terested parties more valuable contributions of sonics to industry may well be expected.

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New Principle of Closed System Centrifugation

James L. Tullis, Douglas M. Surgenor, Robert J. Tinch, Maurice D'Hont, Frederic L. Gilchrist, Shirley Driscoll, William H. Batchelor

Owing to its easy availability, blood was one of the first human tissues to undergo definitive chemical study. However, certain of the components have been difficult to obtain in their true state in nature. This often has given rise to conflicting data. The dynamic state of blood within the body, as well as its peculiar property of being able to change from a liquid to a solid, makes the static conditions of blood outside the circulation highly artificial. The early discovery that citrate and other calcium complexing agents would block coagulation has been estimated (*1*) to have slowed certain types of hematologic research by several decades. This is not due to intrinsic damage from citrate ion. Rather, it is because blood rendered incoagulable can be collected without attention to its labile components. This has led to the universal collection of blood, for either analysis or therapy, under nonphysiologic conditions; rubber tubing, warm glass bottles, and anticoagulant solution, followed by a variable storage period during which the equilibrium state of cell destruction and resynthesis no longer obtained.

In an effort to surmount these conditions, work was begun in 1949 by Edwin J. Cohn and collaborators on equipment designed to collect and fractionate blood as early as possible in its natural state. The underlying principles were simple: rapid cooling, nonwettable surfaces, low turbulence, minimal gravitational forces, closed-system sterility, and rapid removal of the cytologic components before enzymatic degradation could ensue. In an effort to make these fundamental techniques applicable to tissues other than blood, the engineering was developed in such a manner that broad versatility was permitted. As a result, a basic centrifuge system was evolved which has almost equal application to virus purification, milk stabilization, and the separation of other multiphase systems. Its performance thus far has been chiefly assayed in the blood field, owing to the central theme of the originating laboratory (*2*).

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Closed System

In the design of the apparatus, all parts that come into contact with blood or other biologic material were completely segregated from the mechanical and electric components necessary for power and control. The mechanical component, designated the "cartridge," is simple in design; it is sterilizable in an autoclave and has attached to it the collection assembly and receptacles for storage of the individual fractions. The "cartridge" can be stored indefinitely in an open area, because of a locking device which assures maintenance of "closed system" sterility (Fig. 1).

Collection of the effluent fluids and cell suspensions is accomplished by means of coaxial rings which are a part of a dynamic or centrifugal valve. Thus, effluent discharged under centrifugal force is collected in an outer annular space; the material that drains after decelerating the bowl is collected in a separate, inner, annular chamber. Adoption of this principle avoids the need for manifolds to control the flow of liquids into their respective receivers. All connections into and out of the apparatus are thus made on a stationary, collecting assembly (Fig. 2).

Three basic bowl designs are employed in the centrifuge: an inverted conical-shaped, two-compartment bowl (type I); a peripheral-feed, long-traverse bowl (type II); and an inverted, cylindrical, falling-film bowl (type III). These make possible diverse types of separation which involve the removal of cells or precipitates from a liquid medium. The three bowls also possess internal flexibility by means of a locking device in the midportion of the bowl. This permits the insertion of various dividing baffles without change in the outside dimensions or in the relationship of the bowl to the drive mechanism. It also permits facility of disassembly for thorough washing, resurfacing, and removal of pyrogens.

Type-I Bowl

The separation of certain cytologic components of the blood is a typical example of the use of type-I bowl (Fig. 3). Blood contains three formed elements of varying average densities—red cells (1.095), white cells (1.065), and platelets (1.032)—suspended in liquid plasma. Sedimentation (either spontaneous or accelerated by rouleaux reagents) and low-speed centrifugation have generally been used for separation of the three kinds of cells. The densities of the three cell types represent average values only. Considerable variation exists in both size and weight. As a result, no single mechanical system has ever led to a pure yield of cells. Partial purification of a single kind of cells has been achieved by repeated packing of blood in a bucket-type centrifuge with pipette removal of the layer that most closely corresponds to the desired cell population. The present device permits a continuous-flow system

wherein such recycling can be effected in a closed system without alteration of the overlying gas phase and without penetration of a sterile seal.

