Undersea Biomedical Research, Vol. 10, No. 3, September 1983

Patterns of wet suit diving in Korean women breath-hold divers

Y. S. PARK, H. RAHN, I. S. LEE, S. I. LEE, D. H. KANG, S. Y. HONG, and S. K. HONG

Departments of Physiology, Yonsei University College of Medicine, Seoul, Korea; Institute of Marine Sciences, National Fisheries University of Busan, Busan, Korea; and State University of New York at Buffalo, Buffalo, NY 14214

Park YS, Rahn H, Lee IS, Lee SI, Kang DH, Hong SY, Hong SK. Patterns of wet suit diving in Korean women breath-hold divers. Undersea Biomed Res 1983; 10(3):203–215.—Work shifts, diving pattern, diving lung volumes, and counterweights were studied in professional Korean women breath-hold divers wearing wet suits. One of the major differences, compared with their diving pattern only a few years ago when wearing cotton suits, is the prolongation of the diving shifts from 70 to 180 min in the summer and 10 to 120 min in the winter. In sustained diving the average dive and surface times in a 5-m dive are 32 and 46 s, and in a 10-m dive, 43 and 85 s, respectively. During a 3-h shift the total bottom time for harvesting is 37 min in 5-m dives and 17 min in 10-m dives. Rates of descent and ascent are 0.55 and 0.84 m/s. The wet suit divers adjust their counterweights to obtain a 12% positive buoyancy at the surface of sea water in contrast to the 8% positive buoyancy of cotton suit divers. The average lung volumes before and after a dive are 79% and 64% of their vital capacities, values similar to those of previous cotton suit divers.

breath-hold diving
wet suits
counterweight

The earliest written historical records of Korea mention the Hae-Nyo, or women divers, who are still engaged in harvesting the ocean floor for shellfish, sea urchins, seaweeds, and other marine organisms; it is estimated that in Korea today more than 5000 practice this profession. These divers are organized in local unions, usually work in groups, and can be seen on their diving grounds resting between dives on plastic floats (formerly hollow gourds) from which their collecting nets are suspended (Fig. 1).

In 1963 we documented the diving pattern of the unassisted Korean women divers, who wore only cotton suits and face masks (1). This attire provided little protection against eventual hypothermia, which limited their diving time. In the last four or five years, however, these divers have been wearing wet suits to avoid cold water stress. Thus, their working time has been considerably prolonged (Table 1). Moreover, unlike previous divers, the contemporary divers wear fins and use counterweights to compensate for the positive buoyancy of wet suit diving. The present paper describes the diving pattern of the contemporary wet suit diver and

