FLUID AND ELECTROLYTE BALANCE DURING THE COMRADES MARATHON*

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Heat exhaustion and even death have followed marathon running. At the end of the dramatic 1908 Olympic Marathon—run in London on a hot humid day—Dorando, dazed by the heat and exhausted, entered the stadium first, ran in the wrong direction, collapsed twice and was in a semi-coma for two days. During the 1912 Olympic Marathon in Stockholm, again run on a hot humid day, Lazaro collapsed after running 19 miles and died the next day. In the Paris Olympics five runners in the 10 000 metres were hospitalized with heat-stroke following the event, and in the 1960 Rome Olympics three Danish cyclists developed heat-stroke in the 100-km road race.

The danger of inadequate water intake during marathon running has been stressed by Wyndham and Strydom[1] who showed that the rise in temperature in runners was directly related to their water deficit and reached 105°F after a 20-mile marathon. These cases of heat-stroke in the Olympics were no doubt due to deficient fluid intake.

The Comrades Marathon is a particularly gruelling event. It is run over 54 miles—twice the distance of the Olympic Marathon—and over a period of 6 - 11 hours. We were particularly interested in the sweat loss during this period, how competitors compensated for it and what effect it had on the urea and electrolytes. The 1970 Comrades Marathon was run from Durban to Pietermaritzburg.

MATERIAL AND METHODS

Thirty-one runners were randomly selected from Pietermaritzburg competitors. They were aged 19 - 51 years; some were novices, while others were experienced runners, and their training schedules varied from many months to a few weeks.

They were examined and a blood sample was taken during the week before the race and again at the completion of the race, or as soon as possible after they had stopped running. The organizers kindly provided a tent at the finishing line and although we were able to examine some patients immediately they crossed the finishing line, there was a delay of 5 - 10 minutes in seeing some competitors, and occasionally longer. There were two inaccuracies regarding the weighing of competitors: (*a*) the scale available was only sensitive to changes of ½ lb and (*b*) the competitors were not weighed immediately before the race (at 6 a.m. in Durban).

Each competitor was given a questionnaire and agreed to keep a careful record of the quantity of fluid consumed during the race and during a 24-hour period starting at the beginning of the race. He was given separate containers to collect urine passed during the race and for the 24-hour period referred to. He was asked to record any difficulties experienced, i.e. vomiting, diarrhoea and mental confusion. Co-operation was extremely good, but we had to exclude some competitors in the final analysis of fluid balance. The common faults were (*a*) having to pass urine during the race when the assistant with the container was not available, (*b*) in the excitement of the moment a spillage of urine from the containers, and (*c*) occasionally the volume of fluid drunk during the race was not sufficiently well recorded. Adequate records during the race itself were obtained in 24 of these runners, and a fairly accurate 24-hour balance was obtained in 17 runners.

In calculating the fluid consumed after the race, volumes were calculated on the following basis: a bottle of beer = 340 ml (all one type); Coca Cola (one size) = 300 ml; and a glass or cup of fluid = 200 ml.

Blood was taken immediately after the race. Particular importance was attached to analysing all blood samples on the same afternoon and evening that the race was run. Sodium, chloride, potassium, urea and packed cell volumes were estimated using standard techniques.[2-4]

RESULTS

Sweat Loss during the Race (Tables I - III)

Eight runners with an average weight of 160 lb (72·6 kg) lost more than 9 litres in sweat. Eleven whose average weight was 144 lb (65·4 kg) lost between 6½ and 8 litres and five whose average weight was 133 lb (60·4 kg) lost less than 6 litres. There was no correlation between the time taken to complete the race or the age of the runner and the sweat loss.

Fluid Intake during the Race (Tables I - III)

Two competitors drank 9½ litres. Other competitors drank between 2 and 5½ litres except for the competitor who finished in the fourth place whose total intake was six small nips of lemonade.

*Date received: 29 October 1970.

