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Clinical trials of a novel centrifugation method: axial separation

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Specimen centrifugation is one of the most time-consuming tasks associated with preanalytical specimen processing. We report the first clinical use and impact study of the novel centrifugation method, axial separation, using the Axial Separation Module (ASM™). The ASM centrifuges medical specimens one at a time (in 1 min 9 s) in proprietary Axial Process Containers (APC™). Here we report tests of the ASM in an outpatient clinical laboratory. Use of the ASM in the outpatient clinic laboratory led to an average total improvement (decrease in total bench time) of 8 min 9 s per specimen compared with conventional centrifugation. Laboratory analysis revealed no statistical difference between plasma obtained from the APC vs that from a Becton Dickinson Vacutainer Tube. We conclude the ASM offers a cost-effective alternative to conventional centrifugation. Further, the use of axial separation may allow specimen separation to become an integral part of the phlebotomy process.

INDEXING TERMS: sample handling • laboratory management

Over the last two decades, emphasis has been placed on improving the quality, capacity, and rapidity of clinical laboratory analytical instruments. Throughputs of 1600 results per hour are commonplace with >20 analytical results reported per patient. In contrast, little technological progress has been made in the preanalytical phase of specimen processing, particularly specimen centrifugation. Except for more modern looking exteriors and the incorporation of electronic control, clinical centrifuges operate about the same as they did 20 years ago. Modest improvements have been made in speed, durability, and specimen capacity; however, because centrifugation is still a batch process, it remains one of the major bottlenecks in specimen processing.

The latest national trend towards managed medical care ha focused hospital administration on laboratory costs. Because th accessioning area consumes much of the laboratory labor bud get, it is an obvious area to begin cost-saving measures. Th laboratory centrifuge, being one of the most labor-intensiv devices in this area of the laboratory, has begun an evolutionar process *[1–3]*. One approach to improving the task of centrifu gation has been to change it from an inherently batch process t a serial process *[1, 3]*. This paradigm shift required the redesig of the fundamental approach to specimen centrifugation Godolphin et al. *[3, 4]* invented a novel method for centrifuga tion that changed the concept of batch processing to that of serial process. Recently, this concept has been reduced t practice in the form of the Axial Separation Module (ASM™ DuPont Canada, Ontario, Canada).[1] However, whether th ASM concept—which provides small size, serial processing, an ease of use—will necessarily expedite the process of laborator centrifugation is not immediately obvious. To assess the tru return on investment, it is necessary to measure the impact o automation on laboratory efficiency.

Several investigators have used simulation studies to predic the effect of automation *[3, 5, 6]*. Unfortunately, these investi gators did not have the luxury of having installed the automatio to be able to assess its true impact. The focus of the presen study was to investigate the actual use of the ASM so as to tes the effect of rapid serial centrifugation (one specimen at a tim as opposed to batch centrifugation) on overall bench time.

This study was confined to an outpatient laboratory wher the use of the ASM and special Axial Process Containe (APC™) could be compared in a controlled environment wit relatively few specimens per hour. To predict the impact of th ASM in a laboratory with large numbers of specimens per hou we conducted a separate simulation study. Analytical tests wer performed on plasma obtained in APCs and compared with tes on plasma from the same patient obtained in routine evacuate collection tubes.

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[1] Nonstandard abbreviations: ASM, Axial Separation Module; APC, Axi Process Container; RCF, relative centrifugal force; and FTE, full-time equivalen

Materials and Methods

SPECIMENS

Phlebotomy was performed by trained medical technologists employed at The University of Virginia Health Sciences Center. Patients were selected at random from those providing blood specimens as part of their visit to the outpatient clinic. The study was approved by the Human Experimentation Committee, and informed consent was obtained from all subjects. Two tubes of blood were filled from one needle stick: one green-top 10-mL lithium heparin-containing glass Vacutainer Tube™ (Becton Dickinson, Forest Lakes, NJ), and one APC. All tubes were transported across the hall to the analytical laboratory at convenient times for the phlebotomist.

MATERIALS

ASM. The ASM is a specimen separation device that consists of a specimen input tray, a processing chamber, and a holding tray for finished specimens (Fig. 1). The ASM operates at 2400*g* and can accept up to 10 APCs at one time. It separates the fluid from cells in a specimen in ~1 min (1 min 9 s). The ASM *g*-force is similar to that of conventional centrifugation. The conventional centrifuge used in this study requires 10 min to separate plasma from cells that must travel the length of the tube during centrifugation (~7 cm). The ASM accomplishes the same task with the same quality of separation because the cells have to traverse only the radius of the tube (~0.65 cm), taking one-tenth of the time to travel one-tenth of the distance.