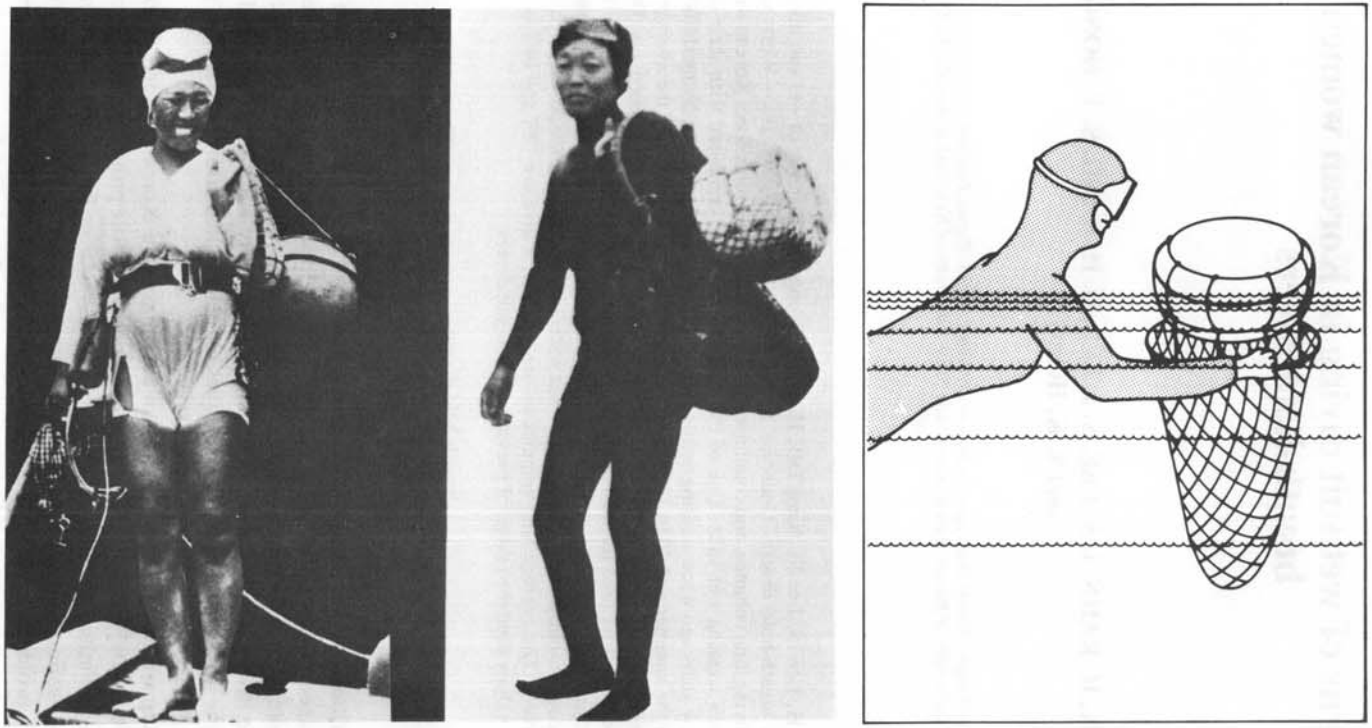

Fig. 1. Changes in diving suits of Korean women divers. *Left,* cotton suits (1960); *middle,* wet suits made of foam neoprene (1980). *Right:* contemporary diver resting on the surface and holding a rim of collecting net attached to Styrofoam float. Note that during the cotton suit period the float was a hollowed-out gourd. Also shown is depth gauge attached to her belt, as well as part of tubing going to pressure gauge. (Picture on *left* from Ref. 1, with permission.)

TABLE 1
TYPICAL DIVING SCHEDULES OF KOREAN DIVING WOMEN

	Work Shift per day	Duration of Shift, min
Cotton suit divers (1960)*		
summer	3	70
winter	1–2	16
Wet suit divers (1980)		
summer	1	180
winter	1	120

*Kang BS et al. (2).

the methods by which divers adjust their counterweights, and compares these strategies with the previous cotton suit diving pattern.

METHODS

This study was conducted in August and September 1981. All experiments were carried out in the village of Hae Woon Dae, Busan, Korea, where about 60 divers are daily engaged in diving work.

Measurement of diving pattern

Depth-time profile. A depth-time profile was determined in 5 divers selected randomly by the same method described for the previous study (1). The depth of submergence was read from an aneroid gauge connected by 30 m of nylon tubing to a rubber balloon inflated to 500 ml. The lag between balloon compression and gauge response in terms of the observed diving velocities was insignificant. The balloon was protected by a perforated cylinder made of stainless steel and Plexiglas and attached to the belt of the diver. The observed pressure change during diving was dictated into a portable tape recorder on a ship. By replaying the record later and timing the readouts with a stop watch, we could determine the rates of descent and ascent and the bottom time and duration of a dive.

Diving time and work shifts. The duration of a dive and the interval between two successive dives were measured during their natural work shifts in 27 randomly selected divers. Each diver was observed for at least 5 successive dives. For some divers, the observation was repeated over several work shifts. All observations were made from an observation post 20 m above sea level and at least 100 m from the diving area, using binoculars and stopwatches. Thus divers were unaware of being observed.