Continuous separation also permits the use of a small centrifuge vessel, since only a part of the total volume is in the bowl at any given time. The shape of the separation vessel is critical and should vary with the centrifugal force employed, the specific gravity of the various cells, and the average viscosity of the liquid phase, in this instance, plasma. For the separation of red cells at a low centrifugal force, the ideal shape is that shown in Fig. 3. Incoming blood enters from below and feeds by gravity to the top of the inverted cone at a flow rate of 50 milliliters per minute. This is controlled by the height of the donor or blood bottle above the apparatus. It impinges onto the revolving surface at nearly dead-center so that minimum shearing force occurs. Thence, it flows to the periphery of the bowl and then by gravitational force passes down through the centrifugal field.

The forces acting on blood cells in the upper compartment of a bowl revolving about a vertical axis are centrifugal force, moving the cells outward, and gravitational force, moving the cells downward. In a centrifuge operating at less than 450*g*, this second factor assumes considerable importance. The shape of the upper compartment of type-I bowl is so designed that it permits maximal cell accumulation with minimal convexity along the inner face of the red cell mass as it advances toward the central (overflow) axis. As the upper bowl fills, plasma is displaced and overflows along a central weir which embodies an automatic valving principle.

After 500 milliliters of blood has passed through the apparatus, 220 milliliters of clear plasma will have passed into an individual container leaving the red cell mass, the overlying layer of "buffy coat," and enough retained plasma to permit fluidity. If a high plasma yield is desired, the centrifugal force is increased to 475*g*, thus packing the cells tighter and yielding an added increment of 25–35 milliliters of clear plasma on partial deceleration.

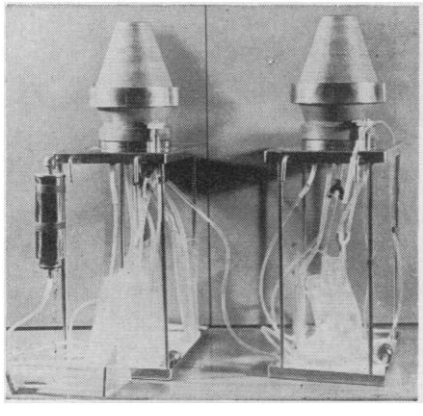

Fig. 1. Two assembled cartridges ready for insertion into centrifuge.

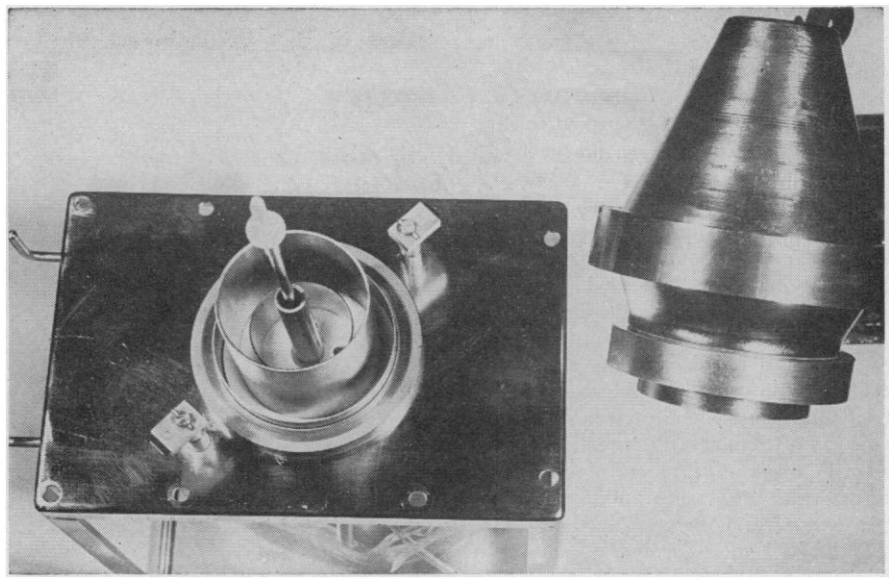

Fig. 2. Collecting cup and assembly with centrifuge bowl removed.

The dynamic state within type-I bowl revolving at 425*g* is postulated as follows: at a fixed flow rate, temperature, and rotational speed, the only variable is that of red cell volume. The inflow blood enters the apex of the inverted bowl and flows outward at a fixed rate of acceleration. Red cells begin to accumulate at the edges of the bowl. The density of material within the bowl ranges from 1.027 (plasma) to 1.095 (red cells). At a given point along a vertical axis within the bowl, a *static zone* will exist whose density is higher than that of white cells and lower than that of red cells. This zone remains static because red cells and plasma leave, owing to centrifugal force, as fast as red cells in miscible plasma enter, owing to constant flow rate. The white cells never penetrate this zone, because of its density. Likewise, they never pack, owing to continual bombardment of entering red cells and escaping plasma. The accumulation of red cells disturbs this static zone as it moves toward the point of overflow.