A special slot provided above the process chamber allows the introduction of a higher-priority specimen at the head of the queue. Separation is initiated by placing a tube in the input tray and pressing the button to start the process. Queued containers are automatically fed into the spin section without the need for operator intervention.

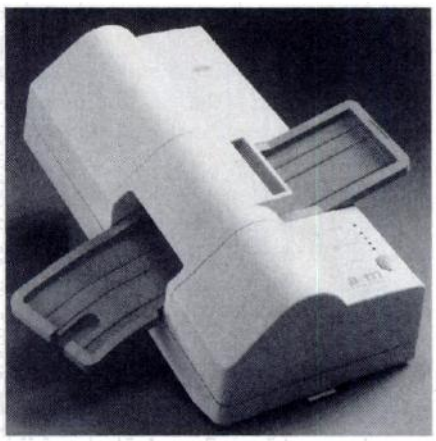

Fig. 1. ASM tabletop instrument for serial separation of medical specimens.

APCs containing whole blood are placed horizontally in the tray on the *right side* of the instrument. After the operator pushes the start button, the ASM separates plasma (or serum) from formed elements in each tube in ~1 min. Samples are processed serially (one at a time) until there are no further specimens to separate. A stat slot is provided above the separation chamber to allow the operator to place tubes at the head of the queue.

Fig. 2. APC after the separation process is complete.

The separated specimen consists of formed elements permanently isolated below a special plastic separator and platelet-free plasma or serum above the separator. The plasma or serum can be accessed by piercing or removing the cap.

Conventional centrifuge. An Accuspin (Beckman Instruments, Brea, CA) operated at 1100*g* for 10 min was used as the conventional batch centrifuge in our studies. The chemical analyzers we used require that specimens be centrifuged for at least 10 min at 1000*g* to avoid cellular material and platelets in plasma, which interfere with some tests. The Accuspin was equipped with four buckets, each with a seven-tube capacity, for a maximum batch capacity of 28 tubes.

APC. An APC is similar in external geometry to a 16 × 100 mm (10-mL) Vacutainer Tube (Fig. 2). One end contains a safety overcap; the other end, which in a standard test tube would be curved glass, contains a rubber draw plug. A movable separator made of clear plastic, positioned at the top end of the tube during manufacture, serves to permanently separate the serum from the blood cells. Blood specimens are drawn into the tube from the bottom end (opposite the cap). The cap is specially designed not to fit into a Vacutainer Tube needle holder to ensure that the technologists use the proper end to draw blood. A 10-mL evacuated APC container will draw ~7.0 mL of whole blood and contains lithium heparin similar in composition to the lithium heparin contained in Vacutainer Tubes.

PROCEDURES

ASM operation. Specimens are placed into the ASM as they arrive in the laboratory. After the start button is pressed, the ASM star wheel indexes an APC into the feeder. As the APC rotates on its long axis, a light-sensitive diode continuously scans for the presence of blood cells in the orifice of the plastic separator placed in the interior of the tube (Fig. 3). During separation, the ASM advances a probe that pierces the rubber cap and pushes the separator along the length of the container. Centrifugal forces create an air column within the center of the