Measurement of buoyancy-mass relationship and counterweight

In 12 divers, the mass and buoyancy were determined under three different conditions: 1) with cotton suits and goggles; 2) with wet suits, goggles, and fins; and 3) with wet suits, goggles, fins, and the counterweight. Each subject was first weighed in the air, then, with a lung volume of approximately 80% of vital capacity, submersed in a water tank. The volume of water displaced by the subject was determined by multiplying the change in water level with the cross-sectional area of the tank, with the accuracy of 0.4 liter. The buoyancy was calculated by multiplying the volume by the density of sea water (1.03 kg/liter). To assess the value of the counterweight to the divers, the counterweight of each subject (counterweight-actual) was compared with the theoretical counterweight required to give a neutral buoyancy (counterweight-neutral). The latter was calculated by subtracting the combined weight of the body, suit, fins, and goggles from the buoyant force (= 1.03 × volume of water displaced).

Measurement of lung volumes

Lung volumes (greater than the residual volume) were measured in 4 randomly selected divers immediately before and after a dive. The observer, equipped with an empty 5-liter anesthesia bag attached to a large three-way stopcock, floated near the diver and obtained the lung volume that could be maximally expired before or after a dive. The collected gas was then returned to the shore and measured with a spirometer.

RESULTS AND DISCUSSION

Diving pattern

Figure 2 compares in one diver the depth-time profiles of diving to depths of approximately 5 and 8 m. In repeated dives, the rate of descent and ascent was rather uniform and did not change significantly with depth of dive. Bottom time, however, and hence the length of a dive, was considerably more variable in shallow dives (4–5 m) than in deeper dives (7–8 m). The coefficient of variation of bottom time was 0.22 for the shallow dive and 0.15 for the deeper dives, and the coefficients of variation of the entire dive time were 0.12 and 0.04, respectively. By questioning many divers we learned that shallow dives are terminated whenever a given amount of harvest has been gathered, and thus the bottom time will vary with each dive. In deep dives, however, bottom time is relatively constant.

Figure 3 depicts the average profile of the shallow dive (4–5 m) in 5 divers. For the purpose of comparison, data obtained in a previous study (1) are also illustrated (broken line). On the average, a single dive lasts about 35 s, of which 24% is used for descent, 15% for ascent, and 61% on the bottom. In our subjects the rate of descent was 0.54 m/s (SE 0.03) and that of ascent was 0.84 m/s (SE 0.02), approximately 60% faster. While the cotton suit diver descends at the same rate as the wet suit diver, her ascent is appreciably slower and, in fact, is equal to her descent rate (0.5–0.6 m/s) (1). Thus the rate of ascent, but not descent, has been selectively improved in modern wet suit divers. The reason for this selective change may be related to the use of fins and to the positive buoyancy (see *Counterweight,* this section). In any event, the increase in the ascent rate is advantageous for divers, since it provides relatively more bottom time for harvesting.

To obtain a typical diving pattern during their natural work shift we next measured overall diving time and surface time between dives in large numbers of divers. Table 2 summarizes the results obtained in 27 randomly selected divers during their diving work at 3–6 m depth. Frequency distributions of dive time, surface time, and ratio of surface time to dive time are given in Fig. 4. The duration of a dive for an individual diver was quite uniform (the mean coefficient of variation of 27 divers was 0.13; see Table 2). The surface time, however, was much more variable (the mean coefficient of variation was 0.34), reflecting either fatigue, search for a new diving spot, recovery of the float carried away by wind or by currents while