TABLE I. SWEAT LOSS/FLUID INTAKE DURING RACE

Runner No.	*Sweat loss (ml)*	*Intake (ml)*	*Water deficit (ml)*	*Water deficit %*	*Weight (lb)*	*Age (years)*	*Time*
17	12 800	9 600	3 200	4·3	162	19	9 hours
6	10 800	7 200	3 600	4·1	190	36	11 hours
5	10 400	9 600	900	1·5	131	23	7 hours
33	10 300	5 800	4 500	6·6	149	19	11 hours
9	9 700	7 200	2 750	4·3	142	22	—
34	9 300	4 800	4 500	6·0	165	18	—
2	9 200	4 800	4 500	5·2	190	35	9½ hours
16	9 000	4 500	4 500	6·4	153	39	—
Average	10 300				160		

TABLE II. SWEAT LOSS 6 600 - 7 800 ml

Runner No.	*Sweat loss (ml)*	*Intake (ml)*	*Water deficit (ml)*	*Water deficit %*	*Weight (lb)*	*Age (years)*	*Time*
7	7 000	4 200	2 750	4·6	134	51	7½ hours
10	7 800	3 300	4 500	7·1	140	49	—
12	7 300	1 800	5 500	7·5	160	45	8½ hours
13	6 900	3 000	3 600	4·7	170	41	8½ hours
14	6 500	4 200	2 300	3·7	135	29	8¾ hours
21	7 400	1 860	5 500	8·2	148	52	7¾ hours
22	7 700	3 600	4 100	6·3	144	32	8 hours
23	7 200	4 000	3 200	5·0	142	38	8¾ hours
29	7 100	3 500	3 600	5·0	148	43	8½ hours
30	7 200	4 500	2 700	4·0	150	22	7¾ hours
31	6 600	3 000	3 600	6·6	120	38	8 hours
Average	7 700				144		

TABLE III. SWEAT LOSS UNDER 6 000 ml

Runner No.	*Sweat loss (ml)*	*Intake (ml)*	*Water deficit (ml)*	*Water deficit %*	*Weight (lb)*	*Age (years)*	*Time*
3	4 300	200	4 100	6·9	130	31	6 hours
25	5 000	1 800	3 200	5·3	133	25	8 hours
26	5 000	4 500	500	0·6	159	23	9 hours
11	5 400	2 400	3 200	6·0	119	34	10½ hours
4	5 750	3 000	2 750	4·9	126	36	8 hours
Average	5 100				133		

Water Deficit during the Race (Tables I - III)

Those whose sweat loss was the greatest had the best intakes. All of those who sweat loss exceeded 9 litres drank more than 4½ litres, but in spite of this the negative balances were alarming. Water deficits of up to 5½ litres were recorded! In fact only two out of twenty-four runners had a water deficit of less than 1 litre or under 3%. One of these lost 10 litres as sweat, but drank 9½ litres during the race. Nearly half the runners (10 out of 24) had a water deficit greater than 6% of their weight. Only three runners had a water deficit of less than 4%.

Rectal Temperatures

The recording of rectal temperatures *immediately* after the race proved very difficult practically. Ten patients had rectal temperatures taken within 5 minutes of the completion of the race. One had a temperature of 99°F (his water deficit was not measured), the remainder had a rectal temperature of 101 - 102°F. All had a water deficit of over 4%. The two with the greatest water deficits (8·2% and 7·1%) had temperatures of 102° and 101°F respectively.

24-hour Fluid Balance from Commencement of Race (Table IV)

Only 2 runners were in positive balance 24 hours after the race. One of these had a water deficit of 4½ litres during the race, but made this up by drinking 6½ litres over the 24 hours.