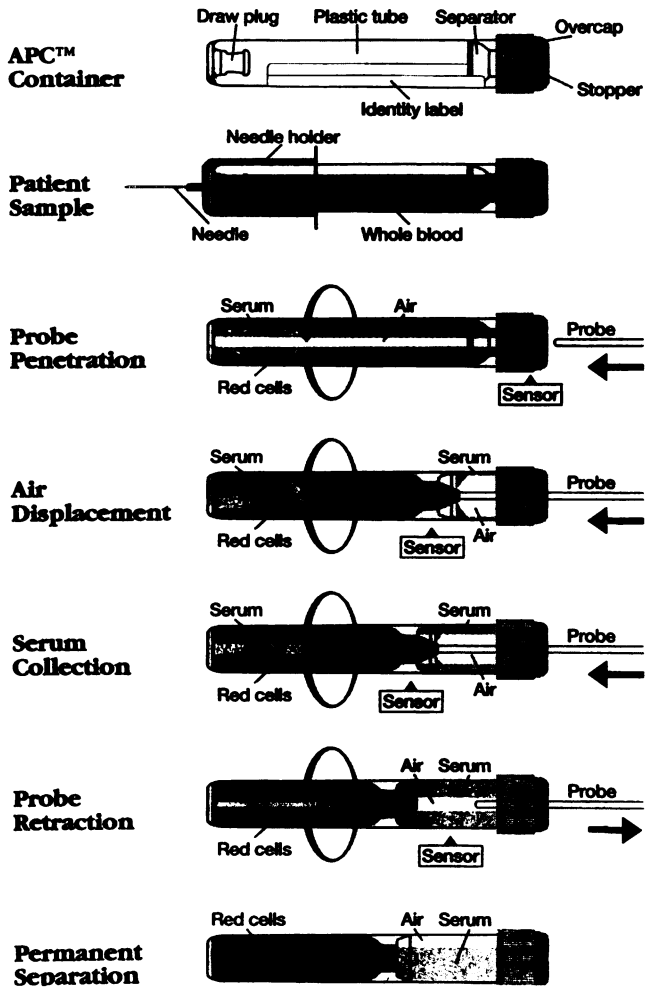

Fig. 3. The axial separation process.

The first diagram depicts the geometry of the empty APC. A patient's sample is then drawn into the evacuated tube through the bottom of the tube by use of conventional Becton Dickinson needle-holder technology. The tube is then rotated on its long axis while a probe is introduced through the rubber septum in the cap. The central column of air is displaced, after which serum or plasma moves into the upper chamber. The probe remains clean and dry because of centrifugal force. A light-sensitive diode sensor immediately stops the process and signals probe retraction when blood cells begin to enter the plastic separator. The finished tube provides serum or plasma permanently separated from the formed elements.

serum, so the probe does not contact the specimen and carryover is prevented. As the blood cells are being compressed longitudinally by the separator, the column of cells becomes thicker and advances closer to the center of the tube (Fig. 3). When compressed to their maximum extent, the cells begin to enter the separator and are detected by the light-sensitive diode. The resulting signal effectively ends the separation process. The probe is automatically withdrawn, the spinning stops, and the specimen-containing APC is ejected into the output tray.

Comparison method. Conventional centrifugation was performed by placing the Vacutainer Tube samples in the Accuspin swinging buckets, which were visually balanced. After 10 min of centrifugation and a 1-min braking period, the specimens were unloaded one at a time.

Test protocol. The ASM was installed in a satellite laboratory that serviced five outpatient clinics in a primary care center at The University of Virginia. Phlebotomy services were provided in a room across the hallway from the laboratory. Only stat tests were performed in the outpatient clinic laboratory; therefore, patients who had requisitions for stat chemistry tests were requested to supply two tubes of blood (one ASM tube and one Vacutainer Tube). The ASM was operated in parallel with conventional centrifugation.

Timing studies. The goal of the timing studies was to determine whether serial centrifugation of stat samples substantially decreased bench time for an individual specimen. Comparisons in labor requirements were made for each step of the processing procedure with use of a manually operated stop watch. To verify that human timing was not affecting the processing speed (the watching supervisor phenomenon), we also derived timings from videotaped procedures. The tripod-mounted video camera (SONY CCD-TR5) was placed in the laboratory several hours before data gathering so that the technologists could become accustomed to its presence. The internal clock feature of the camera was used to facilitate data gathering.

The impact on throughput was assessed by documenting the time required to complete individual steps associated with centrifugation bench time. Timed steps were recorded for both the conventional and ASM centrifugation, including specimen collection, transportation, precentrifugation delay, centrifugation, and postcentrifugation delay.

The University of Virginia Primary Care Center provides outpatient services to ~400 patients each day. The number of stat chemistry tests requested from this population was ~50/day. The timing studies conducted were accurate for these small numbers of specimens; however, the impact of large queues on preseparation delay could only be calculated, not measured, in this outpatient setting.

Chemistry testing. Various analytes were chosen for comparison between the APC (y) and the Vacutainer Tube (x) results. The samples were analyzed with an Ektachem 750 analyzer (Johnson & Johnson, Rochester, NY). Mean, SD, $S_{y|x}$, slope, y-intercept, and R^2 were calculated for each analytical comparison.

Transportation. Transport involved the delivery of the blood sample from the phlebotomy area across a hallway to the primary care center laboratory. This time interval started when the specimen left the phlebotomy area and ended with the placement of the sample in the centrifugation bench receiving rack of the laboratory.

