

PREPARATION AND ASSEMBLY OF THE STAINLESS STEEL SPONGE DEBUBBLER FOR USE IN THE HELIX RESERVOIR BUBBLE OXYGENATOR

BY

C. N. BARNARD, M. B. MCKENZIE, AND D. R. DE VILLIERS

From the Department of Surgery, University of Capetown, and Groote Schuur Hospital, Capetown

(RECEIVED FOR PUBLICATION MARCH 4, 1960)

Pumps to replace the function of the heart temporarily are readily available, but oxygenators that will physiologically perform the function of respiration are still in the process of development. Bubble, membrane, and film oxygenators are now being used in various centres, and some workers attempt to improve the efficiency of their apparatus by adding more and more safety devices and control gadgets.

In medicine few methods are ever ultimate, but the essential of reliability is simplicity, and we feel that, when used without unnecessary gadgets, the bubble oxygenator is safe and efficient. This is not merely an impression. Clinical application to over 70 patients using the high-flow principle during the past one and a half years at the Groote Schuur Hospital and the Red Cross War Memorial Children's Hospital has resulted in only eight deaths. The oxygenator is effective, non-traumatic to blood, easy to assemble and work, and free from mechanical failure. We have lost no patients as a result of failure of the heart-lung machine, and in the last 31 patients operated upon for congenital heart defects there have been no deaths.

Since our detailed description of the assembly and use of the helix-reservoir bubble oxygenator (McKenzie and Barnard, 1958), on the advice of Dr. R. L. Varco, of the University of Minnesota Hospitals (Varco and Hodges, 1959), we have changed to the stainless steel sponge debubbling system. This change simplifies the assembly of the heart-lung machine and has increased its safety and efficiency. It is the purpose of this paper to describe the preparation and assembly of this new debubbling chamber.

Debubbling is effected by four anti-foamed stainless steel sponges arranged around the perforated top of the mixing tube, and seated in a "teflon"-coated can (Fig. 1).

MATERIALS

THE CAN.*—This is a stainless steel cannister, 7 in. deep and $5\frac{1}{4}$ in. in diameter. The inside of the can is coated with "teflon." A hole measuring $1\frac{1}{16}$ in. in diameter is made in the centre of the bottom of this can, and this will just allow the mixing tube (made of "tygon" or "mayon," with an internal diameter of $1\frac{1}{2}$ in. and a wall thickness of $\frac{3}{16}$ in.), to pass through, giving a blood-tight fit. Another hole, $1\frac{1}{4}$ in. in diameter, which will allow the escape of gases, is made in the centre of the can's lid. Two peripherally placed outlets, large enough to take a "mayon" tube $\frac{3}{8}$ in. internal diameter, are fitted and secured in the bottom of the can (Fig. 3).

MIXING TUBE.—The mixing tube (made of "tygon" or "mayon") is 2 ft. 8 in. long, has an internal diameter of $1\frac{1}{2}$ in. and a wall thickness of $\frac{3}{16}$ in. Its top is perforated with about 30 holes, each $\frac{1}{8}$ in. in diameter. The area in which the holes are situated extends from about 1 in. to about $4\frac{1}{2}$ in. from the top of the tube (Fig. 4). These holes are pressed in the tube by means of a specially turned and sharpened piece of pipe (diameter $\frac{3}{8}$ in.) used in conjunction with a vice.

Four stainless steel sponges* are used with each mixing tube. These sponges are first boiled in a 5% solution of sodium hydroxide for half an hour. They are rinsed thoroughly and a sample of the last rinsing water is tested with B.D.H. universal indicator to ensure that there is no alkali left. The sponges are then washed with a solution of powdered detergent (such as "surf"†) and again rinsed thoroughly and then dried in a hot air oven set at 400° C.

ANTI-FOAM.—This is prepared by mixing 75 g. of anti-foam XC-2-0033‡ with 100 ml. of anaesthetic ether to form a thick paste. A further 100 ml. of ether is mixed in and the mixture is allowed to stand overnight. The next day 800 ml. of ether is added in 100 ml. amounts and the mixture is stirred well between each addition of ether.

* Obtainable from the Phelan Manufacturing Co., 2523 Minnehaha Ave., Minneapolis, Minnesota, U.S.A.