TABLE IV. FLUID BALANCE OVER 24 HOURS (ml)

	Intake			*Output*			
Runner No.	*During race*	*From end of race to 24 h*	*Total*	*Sweat loss*	*Urine**	*Total*	*24-hour balance*
2	4 800	6 500	11 300	9 200	630 (100)	9 830	+1 570
26	5 000	1 440	6 440	5 000	1 180 (440)	6 180	+ 260
5	9 600	2 440	12 040	10 400	1 700 (90)	12 100	− 60
7	4 200	2 400	6 600	6 950	320 (—)	7 270	− 670
30	4 500	2 640	7 140	7 200	720 (205)	7 920	− 780
14	4 200	1 920	6 120	6 500	440 (70)	6 940	− 820
6	7 200	3 400	10 600	10 800	1 600 (—)	12 400	−1 800
25	1 800	1 900	3 700	5 000	570 (—)	5 570	−1 870
34	4 800	3 040	7 840	9 300	860 (200)	10 160	−2 320
3	200	2 570	2 950	4 300	1 850 (—)	5 385	−2 435
33	5 800	2 720	8 520	10 300	680 (—)	10 980	−2 460
29	3 500	1 700	5 200	7 100	780 (60)	7 880	−2 680
4	3 000	800	3 800	5 750	810 (—)	6 560	−2 760
17	9 600	1 400	11 000	12 800	1 200 (150)	14 000	−3 000
10	3 300	2 000	5 300	7 800	560 (—)	8 360	−3 060
21	1 860	4 000	5 860	7 360	1 880 (—)	9 240	−3 380
16	4 500	800	5 900	9 000	610 (130)	9 610	−3 710

*Figures in parenthesis represent volume of urine passed during the race.

Four others had a negative balance of under 1 litre at the end of this time. The remaining eleven (64%) who had 24-hour balances showed a negative balance at the end of that time of between 1 800 ml and 3 710 ml. Four still showed a negative balance in excess of 3 litres at the end of 24 hours.

Urine Output over 24 Hours

During the race itself a satisfactory record of urine passed was obtained in 26 runners, 10 of whom passed no urine at all. The others passed small amounts, the total volume varying from 40 ml to 440 ml. The 24-hour urine volume varied from 320 ml to 1 880 ml—6 out of 17 (35%) passed over 1 litre. Eight runners (47%) had a 24-hour output of less than 740 ml but in only two competitors was the 24-hour output less than 500 ml.

The volume of fluid consumed during the race seemed to have more of a bearing on the total 24-hour urine volume than the amount consumed after the race. In comparing six competitors who passed 1 litre in 24 hours to eight who passed under 750 ml, the average fluid consumed during the race was 5·6 litres in those passing over 1 litre and 4·1 litres in those passing under 750 ml. Both groups drank an average of 2·5 litres after the race. There were, however, two notable exceptions, competitors Nos. 3 and 21 whose intake during the race was only 0·2 litres and 1·8 litres, and yet they passed good 24-hour volumes—1·0 litres and 1·8 litres respectively.

Packed Cell Volume, Urea and Electrolytes (Table V)

There were moderate increases in the packed cell volume after the race in most competitors, although in 6 out of 27 it was actually lower after the race and in 2 it was unchanged. In only 7 competitors was the packed cell volume increased by 5% or more. There was no relation between the water deficit and rise in packed cell volume.

The mean blood urea among 34 competitors was 27·1 mg/100 ml before the race (range 21 - 33 mg/100 ml). After the race 30 of these competitors had a mean blood urea of 41·7 mg/100 ml (range 30 - 60 mg/100 ml). There was no good correlation between the extent of blood urea rises and the water deficit.