Precentrifugation delay. This interval began with the arrival of the sample on the centrifugation bench and ended with the push of the start button on the centrifuge. It included the wait for the centrifuge to complete its present spin, loading and balancing of specimen(s), and lid opening/closing.

Centrifugation. The centrifugation interval began with the push of the start button and ended with the centrifuge completely

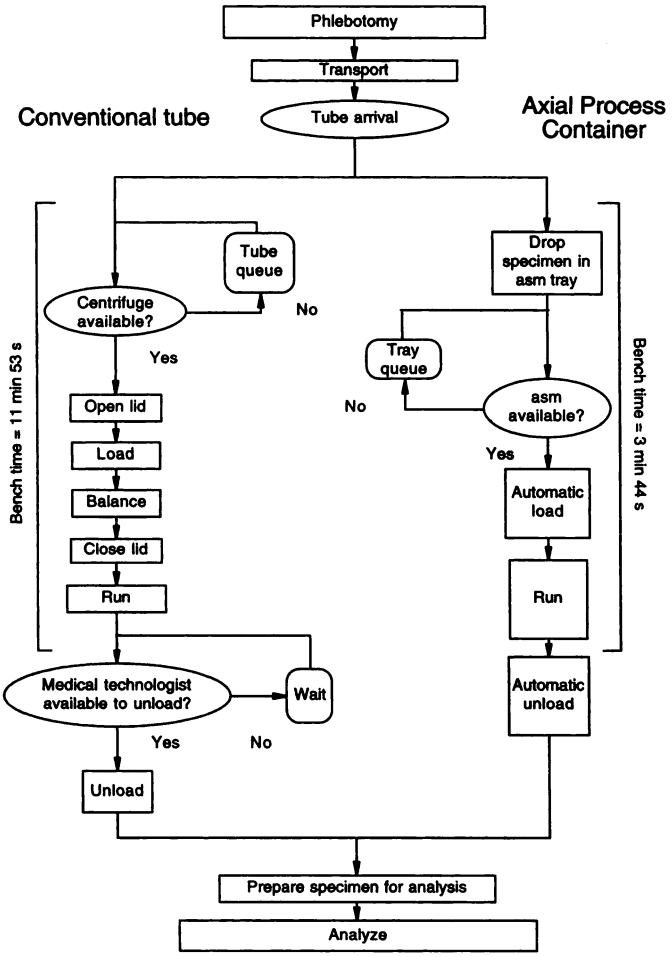

Fig. 4. Flow diagram depicting the steps involved in the preanalytical processing of chemistry specimens by conventional centrifugation vs axial separation.

Specimens queue when the instrument is not available (depicted as feedback loops). Bench times were chosen for comparison in this study.

back to rest. Centrifugation time and separation time are used interchangeably in this study.

Postcentrifugation delay. This period was defined as the time between the end of the centrifugation cycle and the placing of the specimen into the chemical analyzer. The interval includes the delay before a medical technologist returns to the centrifuged specimen, lid opening/closing, aliquoting, and any other preanalysis specimen handling.

Bench time. Bench time was the total time a specimen spent on the processing bench. Timing was initiated with the arrival of the specimen at the processing bench and was terminated with the completion of specimen centrifugation (i.e., bench time = precentrifugation delay + centrifugation).

Results

The steps involved in preanalytical processing are depicted diagrammatically in Fig. 4. The window of time analyzed was bench time (specimen arrival at centrifugation bench to end of spin). Phlebotomy and transportation were assumed to be the same for the ASM and conventional centrifugation. Throughout the experimental day, 92 duplicate specimens (46 samples to each centrifuge) were transported to the laboratory and either placed directly into the ASM input tray or the conventional centrifuge. If the conventional centrifuge was in use, the specimen was put in a holding rack until the centrifuge finished the spin and was unloaded by a medical technologist. If the ASM was in use, the specimen remained in the input tray until the ASM was free and ready to be automatically loaded with the next specimen.

The conventional centrifuge required 11 min for a complete centrifugation cycle, including acceleration; 1 min was necessary for deceleration. Of the total bench time for the conventional centrifuge, an average of 53 s was required for centrifuge balancing, loading, or waiting to be loaded (Fig. 5 inset pie graph). The ASM required 1 min 9 s to perform the separation process. On average, the ASM specimens had to wait 2 min 35 s for separation because of the waiting queue in the input tray (some batches were 4 tubes or larger). The use of the ASM saved 8 min 9 s in bench time. The histogram in Fig. 5 illustrates the distribution of separation times for the ASM vs the conventional centrifuge for the samples that arrived in the laboratory during these experimental observations. Note that all of the tubes that were placed in the ASM remained on the bench for a shorter period than did those tubes that were separated in the conventional centrifuge.