† Manufactured by Lever Bros. (SA) (Pty.) Ltd., Durban.

‡ Manufactured by Dow Corning Corp., Midland, Michigan, U.S.A., and distributed by the Phelan Manufacturing Co., Minneapolis.

FIG. 1.—Diagrammatic cross-section of stainless steel sponge debubbler for use in the De Wall/Lillehei helix-reservoir bubble oxygenator, showing the arrangement of the various components.

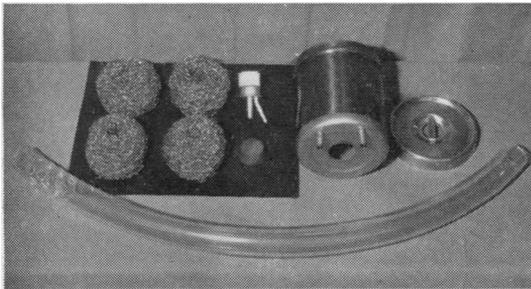
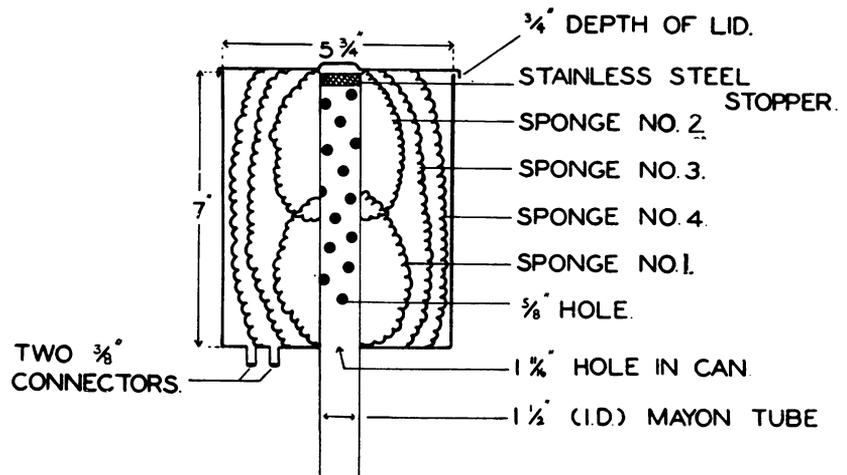


FIG. 2

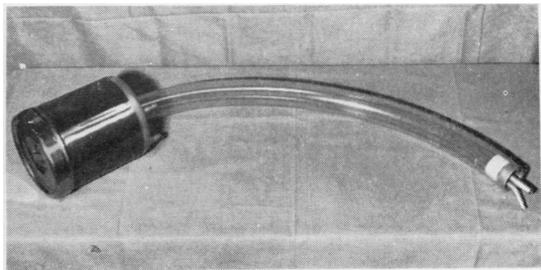


FIG. 3

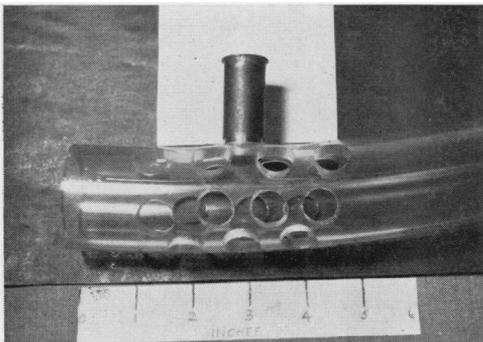


FIG. 4

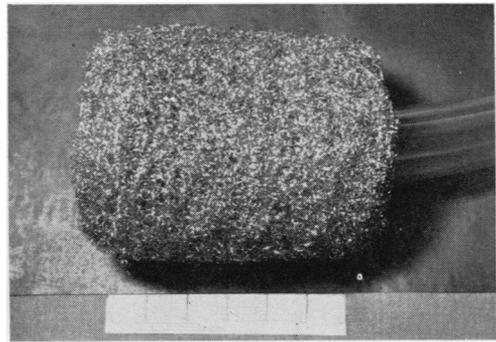


FIG. 5

FIG. 2.—The various unassembled parts of the debubbler system.

FIG. 3.—The mixing tube is shown after insertion into the bottom of the can. The two peripherally placed outlets can also be seen.