The potassium levels rose from a mean of 4 mEq/litre before the race to 4·6 mEq/litre after the race. In only 5 of 24 competitors did the post-race elevation exceed 1 mEq/litre. The extent of the rise in potassium was not

TABLE V. BLOOD TESTS

		PCV			Urea (mg/100 ml)			Potassium (mEq/litre)			Chloride (mEq/litre)		Sodium (mEq/litre)	
Runner No.	*Water deficit (ml)*	*Before*	*After*	*Diff.*	*Before*	*After*	*Diff.*	*Before*	*After*	*Diff.*	*Before*	*After*	*Before*	*After*
12	5 500	43	44	+1	27	38	11	4·4	5·1	0·7	102	100	134	140
21	5 500	42	47	+5	33	60	27	4·0	4·6	0·6	105	99	137	141
10	4 500	48	49	+1	37	40	3	—	3·7		100	103	135	138
33	4 500	44	50	+6	21	31	10	3·8	4·3	0·5	106	95	130	132
34	4 500	47	48	+1	25	36	11	4·1	4·3	0·2	102	97	136	132
2	4 500	43	48	+5	33	42	9	—	4·0		102	95	137	140
16	4 500	40	42	+2	29	37	8	4·2	5·0	0·8	103	107	141	137
22	4 100	46	47	+1	32	34	2	—	4·2		96	101	132	137
3	4 100	45	48	+3	32	44	12	3·9	5·0	1·1	95	102	135	139
6	3 600	41	—		23	49	26	4·3	4·5	0·2	99	102	136	134
13	3 600	47	48	+1	21	30	9	4·4	5·2	0·8	98	103	134	137
29	3 600	43	49	+6	22	58	36	3·9	5·3	1·4	100	99	134	139
31	3 600	50	46	−4	33	44	11	5·4	5·9	0·5	104	99	151	137
25	3 200	47	47		22	37	19	4·3	4·0	—0·3	100	103	143	143
11	3 200	49	51	−2·1	26	43	17	3·7	4·4	0·7	103	95	137	132
17	3 200	44	45	+1	26	50	24	3·7	4·6	0·9	102	102	135	134
23	3 200	41	40	−1	26	48	22	3·4	3·9	0·5	102	105	132	140
4	2 750	46	—	—	22	44	22	3·9	—		102	99	134	137
9	2 750	45	46	+1	23	35	12	3·9	4·3	0·4	105	103	137	136
7	2 750	43	48	+5	29	37	8	4·1	5·5	1·4	100	105	141	132
30	2 700	49	43	−6	29	37	8		4·1		95	96	126	139
14	2 300	43	45		27	49	22		4·8		95	98	134	142
5	900	44	46	+2	33	46	13	4·0	4·5	0·5	104	102	139	137
26	500	47			28	33	5	4·0	4·3	0·3	104	105	139	140
1		44	44	—	31	30	—1	3·7	4·2	0·5	102	98	136	134
8		48	50	+2	28	37	9	3·5	4·8	1·3	105	103	136	139
15		47	46	−1	31	54	23	4·0	4·7	0·7	99	104	137	140
18		48			22			4·0			103		137	
19		47	55	+8	27	50	23	4·0	4·6	0·6	107		138	
20		44	49	+5	28	44	16	3·7	4·7	1·0	99	100	134	140
24		48	47	−1	22	34	12	3·6	4·0	0·6	100	99	137	130
27		44			23			3·7			102		136	
28		46			27			4·2			101		138	
32		46			27			3·9			106		140	
Means					27·1	41·7	14·6	4·0	4·6	0·6	101	101	136	137

TABLE VI. AVERAGE FLUID REQUIREMENTS BASED ON WEIGHT

	Average sweat loss (ml)	*3% deficit of weight (ml)*	*Average fluid requirements (ml)*
Above 160 lb (5 runners): average 175 lb (79·45 kg)	9 800	2 280	7 520
140 - 160 lb (11 runners): average 149 lb (68 kg)	7 800	2 040	5 760
Under 140 lb (8 runners): average 128 lb (58·12 kg)	6 350	1 640	4 710

related to water deficit or rise in blood urea. Rises in urea and potassium after the race occurred in all competitors except two: the blood urea fell from 31 mg/100 ml to 30 mg/100 ml in competitor No. 1 and potassium fell from 4·3 mEq/litre to 4·0 mEq/litre in competitor No. 25.