Because it was not possible to place the ASM in the central laboratory, we simulated the effects of batch size on separation efficiency (Fig. 6). The assumptions made for this model included a minimum of a 10-min spin in the conventional centrifuge, precentrifugation tube handling of 7 s for the conventional tubes, and availability of the conventional centrifuge whenever needed. The simulation model predicted that the ASM was more efficient for batch sizes <10, whereas the conventional centrifuge was preferred for batches >10.

Under the usual conditions in our outpatient laboratory, samples arrive in the laboratory at the rate of one every 4 min. Because arrival rates lower or equal to 1 tube each 1 min 9 s theoretically will not queue the ASM (i.e., the next tube would not arrive before the ASM is free for use), the arrival rate in our outpatient laboratory favors use of the ASM for specimen separation. Therefore, serial processing is more efficient than batch processing until the arrival rate of specimens exceeds the average 1 min 9 s processing time for the ASM. The serial nature of the ASM makes it preferable for laboratories with low to moderate volume (~60/h).

We also applied our simulation model to the separation process in our central laboratory. For this, we gathered data based on laboratory observations of our technologists processing Vacutainer Tubes. During our study period of 2 h 25 min, 30 specimens arrived in the laboratory. The technologists required 1 h 51 min to process these specimens in two conventional centrifuges. When we simulated the effect of placing an ASM in the laboratory to process the same number of tubes at the same arrival times without using the conventional centrifuges, the processing time was only 42 min. Therefore, our simulation

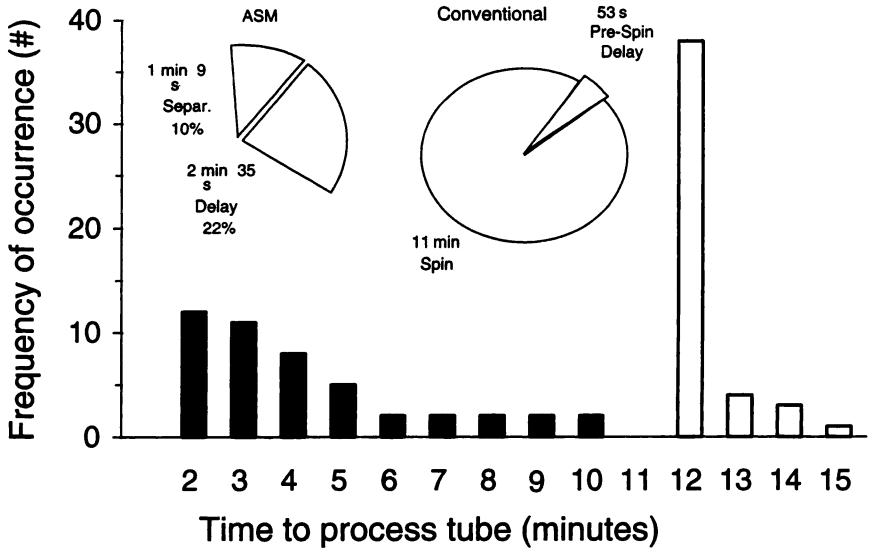

Fig. 5. Histogram depicting the distribution of bench times measured for specimen separation by ASM (*shaded bars*) and conventional centrifuge (*open bars*) in an outpatient laboratory.

Note that all specimens separated in the ASM had shorter bench times than comparable specimens in the conventional centrifuge. Individual *bars* represent the number of specimens centrifuged in *x* min or less. The *inset pie graphs* compare the average bench time for the ASM (*left*) and conventional centrifuge (*right*). Total bench time for the ASM was 3 min 44 s ± 2 min 18 s (separation = 69 ± 3 s; preseparation queue = 2 min 35 s ± 2 min 18 s); for the conventional centrifuge, 11 min 53 s ± 1 min 25 s (separation = 11 min ± 0 s; precentrifugation queue = 53 s ± 1 min 25 s). The percentages labeled on the ASM pie graph are relative to the conventional centrifuge bench time (i.e., 11 min 53 s = 100%).

model predicted a total time savings of 67 min (62%) for the ASM . If we assume that a technologist is dedicated to the task of specimen separation (as is sometimes the case in stat laboratories), then ~0.5 full-time quivalent (FTE) could be saved by using the ASM.