A buffy coat layer begins to form after the bowl capacity has been reached, because the effective centrifugal force has decreased owing to red cell accumulation, thus producing less disturbance at the zone of interface. If the buffy coat is desired as a separate component, the revolving bowl is decelerated slowly to 40*g*, but is not stopped. The resulting decrease in volume causes spillage of approximately 25 milliliters of cell concentrate with a mixed population of red and white cells in an average proportion of 5 red cells to 1 white cell. The white cell yield of this mixture may later be increased, either by recycling the buffy layer or by recycling plasma as a "wash" over the inner surface of the revolving red cell mass.

White cell recovery. In attempts to improve the recovery of the "buffy coat," many variations in bowl principle and operating technique have been studied. These include peripheral feed, rather than central feed, and variation in flow rate and centrifugal force. One method consists of blood collection into a bowl in which the standard central part is replaced by a single baffle dividing the bowl into upper and lower compartments. At the end of a 500-milliliter phlebotomy, the red cell bowl is decelerated to 60*g*, and saline is introduced through the feed port at a rate of 250 milliliters per minute. This effectively removes part of the buffy coat layer and yields as high as 70 percent of the theoretically available

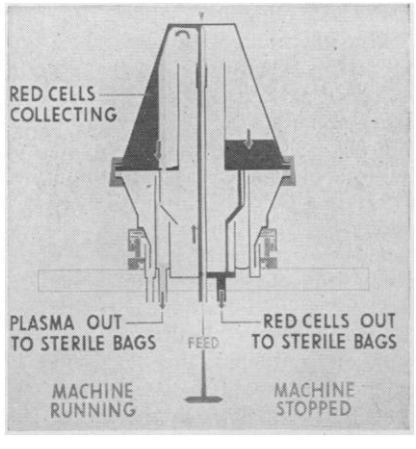

Fig. 3. A stainless steel, two-compartment bowl with continuous flow to the top of inverted cone. Capacity of upper compartment, 280 milliliters at 425*g*. Lower weir contains dynamic valve for separation of overflow liquid from precipitate, which remains in bowl during operation and drains through separate port after deceleration.

white cells, mixed with 7–10 percent of the red cells.

The suspension can be purified further by passing it through a second bowl (*3*) containing a thin layer of albumin of density 1.078. The recovery of leucocytes from this second purification averages 20 percent of the theoretic number of cells entering the second bowl. The ratio of white cells to red cells averages 1/4.

Another method requires interruption of the initial red cell-plasma separation after 8 minutes of centrifugation. Blood from the donor is collected into a reservoir rather than into the revolving bowl. Four hundred milliliters of blood is then forced from the reservoir at 50 milliliters per minute and is centrifuged at 425*g*. The bowl is then decelerated slowly to 60*g* over a 45-second period. A yield of 50 milliliters of plasma is obtained by this deceleration. An average of 17 percent of the white cells is present in this plasma with a white cell-to-red cell ratio ranging from 1/1 to 1/3. The bowl is then reaccelerated to 425*g*, and the remaining 100 milliliters of blood is introduced from the reservoir in a 2-minute period. Deceleration is again accomplished as in stage one with a recovery of an added white cell increment which averages 25 percent.

Mixed platelet and buffy coat recovery. Under routine methods of collection, the concentration of platelets in the buffy coat is generally small, averaging less than 20 percent. This is due to the low density of platelets and the high viscosity of plasma at operating temperatures of +4° to +10°C. If it is desired deliberately to include platelets in the buffy coat, the original separation can be effected at higher gravitational force or the inflow of blood can be halted after full-bowl capacity is reached, and the entire mass can be centrifuged in a static state. The method for obtaining platelets in a high yield without admixture of white and red cells is described in another section.

Packed red cells and plasma. The routine, semiautomatic recovery of packed red cells (with overlying buffy coat) and cell-free plasma is easily accomplished with type-I bowl. Separation takes place during the actual bleeding and is completed synchronously with removal of the needle from the donor's arm. Flow rates and centrifugal force have been designed to correspond to bleeding times of 10 minutes. If desired, the blood may be collected in an area remote from the centrifuge with later attachment of the machine and subsequent sterile fractionation. A separate individual "cartridge" consisting of the revolving bowl, attached containers, in-flow tube, cooling coil, and anticoagulant solution or ion-exchange resin column, is used for each individual phlebotomy. In a consecutive series of 1575 red cell-plasma separations, clear plasma was obtained on 1480 occasions. In 30 collections, slightly pink plasma was obtained, owing to friction at the top of the feed tube from excessive spring pressure. A small overflow of red cells occurred during the last 50 milliliters of plasma in 65 other collections. This was generally due to an abnormally high red cell mass in the donor blood.