FIG. 4.—The top of the mayon mixing tube, showing the placing of holes which are made with the specially turned pipe which can also be seen in this photograph.

FIG. 5.—The stainless steel sponges have all been placed over the holes at the top of the mixing tube to form the closely knit barrier through which the oxygenated blood must pass.

FIG. 6.—The lidless cannister, as seen from the top. The stopper can be seen in place at the end of the mixing tube, around which the sponges are arranged.

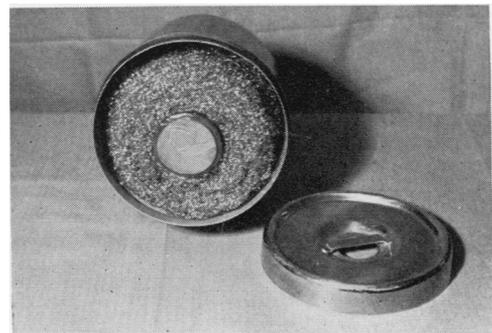


FIG. 6

The antifoam mixture is now transferred to four large centrifuge bottles and then centrifuged in an M.S.E. refrigerated centrifuge at 1,500 r.p.m. for 30 minutes. The supernatant fluid, which is pure antifoam in ether solution, is slightly opalescent, but not cloudy. (Separation of the particulate matter, particularly silica, can also be achieved by allowing the solution to stand for two days.) This fluid is decanted into dark bottles and

the residue is discarded. One thousand millilitres of antifoam is sufficient for dipping about 20 sponges.

ASSEMBLY

The mixing tube is washed, rinsed, and dried. The sponges are dipped in the antifoam/ether solution and allowed to drip dry. They should be spotlessly clean and when dipped into the antifoam/ether solution they should

TABLE I
PERFUSION DATA OF FIRST 53 OPEN HEART OPERATIONS PERFORMED USING STAINLESS STEEL SPONGE DEBUBBLING SYSTEM IN CONJUNCTION WITH HELIX-RESERVOIR OXYGENATOR