Table 1 summarizes the chemistry analysis comparisons between samples drawn in conventional Vacutainer Tubes and APCs. No clinically significant differences between the two methods were found. A graph of the data for which the correlation coefficient was lowest is shown in Fig. 7.

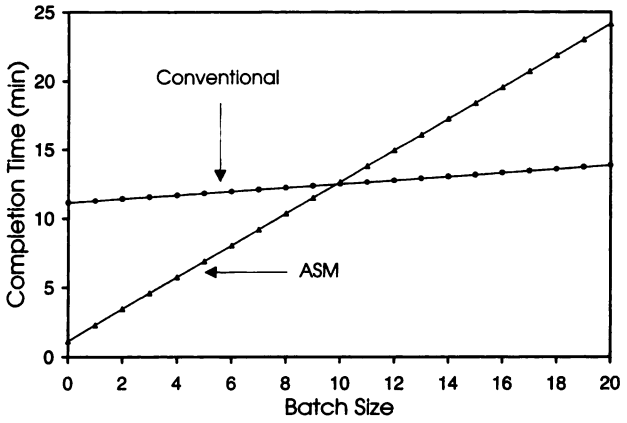

Fig. 6. Simulation of the effect of the arrival of different batch sizes on bench time for the ASM vs the conventional centrifuge, assuming no wait for either instrument, 3 s to load a single tube into either instrument, and 4 s to open/close the lid of the conventional centrifuge.

Note: If 10 tubes arrive at one time in the laboratory, the time required to process the tubes will be ~11.3 min for either separation method. The simulation defines the end of the separation process as the point when the last tube in the batch is completely separated and ready for removal from the centrifuge.

Discussion

High throughput and wide variety of analysis have been the focus of the diagnostic industry for 20 years. With high-volume analyzers has come the need for increasing numbers of employees in the preanalytical phase to keep up with the analytical systems. Currently, almost 30% of laboratory employees are used to prepare specimens for analysis. Limited reimbursements to laboratories in an era of managed care has made it impossible to increase laboratory staff in proportion to increasing test requests and still remain competitive. Therefore, laboratories have been looking for ways to improve efficiency and reduce costs. However, only limited progress has been made in providing affordable automation to improve the efficiency of the preanalytical phase of specimen analysis.

Commercially available devices for automatic centrifugation are beginning to appear on the market *[7]*. However, many of these automated centrifuges are being sold as large, integrated, preanalytical processing devices. For example, preanalytical automation is available from IDS Ltd. of Japan through Coulter (Miami, FL), Hitachi/Boehringer Mannheim (St. Louis, MO), Olympus America (Lake Success, NY), Lab Interlink (Omaha, NE), and Autolab (Etobicoke, Ontario, Canada). Fully configured systems require >10 m^2 of floor space and cost >$400,000. The centrifuges used in these systems are inherently large to attain the high throughput capacity. For example, the Coulter IDS system has been designed with an integrated centrifuge that has the necessary robotic devices to automatically load the centrifuge. Automated balancing is achieved by adding balanc-

Table 1. Chemistry comparison between samples in Becton Dickinson Vacutainer Tubes (BD, *x*) and those in APCs (*y*).