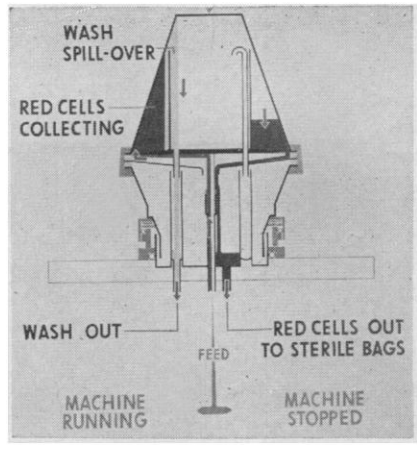

Fig. 4. Stainless steel, two-compartment bowl with continuous feed to the undersurface of central plate. Capacity of upper compartment approximately 350 milliliters at 425*g*. During operation, the upper compartment drains by overflow along a central tube that traverses the lower compartment without entering it. Cells from the upper bowl drain backward into a separate container following cessation of centrifugal force.

Four hundred eighty of the 1575 collections were made with the blood first passing into a reservoir containing anticoagulant solution with subsequent transfer into the revolving bowl. Anticoagulation in the other experiments was by calcium removal on a sodium cycle, cation-exchange resin. The average plasma yield was 220 milliliters.

In order to check accurately on the viability of red cells separated in the centrifuge, a collaborative study was made in association with John G. Gibson II, at the Harvard Medical School. The postinfusion survival of red cells that had been separated and processed in the centrifuge was studied in ten experiments by the radiochromium technique. The *in vivo* survival characteristics were compared with the well-documented survival of red cells collected into ACD anticoagulant solution NIH Formula B and manually separated. The results are fully reported elsewhere (*4*). It was concluded from the study that red cells separated in this apparatus, showed *in vivo* survival which compared favorably with cells that had been collected and separated by standard techniques.

Type-I bowl recently has been used elsewhere for experiments in plasmapheresis and leucopheresis. The completely closed system makes possible the reinfusion of a selected component of blood back into the original donor without fear of bacterial contamination. Early plasmapheresis experiments in an "open system" by Griffols-Lucas (*5*) suggested this as a means of increasing the yield of a given component of blood. Later calculations by Stokes (*6*) emphasized the public-health implications of such controlled bleedings. It was postulated that the (biweekly) bleeding of 2900, high-titer, hyperimmune donors with reinfusion of their red cell mass at the time of each bleeding would result in the same yield of antibody-containing gamma globulin as the present random annual bleeding of 4 million normal donors. Experiments on the adaptability of type-I bowl to plasmapheresis is under study by Stokes and Smolens and is the subject of a separate report (*7*). To date, 550 plasmapheresis experiments have been carried out in this manner without reaction.

Studies by Stephen Chapman at the University of Louisville have shown a unique effectiveness of the standard red cell-plasma bowl for concentration of virus by adsorption on red cells and by precipitation through the addition of zinc reagent inside the revolving bowl. The continuous-flow (recycling) capability of the system makes possible the isolation of small amounts of virus from large quantities of material. The closed system simultaneously assures protection of the experimenter and of the virus itself (*8*).

Type-II Bowl

The infusion of glycerol into red cells and the removal of glycerol from frozen and thawed red cells are typical examples of the use of type-II bowl (Fig. 4). It has recently been demonstrated (*9, 10*) that treatment of red cells with glycerol or other polyhydric alcohols will permit subsequent long-term storage at a temperature below freezing. Such cells possess *in vivo* and *in vitro* survival which compares favorably with that of ordinary "banked" blood which has a 3-week dating period at +4°C. The single factor that has most significantly delayed the application of this revolutionary principle to blood preservation has been the advisability of removing the glycerol prior to reinfusion into a recipient. The rate of water endosmosis is roughly 4 times greater than glycerol exosmosis. Red cells containing a high concentration of glycerol, when placed in an aqueous phase containing 0.15*M* sodium chloride and no glycerol solution, will take in water so much more rapidly than they will give up glycerol that prompt swelling and lysis occur. The standard laboratory methods of equilibrating with

glycerol before freezing and removing glycerol after freezing and thawing are time-consuming and difficult to accomplish with sterile technique.