Case No.	Lesion	Weight (kg.)	Perfusion Duration (min.)	Highest Flow Rates		Arterial Pressure During Perfusion (Mean mm. Hg)	Haemolysis (mg.%)	Result
				Total	Per kg.			
18	Pulmonary valvular stenosis	35	14	2,450	70	70	—	Satisfactory
19	Atrial septal defect ost. sec.	40	27	3,000	75	80	—	"
20	Tetralogy of Fallot	57	99	3,135	55	80	101	"
21	Atrial septal defect ost. sec.	42	29½	2,730	65	55	—	"
22	Ventricular septal defect with pulmonary hypertension	48	80	3,120	65	55	78	"
23	Pulmonary infundibular stenosis with tricuspid incompetence	32	69	3,200	100	100	80	Died
24	Atrial septal defect ost. sec.	52	32	3,380	65	65	21.9	Satisfactory
25	Pulmonary infundibular stenosis + ventricular septal defect	62	45	3,720	60	70	75	"
26	Ventricular septal defect with pulmonary hypertension	22	75	1,870	85	85	64.6	"
27	Ventricular septal defect + pulmonary infundibular and valvular stenosis	20	77	1,900	95	90	68.3	"
28	Atrial septal defect with anomalous return of right superior pulmonary vein	32	62	2,720	85	75	40.3	"
29	Atrial septal defect ost. sec.	28	28	1,600	80	—	32.2	"
30	Mitral stenosis	69	54	3,795	55	65	64	"
31	Pulmonary valvular stenosis	43	23	2,800	65	70	44	"
32	Aortic stenosis with calcified leaflets	50	146	3,750	75	48	—	Died
33	"	55½	56	3,780	70	100	71.3	Satisfactory
34	Ventricular septal defect	28	61	2,430	90	100	60	"
35	Tetralogy of Fallot	58	83	3,480	60	115	72	Died
36	Atrial septal defect ost. sec.	48	36	3,360	70	58	43	Satisfactory
37	Ventricular septal defect with corrected transposition	20	70	1,700	85	85	116	"
38	Ventricular septal defect	30	44	2,400	80	100	84	"
39	Traumatic fistula (aorta R. atrium) with tricuspid incompetence	54	39½	3,250	65	100	51	"
40	Endocardial cushion defect	23½	120	1,650	75	86	213	"
41	Valvular and infundibular pulmonary stenosis	24	71	1,800	75	120	94	"
42	Mitral stenosis and incompetence	50	67	3,000	60	90	101	"
43	Tetralogy of Fallot	32	111	2,560	80	50	150	"
44	Mitral regurgitation (no stenosis)	72½	87	3,630	55	115	78.6	"
45	Endocardial cushion defect (partial)	23½	54	1,870	85	60	51.6	"
46	Atrial septal defect ost. sec. + pulmonary stenosis	54	65	3,250	65	80	61	"
47	Pulmonary valvular stenosis	20	34	1,600	80	80	23.4	"
48	Atrial septal defect ost. sec. with partial anomalous pulmonary venous return	47	41	2,820	60	60	38	"
49	Atrial septal defect ost. sec.	35	30	2,450	70	95	32	"
50	Pulmonary valvular stenosis with hypoplasia of pulmonary artery	12	60	1,080	90	80	54	"
51	Atrial septal defect ost. sec.	66	23	3,300	55	100	30	"
52	Pulmonary infundibular stenosis	28	35	1,950	75	58	58	"
53	Ventricular septal defect + patent ductus arteriosus	28	47	1,190	85	55	39.5	"
54	Mitral incompetence	56	56	65	65	95	55.3	"
55	Tetralogy of Fallot	20	72	2,112	110	60	81	"
56	Endocardial cushion defect (complete)	21	82	1,500	85	60	73	"
57	Ventricular septal defect with tricuspid, pulmonary and aortic incompetence	70	84	3,500	50	55	75	"
58	Mitral incompetence and stenosis, aortic and tricuspid incompetence	67	85	4,020	60	100	85.6	Died
59	Ventricular septal defect	19	68	1,710	95	45	62	Satisfactory
60	"	12	67	1,080	90	45	67.5	"
61	Tetralogy of Fallot	14	92	1,600	113	40	95	"
62	Mitral regurgitation	45	82	3,150	70	90	91	"
63	Pulmonary valvular stenosis	26	26	2,080	80	55	16.5	"
64	Atrial septal defect ost. sec.	19	27	1,980	90	50	35	"
65	Tetralogy of Fallot	52	80	3,520	68	70	82	"
66	Atrial septal defect ost. sec.	30	33	2,820	94	50	35.4	"
67	"	29	31	2,400	80	50	23	"
68	"	67	60	3,350	50	80	47	"
69	Tetralogy of Fallot	30	84	2,550	85	60	72	"
70	Aortic stenosis	45	47	2,925	65	60	47	"
71	Endocardial cushion defect (complete)	16	92	1,440	90	60	89	"

TABLE II

pH AND CO₂ DETERMINATIONS FROM SAME BLOOD SAMPLE FROM INTERNAL MAMMARY ARTERY IN EACH CASE

Case No.	Defect	Duration of Perfusion (min.)	pH			Total CO ₂ (m Eq. l.)			Total Oxygenation (%) During Bypass	
			Before	During	After	Before	During	After	Arterial	Venous
59	Ventricular septal defect	68	7.35	7.44	—	23.2	13.5	—	94	76
31	Pulmonary valvular stenosis	23	—	7.36	7.32	—	17.4	24.2	98	75
29	Atrial septal defect	28	7.39	7.42	7.32	—	—	—	97	73
64		27	7.36	7.43	7.41	13.52	21.24	14.35	96	64
40	Endocardial cushion defect	120	7.41	7.33	7.36	—	—	—	94	75
43	Tetralogy of Fallot	111	7.48	7.53	7.34	—	—	—	95	60
45	Endocardial cushion defect	54	7.28	7.41	7.26	27.4	19.0	29.2	93	64
47	Pulmonary valvular stenosis	34	7.41	7.41	7.38	22.6	16.1	24.6	97	60
52	Pulmonary infundibular stenosis	35	7.41	7.43	7.39	23.5	16.0	22.3	97	65
53	Ventricular septal defect + patent ductus arteriosus	47	7.35	7.40	7.34	25.0	15.0	22.0	97	71
55	Tetralogy of Fallot	72	7.42	7.38	7.38	22.2	13.9	19.1	97	78
63	Atrial septal defect	26	7.43	7.39	7.44	25.4	17.8	25.2	95	60