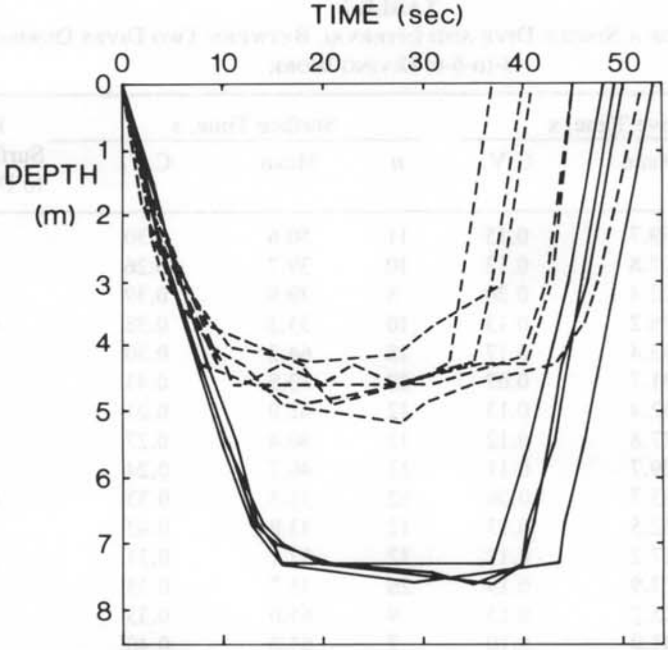

Fig. 2. Depth-time profiles of repeated shallow (4–5 m) and deep (7–8 m) dives of one diver wearing wet suit and fins.

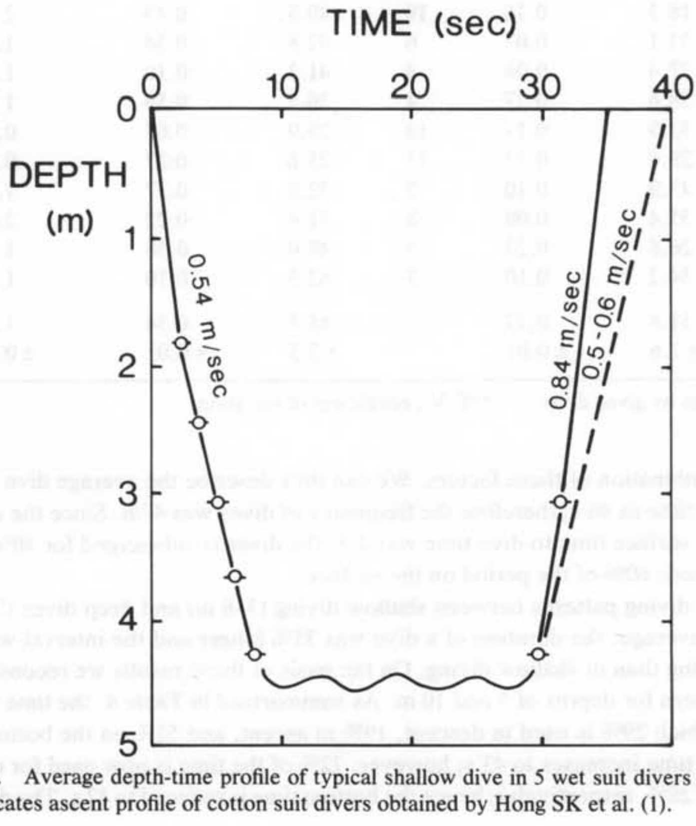

Fig. 3. Average depth-time profile of typical shallow dive in 5 wet suit divers (mean ± SE). *Broken line* indicates ascent profile of cotton suit divers obtained by Hong SK et al. (1).