Glycerolization and deglycerolization. Blood collections of 500 milliliters each are made into a reservoir containing anticoagulant solution. The blood is then forced to the undersurface of the metal plate in the mid-portion of the bowl at a flow rate of 45 milliliters per minute, with a gravitational force of 425*g* within the revolving bowl. The suspension passes to the periphery and enters the upper chamber by centrifugal force. As the upper bowl fills to its capacity of 350 milliliters, the blood separates into a lighter plasma layer and a heavier red cell layer. The clear plasma rises to the inner axis and overflows through an exit tube. The overflow plasma is collected separately and may be used for platelet concentration or any other desired purpose. Without interruption, a glycerol solution (Table 1) is introduced at a flow rate of 30 milliliters per minute until a total of 1000 milliliters has been passed through the bowl. When desired, a series of solutions of increasing glycerol content may be used. This permits a more rapid flow rate (owing to lower viscosity) and avoids the slight hemolysis that sometimes follows the direct introduction of 40-percent glycerol. The bowl is then stopped, and the glycerolized red cells drain into a suitable container for removal and storage at the desired temperature below freezing.

To remove glycerol from previously frozen and thawed cells, the process is essentially reversed. The thawed cells are fed into an empty revolving bowl. Glycerol rises to the inner axis and overflows. Two wash solutions (Table 1) are attached to the assembly in a tandem arrangement and are forced into the bowl in such a manner as to give a gradual gradient between the two solutions so that the first wash contains 10-percent glycerol and 0.496*M* lactate, whereas the final wash contains 0-percent glycerol and 0.156*M* lactate. These solutions have less density than the heavy glycerolized cells and rise toward the inner axis, maintaining a slow but constant flow, thus dialyzing all glycerol from within the red cells. A total wash volume of 4 liters is used. Finally, a suspending medium is introduced to displace the final wash solution. The centrifuge is stopped and the red cells are allowed to drain by gravity into a bottle or bag containing protein, glucose, and isotonic salt.

Table 1. Ingredients for solutions

Glycerolizing Solution	
Sodium lactate	0.156*M*
Glycerol	40% (w/v)
Potassium Chloride	0.004*M*
Distilled water	q.s.
Deglycerolizing solutions	
Wash solution No. 1:	
Sodium lactate	0.496*M*
Glycerol	10% (w/v)
Potassium Chloride	0.004*M*
Distilled water	q.s.
Wash solution No. 2:	
Sodium lactate	0.156*M*
Potassium Chloride	0.04*M*
Distilled water	q.s.

The recovery of red cells at the completion of the full processing of glycerolization, freezing, thawing, and deglycerolization varies from 70 to 90 percent. The final glycerol concentration averages less than 200 milligrams, as assayed by the method of Karnovsky (*11*). Cells so treated have shown osmotic fragility curves equal to freshly isolated cells that have not undergone glycerolization and freezing. Successful *in vivo* survival studies utilizing chromium-tagged cells processed in this manner are the subject of a separate report (*12*).

Approximately 150 units have been glycerolized and 200 units deglycerolized by these techniques. The average elapsed time for glycerolization has been 45 minutes and for deglycerolization 120 minutes. The process is semiautomatic, and, once proper flow conditions are established, multiple separations can be instituted, thus greatly shortening the operation time per unit of cells. The amount of hemolysis and free hemoglobin in the supernate is related to the time of storage, temperature of storage, and glycerol content rather than the processing itself. For direct processing and freezing without prolonged storage, the cell loss from hemolysis averages less than 1 percent (*13*).

Type-III Bowl

The separation of platelets from fresh plasma is a typical example of the use of the type-III bowl (Fig. 5). Platelets have an average density of 1.032. Their removal from plasma, which possesses only a slight difference in density, is further complicated by the increased viscosity of plasma at low temperatures (0° to +4°C) that are optimal for platelet preservation.

Classic methods for platelet concentration require prolonged centrifugation at high speeds in order that the platelets may traverse the depth of plasma present in an ordinary blood bottle or plastic bag. This lengthens the time that the cells are in contact with their substrate coagulation proteins under *in vitro* conditions. Moreover, the standard techniques do not permit continuous-flow, closed-system methods which are necessary in order to wash completely the platelets free of plasma proteins. Experience with the new falling-film type of bowl points to markedly increased platelet yields with fewer altered properties.