There was no consistent pattern in sodium and chloride levels before and after the race—in some competitors levels were higher after the race and in others they were lower. The mean chloride level remained at 101 mEq/litre before and after the race, and the mean sodium level was also virtually the same (136 mEq/litre before the event and 137 mEq/litre afterwards).

DISCUSSION

As would be expected in a race of this nature, sweat losses were very high. One-third of these runners lost more than 9 litres during the race. This is more than double the maximum sweat loss experienced in a 20-mile sugar marathon.[1] The runner's weight is the most important factor determining the volume of sweat lost. It is the heavier man who loses most sweat. The time taken to complete the race did not affect the volume of sweat lost nor did the age of the competitor.

Water deficits in these runners were very high and it was surprising that none showed evidence of heat exhaustion or higher rectal temperatures. Only two runners really adequately replaced fluid loss and in the majority the water deficits reached dangerous proportions (above 7% in 3 runners). Fortunately the race was run on an unusually cool day which contributed towards the lower rectal temperatures, but runners and their assistants are still unaware of the risks involved in not adequately replacing sweat loss. Wyndham and Strydom[1] stressed that if the water deficits exceed 3% of the body's weight rectal temperatures rise, and if the water deficit exceeds 4% it may rise excessively.

In spite of these alarming water deficits we were relieved that no competitors developed severe oliguria or uraemia. Urine volumes after the race were surprisingly good—only two excreted less than 500 ml over 24 hours and the highest blood urea recorded after the race was 60 mg/100 ml.

The mean elevation in potassium after the race was only 0·6 mEq/litre, which was very much lower than found by McKechnie *et al*. after the 1965 marathon.[5] None of these competitors had alarming potassium levels—the highest recorded was 5·5 mEq/litre.

In estimating the average fluid requirement a runner should consume roughly between 5 and 8 litres, depending on his weight (Table VI), to maintain the water deficit at 3%. The increased requirements of the heavier runners is striking. However, there are individual variations, e.g. one of the runners who only lost 5 litres as sweat weighed 159 lb, whereas one who lost over 10 litres weighed 131 lb. It would therefore be preferable for each runner to weigh himself in kilograms on a sensitive balance immediately before and after a long training run (approximately 50 miles). The difference should be expressed in grammes and to this figure the volume of water consumed during the run (in ml) is added. The volume of fluid a runner should drink should be at least three-quarters of the total (expressed in ml) and in the heavier runners (over 150 lb) four-fifths of the total. It is easier not to include any urine passed as the volume is so small. It is quite practical to drink over 9 litres in the Comrades Marathon—one runner did this over 7 hours and another in 9 hours. Taking 300 ml (half a pint or a large cup) every twenty minutes as recommended by Wyndham, would result in just over 8 litres in 9½ hours, and as he stresses this should start right from the beginning of a race.

SUMMARY

The fluid balance was recorded in 24 runners during the Comrades Marathon, and in 17 of these it was extended over 24 hours. The sweat loss during the race ranged from 4·3 to 12·8 litres. There was a relation between the weight of the runner and the sweat loss, the heavier runners losing most. Neither the age of the runner nor the time taken was related to the sweat loss.

The fluid intake during the race was totally inadequate in all but 2 of the 24 competitors, and in the majority the water deficit assumed dangerous proportions. Despite good fluid intakes after the race only 2 runners had completely compensated for their fluid loss at the end of 24 hours, and the water deficit was still in excess of 1 litre in the majority (64%). In spite of the severe water deficits rectal temperatures of over 102°F were not recorded, and elevations of urea and potassium were only moderate.

The lighter runners (under 140 lb) should consume 5 litres of fluid during the race and the heavier runners (over 160 lb) should take about 8 litres (roughly a large cupful every twenty minutes).

We should like to thank Dr E. Naude and Mr S. Sydenham for the blood urea and electrolyte estimations.

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