TABLE 2

DURATION OF A SINGLE DIVE AND INTERVAL BETWEEN TWO DIVES DURING 3-TO-6-M DIVING WORK

Diver No.	Dive Time, s			Surface Time, s			Ratio, Surface Time to Dive Time
	n*	Mean	C.V.	n	Mean	C.V.	
1	12	39.7	0.15	11	50.6	0.30	1.28
2	10	27.8	0.12	10	39.7	0.26	1.43
3	9	22.4	0.20	8	39.9	0.39	1.78
4	13	36.2	0.13	10	33.3	0.38	0.92
5	24	43.4	0.17	18	64.2	0.30	1.48
6	24	31.7	0.07	20	50.8	0.43	1.60
7	17	52.4	0.13	12	62.9	0.23	1.20
8	12	27.8	0.12	12	40.4	0.27	1.45
9	12	29.7	0.11	12	40.7	0.24	1.37
10	12	33.7	0.08	12	33.5	0.33	0.99
11	12	32.5	0.13	12	33.8	0.43	1.04
12	12	17.2	0.17	12	37.1	0.31	2.16
13	26	22.9	0.19	26	33.7	0.33	1.47
14	10	25.2	0.13	9	65.0	0.33	2.58
15	10	41.0	0.10	7	63.0	0.40	1.54
16	13	25.8	0.08	13	36.5	0.32	1.42
17	7	38.9	0.21	5	54.4	0.29	1.40
18	19	18.3	0.16	19	49.3	0.43	2.70
19	8	33.1	0.07	6	42.8	0.34	1.29
20	5	27.4	0.08	4	41.3	0.10	1.51
21	5	28.6	0.27	4	30.5	0.59	1.07
22	12	33.9	0.13	10	29.9	0.67	0.88
23	11	29.0	0.13	11	25.6	0.27	0.88
24	7	43.9	0.10	5	52.8	0.37	1.20
25	8	35.4	0.08	8	71.4	0.22	2.02
26	5	26.8	0.22	5	48.0	0.58	1.79
27	5	34.2	0.10	3	62.3	0.10	1.82
Mean		31.8	0.13		45.7	0.34	1.49
SE		±1.6	±0.01		±2.5	±0.02	±0.09

*n, Number of dives by given diver. **C.V., coefficient of variation.

submerged, or a combination of these factors. We can thus describe the average dive time as 32 s and the surface time as 46 s; therefore the frequency of dives was 47/h. Since the average value of the ratio of surface time to dive time was 1.5, the diver is submerged for 40% of the work period and spends 60% of the period on the surface.

Table 3 compares diving patterns between shallow diving (3–6 m) and deep dives (7–12 m) in 3 divers. On the average, the duration of a dive was 35% longer and the interval was 80% longer in deeper diving than in shallow diving. On the basis of these results we reconstructed a general diving pattern for depths of 5 and 10 m. As summarized in Table 4, the time for a 5-m dive is 32 s, of which 29% is used in descent, 19% in ascent, and 52% on the bottom. For 10-m depth the dive time increases to 43 s; however, 72% of the time is now used for descent and ascent (44% and 28%, respectively); hence the bottom time is reduced to 12 s. The duration