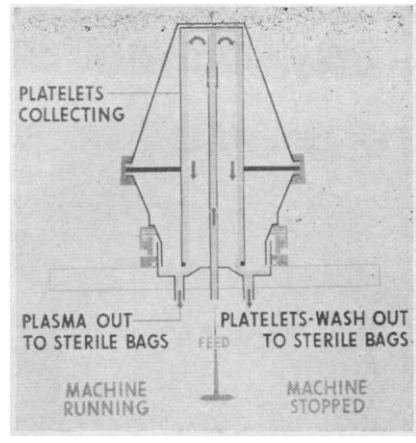

Figure 5. Stainless steel, single-compartment cyclindrical bowl, with continuous flow to top plate. Capacity 25 milliliters at 250*g*. Drainage through single outlet port in collecting cup.

Platelet concentration for in vitro and in vivo use. Five hundred milliliters of fresh whole blood is collected over an appropriate deionizing column of carboxylate resin on the sodium cycle or into an attached reservoir containing anticoagulant solution. The blood then flows into type-I bowl, which is modified by the inclusion of a ¼-inch spacing ring to increase the volume to 324 milliliters. Operating conditions for this separation include reduction of centrifugal force to 300*g* or less with maintenance of the standard flow rate of 50 milliliters per minute. This permits retention of a higher platelet content in the overflow plasma: averaging slightly greater than 60 percent in 50 experiments.

If it is desired to recover the platelets that remained with the red cell mass, the packed red cells may later be resuspended in the platelet-free plasma and recycled through type-I bowl (*14*). The overflow plasma containing platelets is then passed at a flow rate of 10 milliliters per minute under positive nitrogen pressure through a connnecting tubing into type-III bowl and centrifuged at 250*g*. After the first 25 milliliters of plasma has entered, all subsequent plasma passes as a film over the surface and emerges through the single collecting port at the bottom. This reduces to a few millimeters the distance any platelets or precipitate must move to be freed of the liquid phase as it falls in a film through the centrifugal field.

During the exposure to the centrifugal field (approximately 8 seconds) the cells move out of the axial flow and eventually concentrate in a capillary layer along the sides of the bowl. At the com-

pletion of the separation, the bowl is decelerated slowly allowing the hold-up volume of plasma to drain without removal of the capillary film of platelets evenly distributed along the wall. The bowl is then reaccelerated and a series of wash solutions is introduced through the original feed port. The process of washing and draining can be repeated until the desired freedom from entrained protein is achieved. The bowl is then decelerated abruptly. This has the effect of scooping the platelets from the wall of the container, causing them to flow out in an even suspension.

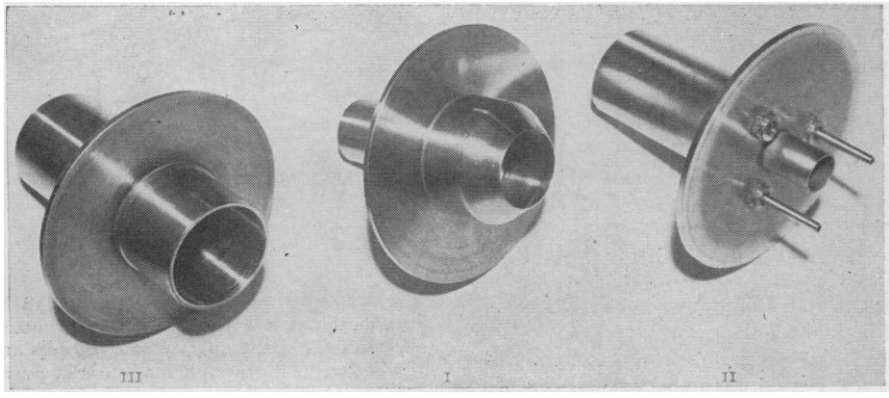

Fig. 6. Angle view bowl inserts 1, 2, and 3.

