52 weeks of 42 hours) = 2184 hours less 226 hours leave and national holidays = 1958 hours Take 90% of time as spent on relevant work = 1762.2 hours or 105732 minutes	
Technicians' working time per minute = $\frac{11657.14}{105732.00}$ = 0.11025	
1000 pairs of vials (BACTEC NR 6A and NR 7A) including surcharge*	= 5142.86 (A)
Production of 1000 pairs of bottles for conventional blood culture	= 1714.28 (B)
A single reading of 1000 blood cultures (pairs) by BACTEC (technicians' time for handling, recording)	= 22.03 (C)
by conventional method (technicians' time for visual inspection, manual recording)	= 55.08 (D)
Subculture of 1000 pairs, once only materials $1208.57, labor $654.56	= 1863.13 (E)
1000 negative blood cultures examined by BACTEC NR-730 $= A + 6C + E + \frac{48E^{**}}{1000}$	= 7227.60
1000 negative blood cultures examined by conventional method = B+ 7D + 3E	= 7689.23

Estimated savings using BACTEC NR-730 = US$ 461.63 per 1000 negative blood cultures

* surcharge on media consolidates costs of equipment, maintenance and depreciation.
** adjustment for the 4.8% false-positive BACTEC readings observed in this series.

would have been achieved by our use of the BACTEC system.

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