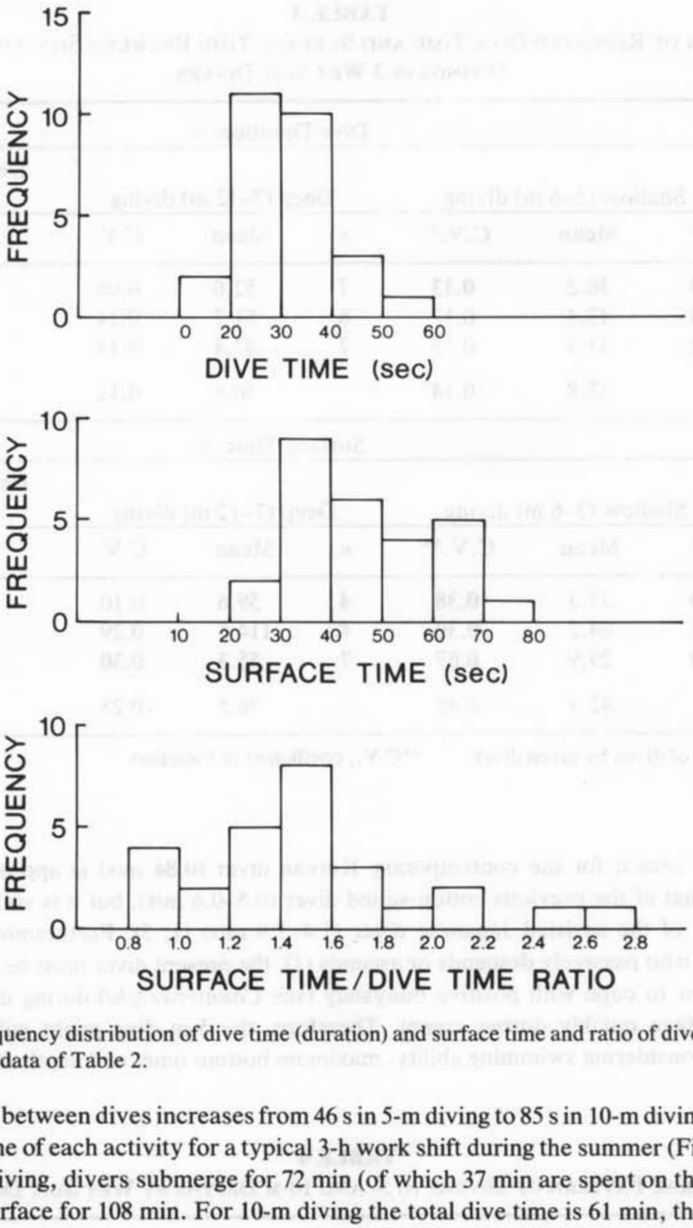

Fig. 4. Frequency distribution of dive time (duration) and surface time and ratio of dive time to surface time, based on data of Table 2.

of the interval between dives increases from 46 s in 5-m diving to 85 s in 10-m diving. Calculation of the total time of each activity for a typical 3-h work shift during the summer (Fig. 5) indicates that for 5-m diving, divers submerge for 72 min (of which 37 min are spent on the bottom) and stay on the surface for 108 min. For 10-m diving the total dive time is 61 min, the surface time 119 min, and the bottom time only 17 min. This indicates that shallow dives are more efficient than deeper dives in terms of bottom time for harvest. During the course of the present series of studies, which lasted over a period of two years, we have observed that most divers prefer to engage in shallow diving rather than deeper diving. Although this may be dependent on many factors, such as 1) breath-holding capacity, 2) water current, and 3) the flora and fauna of the bottom, the most important reason seems to be the relatively longer bottom time they can have in shallow diving. In this connection, it is interesting to note that the assisted divers of Japan (Funado), who use a large counterweight during descent and are pulled back to the surface during ascent, routinely engage in dives to 20 m, while the unassisted divers (Cachido) display a diving pattern similar to that observed in this study (1, 4).

TABLE 3

COMPARISON OF REPEATED DIVE TIME AND SURFACE TIME BETWEEN SHALLOW AND DEEP DIVINGS IN 3 WET SUIT DIVERS

Diver	Dive Duration, s						
	Shallow (3–6 m) diving			Deep (7–12 m) diving			Deep-to-shallow ratio
No.	*n**	Mean	C.V.**	*n*	Mean	C.V.	Mean
4	13	36.2	0.13	7	52.6	0.08	1.45
5	24	43.4	0.17	6	51.7	0.14	1.19
22	12	33.9	0.13	7	47.4	0.13	1.40
Mean		37.8	0.14		50.6	0.12	1.35

Diver	Surface Time, s						
	Shallow (3–6 m) diving			Deep (7–12 m) diving			Deep-to-shallow ratio
No.	*n**	Mean	C.V.**	*n*	Mean	C.V.	Mean
4	10	33.3	0.38	4	59.6	0.10	1.79
5	18	64.2	0.30	4	114.5	0.29	1.78
22	10	29.9	0.67	7	55.3	0.30	1.85
Mean		42.5	0.45		76.5	0.23	1.81

**n*, Number of dives by given diver. **C.V., coefficient of variation.

The rate of ascent for the contemporary Korean diver (0.84 m/s) is approximately 60% greater than that of the previous cotton-suited diver (0.5–0.6 m/s), but it is still considerably less than that of the assisted Japanese diver (1.4–1.9 m/s) (1, 5). Furthermore, unlike the assisted diver who passively descends or ascends (1), the present diver must be active continuously in order to cope with positive buoyancy (see *Counterweight*) during descent and to reach the surface quickly during ascent. Therefore, the 5-m dive might still be the best compromise considering swimming ability, maximum bottom time, and depth of dive.