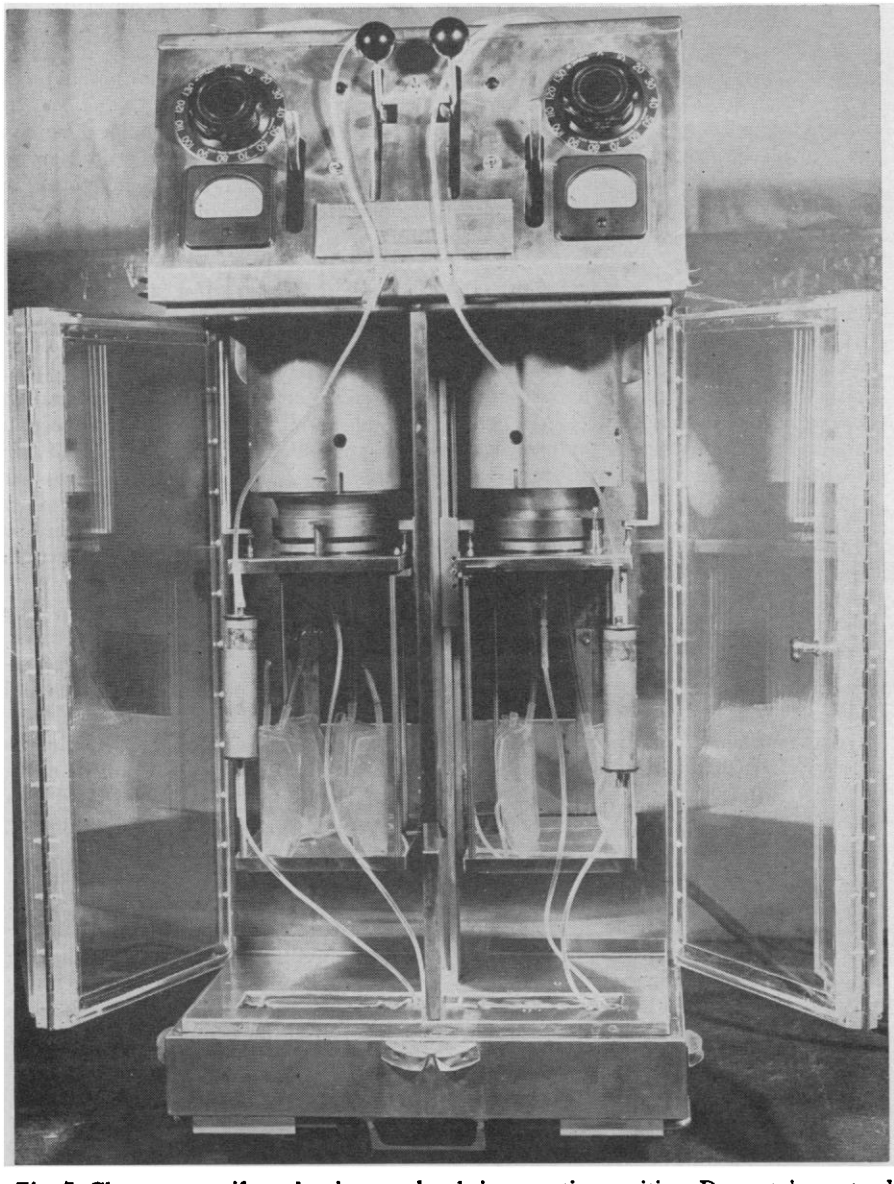

Fig. 7. Close-up centrifuge showing two bowls in operating position. Donor tubes extend from top to ion-exchange columns, cooling baths and thence into centrifuge bowls.

In 150 consecutive experiments, the platelet counts in the final storage media have averaged 800,000 per cubic millimeter, representing an average yield of about 50 percent of the available numbers (*15*). Platelets isolated by this technique have been the subject of extensive *in vitro* and *in vivo* study. They have shown stability sufficient for preservation in excess of a year by methods outlined elsewhere (*16*).

Sterile Seal

The desired bowl, centrifugal valve, stationary feed tube, collecting assembly, and attached plastic bags, tubing, resin column (or anticoagulant), and donor set are all mounted prior to sterilization. A firm locking device holds the various rotating parts in firm apposition with the collection system, so that no precautions are necessary for prolonged storage in an open room. Moreover, the autoclave methods include passage of steam and sterile nitrogen gas through the bag or bottle assembly, so that positive pressure is maintained during storage. Inspection of the "cartridge" before use for presence of inflated bags assures effectiveness of the seal. Any leak, if it were to occur, would be in an outward, rather than an inward, direction, owing to the internal positive pressure during storage.

At the time of use, the locking device is removed. Contact is maintained between the bottom of the revolving centrifuge bowl and the uppermost part of the stationary collecting system by gentle spring pressure on a graphite ring which mates with a stainless steel ring. The opposing stainless steel and graphite surfaces are ground flat, with the result that minimal contact between the two surfaces will still result in an airtight and bacteriologically sterile barrier. The properties of the graphite are such that high rotational force can be employed without significant frictional heat and without resorting to lubrication.