Samples were taken just before bypass, during bypass at 20 minutes, and 10 minutes after bypass. Blood for oxygen estimation was taken from the arterial and venous lines immediately after bypass.

not discolour it. The sponges are then arranged over the holes as follows (Fig. 1): two are arranged one above the other, well above and below the level of the holes, overlapping slightly at their junction. The third and fourth sponges are then pulled right over the first two, to form a closely knit barrier through which the oxygenated blood passes (Fig. 5). This unit is then wrapped in a cloth and autoclaved. The can is wrapped and autoclaved separately.

On the morning of surgery the debubbling system is assembled under sterile conditions. The bottom end of the mixing tube is inserted through the centre hole in the can and the tube is then pulled down until the sponges are seated in the can. Care must be taken not to move the position of the sponges and to see that all the holes in the tube are well covered. The upper end of the mixing tube is closed with a stainless steel or rubber-covered nylon stopper (Fig. 6).

The oxygen dispersal plate is placed in position at the lower end of the mixing tube. The lid is placed over the top of the can and strapped down. A piece of $\frac{3}{8}$ in. "mayon" tubing is placed over one of the connectors in the can, and this 16-in. long tube delivers blood into the helix. An adjustable clamp is placed on this tube to regulate the flow of blood. A shorter piece of $\frac{3}{8}$ in. tubing is placed over the other connector, bent to 180°, and strapped to the side of the can to act as a depth gauge. To avoid aspirating air, a reservoir of about 100 ml. blood is kept in the can and this level is marked on the gauge.

RESULTS

This type of debubbling system has been used in our last 53 open heart cases, and Table I gives some perfusion data. Flow rates were calculated in ml. per kilogram body weight per minute, varying according to the weight of the patient, a higher flow per kg. per minute being used in the smaller patient. The minimum flow rate in this series was 50 ml./kg./min. and the maximum 113 ml./kg./min. The time

of perfusion varied between 14 minutes and 146 minutes, the average length of time being 80 minutes.

Venous drainage was obtained by gravity, a difference of 25 cm. being established between the height of the operating table and the venous well. The venous pressures measured between 7 mm. Hg and 20 mm. Hg with a mean of 14 mm. Hg.

On an average, haemolysis was about 1 mg. % haemoglobin per minute of perfusion, except in patients Nos. 37 to 43 during which period faulty pump hoses with rough inside surfaces were used. Since these were discovered and replaced, no abnormal haemolysis has been encountered. In all patients there was minimal post-operative bleeding, indicating very little disturbance in the blood clotting mechanism. These facts show that destruction of blood was minimal.

The return of oxygenated blood was always into the right femoral artery and the perfusion pressure varied from 40 mm. Hg to 120 mm. Hg with a mean of 80 mm. Hg. Oxygenation and removal of carbon dioxide was always adequate (Table II).

All patients who survived the operation regained consciousness immediately anaesthesia was discontinued, and the electroencephalographic follow-ups indicated no major variation from pre-operative studies.

CONCLUSION

Though there are several types of oxygenators, we have found the bubble oxygenator, used with a modicum of extra gadgets, to be reliable and efficient. We have used this system in 53 open heart operations and the results bear out the reliability and safety of this equipment. From these results we may conclude that the bubble oxygenator, when used with the necessary precautions, is efficient and safe,

and, using the new debubbling system, there is no danger of antifoam or air embolism, even when high flows of up to 4 litres per minute are used.

We wish to thank Professor J. H. Louw, of the Department of Surgery, University of Cape Town, for his encouragement and support, and the technical staff of the Marais Laboratory—Mr. C. C. Goosen, Mrs. V. M.

Connell, and Mr. C. J. Lockett—for their valuable assistance.

We are greatly indebted to the J. S. Marais, C. L. Herman, and Fourcade bequests, and also to the Council for Scientific and Industrial Research, for financial assistance.

REFERENCES

- McKenzie, M. B., and Barnard, C. N. (1958). *S. Afr. med. J.*, **33**, 1145.
Varco, R. L., and Hodges, P. (1959). Personal communication.