Analyte	Mean		SD						
	BD	APC	BD	APC	n^a	Slope	*y*-intercept	R^2	$S_{y|x}$
Anion gap	10.4	10.2	1.7	1.7	51	0.64	3.52	0.43	1.30
Albumin	3.98	3.97	0.31	0.32	51	0.99	0.02	0.94	0.08
Alkaline phosphatase	81.6	84.5	32.6	33.3	51	1.02	1.30	0.99	3.01
Alanine aminotransferase	20.9	24.1	19.5	22.3	22	0.99	−5.16	0.98	3.00
Amylase	58.3	58.0	24.2	24.8	33	1.02	−1.49	0.98	3.48
Aspartate aminotransferase	20.3	23.3	12.3	14.5	49	0.94	4.29	0.63	9.03
Blood urea N	12.0	11.6	3.5	3.4	51	0.94	0.25	0.97	0.58
Chloride	105	105	2.9	2.9	51	0.92	8.12	0.84	1.18
Carbon dioxide	25.0	25.2	2.6	2.6	51	0.91	2.32	0.82	1.15
Creatine kinase	127	124	105	106	36	1.01	−0.91	0.99	2.91
Delta bilirubin	0.13	0.13	0.06	0.06	41	0.79	0.03	0.63	0.04
γ-Glutamyltransferase	29.5	30.9	45.5	46.1	36	1.03	0.17	0.99	1.13
High-density lipids	48.1	48.8	13.3	13.4	45	1.01	−0.05	0.99	1.36
Potassium	3.99	3.95	0.38	0.35	51	0.85	0.56	0.85	0.14
Lactate dehydrogenase	308	306	50	50	51	0.99	1.60	0.97	8.22
Sodium	141	141	2.1	2.2	51	0.82	25.91	0.61	1.40
Phosphorus	3.40	3.36	0.48	0.46	51	0.94	0.18	0.97	0.08
Total bilirubin	0.54	0.52	0.16	0.16	51	0.90	0.04	0.80	0.07
Total protein	7.51	7.50	0.51	0.52	51	0.97	0.24	0.89	0.18
Triglycerides	198	192	181	171	51	0.94	5.30	0.99	7.66
Unconj. bilirubin	0.22	0.23	0.16	0.16	47	0.96	0.02	0.93	0.04
Uric acid	4.60	4.40	1.32	1.23	51	0.93	0.12	0.99	0.15
Thyroid-stimulating hormone	1.94	2.01	1.51	1.53	25	1.02	0.03	0.99	0.07

[a] *No. of data points.*

ing tubes. Some automated centrifuges rely on a larger centrifuge head to reduce spin time by increasing the *g* force; this also reduces the need for accurate balancing of the test tubes because they represent only a fraction of the total mass. Rapid accelerations and decelerations accomplished through the use of large, high-torque motors and high-capacity brakes are used to shorten the total centrifugation time. Throughput on the IDS centrifuge is quoted by Coulter as 500 tubes per hour. Hitachi/Boehringer Mannheim also offers an automated centrifuge. This autoloading centrifuge has a 250/h, 60-sample capacity, with centrifugation times of typically 5 min at 2000*g*; it can be programmed to run when full, after an elapsed time, or in stat mode. The advantage of this approach to centrifugation is the ability to use any commercially available blood tube. Costs for these types of centrifuges exceed $30,000.

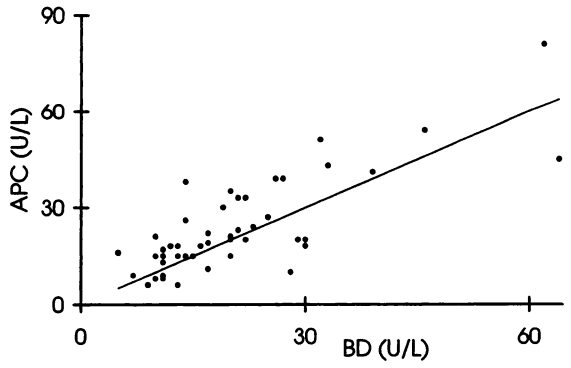

Fig. 7. Correlation between AST results obtained in Becton Dickinson (BD) Vacutainer Tubes (*x*) vs APCs (*y*), based on data from Table 1. *Solid line*, line of identity.

The ASM technology, invented by Godolphin et al. in 1988 *[3, 4]*, has the advantage over conventional centrifugation of being simple to operate, small, and relatively low cost. As Figs. 5 and 6 show, the ASM is immediately useful in smaller laboratories where average specimen arrival rates are ~60/h (1/min). We found that at this rate (or slower) the serial nature of the ASM makes it more efficient than a conventional centrifuge.

The ASM achieves specimen separation by applying gravitational forces to the side of the tube (radially) instead of to the bottom of the tube (longitudinally). The result is shorter separation times because the blood cells have only the shorter radial distance to traverse (0.65 cm radius instead of ~7.0 cm length). Axial separation subjects the cells to shear forces, whereas the forces applied in conventional centrifugation are more compressive. However, the forces in the ASM are not great enough to damage the cell walls: We measured no increases in hemolysis or potassium (present in high concentrations in erythrocytes) and no increases in lactate dehydrogenase (present in high concentrations in leukocytes). When chemistry results obtained from axially separated plasma were compared with those from conventionally separated plasma, no clinically significant differences were seen.