During operation, the drive force on the centrifugal bowl is applied from the outside. Positive pressure can be maintained in the bowl during operation, and any desired mixture of gases may be employed. The seal effectively protects the centrifuged material from bacterial contamination as well as the operator from the material being centrifuged. This latter condition is of singular importance in the handling of plasma contaminated by icterogenic virus or other toxic materials.

In order to corroborate the effectiveness of the seal, a collaborative program was conducted in association with the

research laboratories of a manufacturer of commercial sterilization equipment. Plastic bags containing red cells and plasma processed through the various afore-described bowls were shipped from Boston to Erie, Pennsylvania, by air express. Shipments were made twice weekly during an 8-month period and comprised 81 samples: 39 bags of red cells, 41 bags of plasma, and one bag of whole blood reconstituted after processing. Upon arrival in the collaborating laboratory, all samples were cultured and studied, utilizing techniques that followed closely those outlined in the 14th revision of *U.S. Pharmacopoeia.*

The results of this study, comprising 1040 cultures on 39 samples of red cells, 41 samples of plasma, and one sample of whole blood, were negative for bacterial growth with the single exception of the cultures from one bag of plasma that had ruptured during aerial shipment. Since completion of this study, the adequacy of the seal has been further corroborated by the routine processing of more than 500 samples of blood products which subsequently have undergone culture or direct *in vivo* use.

Concurrently with the bacteriologic testing, 43 routine samples of red cells, plasma, and platelets were also tested in animals for pyrogenicity. Rabbit testing was carried out at the Commonwealth of Massachusetts, Division of Biologic Laboratories according to *U.S. Pharmacopoeia,* revision 14. The tests showed a uniform absence of pyrogens. The same 500 samples of blood that have corroborated the sterility data also have shown freedom from pyrogens. The satisfactory performance of the equipment in this regard is believed to be due to the simplicity of the bowl assembly. Each of the three bowls can be disassembled into a conical-shaped upper and lower half (similar for all types of assembly) plus any one of the three central bowl inserts (Fig. 6). These latter are varied according to the type of centrifugation desired.

General Equipment

The three bowl principles outlined here and the complete seal unit have been incorporated into a single dual-unit drive mechanism (Fig. 7). This equipment has recently become available commercially (*17*) for research use. It contains complete refrigeration equipment for prompt cooling to +4°C with maintenance at temperatures between 0° and +10°C throughout the period of experimentation. It is mobile and can be operated from standard electric circuits of 25-ampere, 115-volt, 60-cycle single phase. Its dual-drive control permits two completely different experiments or types of centrifugation to be carried on simultaneously. The activation and braking mechanisms permit sensitive control, so that the speed of centrifugation can be varied without turbulence.

Visualization of the separation process is not possible until after the initial overflow of plasma. This occurs at about 7 minutes following institution of a standard red cell-plasma separation. For volume measurement, one can compute the measured overflow content (volumetrically in a bottle, gravimetrically in a bag) and add to the fixed volume of the bowl. For standard operations in which accurate volume measurement is not required, simple timing of flow rate has proved satisfactory. For example, in standard blood separation directly from a donor, the flow is interrupted after 10 minutes on the presumption that approximately 1 pint of blood has been collected.

References and Notes

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2. Grateful appreciation is expressed for many years of financial support to this project by the National Institutes of Health, Rockefeller Foundation, National Foundation for Infantile Paralysis, Harvard University, Protein Foundation, and industry. We also wish to acknowledge the suggestion of George R. Ryan, Abbott Laboratories, North Chicago, Ill., for a divided bowl to allow interchangeable parts, and the kind assistance and voluntary cooperation of John J. Perkins, American Sterilizer Company, Erie, Pa., during a 1-year project on sterility testing of the centrifuge products.

3. Type-III bowl: falling film.
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Solar Furnace in High-Temperature Research

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The large amount of solar energy that reaches the surface of the earth and is freely available to everyone is a great challenge to energy-conscious scientists and technicians. The world-wide interest in this problem was strikingly demonstrated at the first World Symposium on Applied Solar Energy held in Phoenix, Arizona, in November 1955 (*1*).

Solar energy is already used in experimental installations to drive engines, to heat and cool houses, to distill water, to cook food, and to generate electricity. Wherever conventional fuels are in short supply, wherever energy requirements are small and sunshine is abundant, solar energy may find limited application. But in all these uses it remains a substitute in the true meaning of the word. It must compete economically and in convenience with other forms of energy. Accordingly, whenever conventional forms of energy, including nuclear energy, become readily available, the use of solar energy loses its economic or technical justification.

There is, however, one application in which solar energy is superior to any

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