The ASM used in these studies accepts as many as 10 tubes in its sample introduction tray. Finished APCs accumulate in the

output tray. To accomplish cell separation radially requires a special container. The phlebotomist draws blood in through the bottom of the APC. A specialized separator in the container is pushed down the length of the tube while the sample is spinning, causing the plasma to accumulate in the upper chamber of the container and the blood cells to remain permanently trapped below the separator. This process recovers ~80% of the plasma with negligible cell contamination. We found the plastic separator to be a superior permanent barrier between formed elements and plasma when compared with the silicone gel in traditional centrifuge tubes, particularly when specimens have to wait long periods before decanting, experience harsh transportation environments, or are subjected to excessive heat.

The throughput advantages of axial separation are readily observed in situations such as the low-volume outpatient laboratory used in this study. Specimen bench time was reduced dramatically when samples arrive in the laboratory about one every minute. Occasional bolus arrivals exceeding two tubes per minute may also be accommodated. Tube balancing is not required. The automated loading feature of the ASM for a specimen in the input tray queue allows continuous operation, avoiding the delay encountered when the technologist is unavailable to load the centrifuge—unlike the situation for a conventional centrifuge. The ASM also automatically unloads the specimens.

The greater per run capacity of conventional centrifugation results in improved efficiency for that method when specimen arrival rates are faster than the ASM separation time (>~60/h) (Fig. 6). The University of Virginia Health Sciences Center (620 beds) experiences high-volume arrivals of this magnitude only during several morning hours. For the remainder of the day, specimens arrive more slowly than 1/min. In the stat area of the laboratory, medical technologists generally centrifuge queued specimens as soon as the centrifuge is available. We observed that such stat batches are seldom >5 tubes and most commonly were <3. This agrees with data gathered for hospitals with similar occupancies *[3]*. Except for the busy morning hours, we calculated that one ASM could replace the load handled by two conventional centrifuges.

Calculating the return on investment for the ASM must take into account the time saved for the technologist in specimen-handling time as well as the additional utilization of technologist time while the centrifuge is in operation. Active time for a technologist includes loading and balancing the centrifuge, unloading, sorting, and sample handling. The ability to multitask while running the ASM might result in net FTE savings. Godolphin et al. predicted time savings for serial processing of 58% on urgent specimens and 10% on routine specimens *[3]*. Under optimal conditions, we found a 69% reduction in bench time. This degree of FTE savings can be achieved only if the technologist is dedicated to the separation task. If technologists are performing other duties as well, then the time savings is closer to 10%, depending on the degree to which they can multitask. Because the ASM requires little interaction, however, more time is available for performing other duties while specimens are being separated.

The shortened bench time for medical specimens by the use of the ASM results in an 8-min savings in total specimen turnaround (blood collection to result availability). Bench time savings can be as much as 22 min for specimens that arrive in the laboratory just after the time the batch centrifuge has been started. This time savings may not seem dramatic but could greatly affect some analytical tests that are perceived by physicians to be needed in <1 h, e.g., prothrombin time and partial thromboplastin time in critically ill patients. Adding phlebotomy and labeling times (10 min) and transportation time (20 min) to analytical time (20 min) leaves only 10 min for separation to meet this request. Using conventional centrifugation, we currently require an average of 60 min to provide coagulation results on inpatients, but the range of total turnaround time for this is 48–72 min. Fig. 2 shows, however, that 75% of all specimens were processed in <4 min by the ASM and 11 min by the conventional system. This time savings with the ASM may allow a greater number of coagulation test results to be returned to the physician in less than the perceived ideal turnaround of 1 h.

When one considers the entire specimen analytical process (not just bench time), use of the ASM can save time in additional areas as well. For example, performing separation at the point of care would allow only separated specimens to arrive in the central laboratory facility; separated specimens can be immediately dispatched to the analyzer, thereby avoiding the queue in the accessioning area. Combining use of the ASM with other time-saving technology (e.g., consolidating more testing at the patient's bedside *[8]*) would further significantly improve turnaround time. Given that further studies are needed on the effect of specimen separation time on overall turnaround time, we are currently evaluating the effect of the ASM on total specimen turnaround time in an outpatient clinic where the ASM is integral to phlebotomy.

In conclusion, the ASM in combination with the APCs offers an excellent alternative to batch centrifugation. We have demonstrated directly its use in an outpatient clinic and recorded a bench time savings of 69%, a savings of at least 8 min of specimen turnaround time. The ASM is also easier to use than a conventional centrifuge because loading, balancing, and unloading tasks are eliminated. Furthermore, separation can become an integral part of the phlebotomy process, which will eliminate the separation queues that occur in a centralized processing area.

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