TABLE 4

GENERAL PATTERN OF DIVING TO 5- AND 10-M DEPTHS BY WET SUIT DIVERS

	5-m Dive	10-m Dive
Single dive time, s	32 (100%)	43 (100%)
Time for descent, s	9.3 (29%)	19 (44%)
Time for ascent, s	6.0 (19%)	12 (28%)
Bottom time, s	16.5 (52%)	12 (28%)
Single surface time, s	46	85
No. of Dives/h	46.2	28.1

Values calculated for 5- and 10-m dives using various parameters of dive shown in Figs. 2 and 3, and Tables 2 and 3.

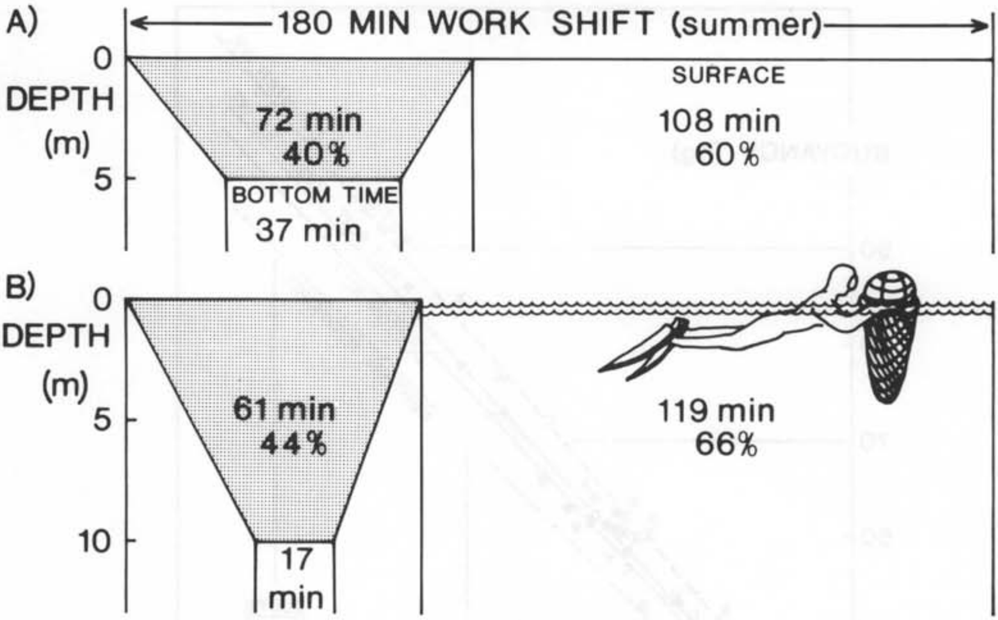

Fig. 5. Estimated total dive time, total surface time, and total bottom time in 5-m *(panel A)* and 10-m *(panel B)* dives during 3-h work shift in summer. Note that total time of submergence as well as harvesting time during a work shift is much longer in shallow diving than in deep diving.

Counterweight

To understand the principle by which divers adjust their counterweights, we initially attempted to relate the counterweight with the body weight, the fat content, and the suit weight in 15 divers, but we failed to find any clear correlation between the counterweight and these variables. We therefore examined the buoyancy-mass relationship and the role of the counterweight.

Figure 6 depicts the buoyancy-mass relationships of divers at the surface under 3 conditions: 1) with cotton suits and goggles; 2) with wet suits, goggles, and fins; and 3) with wet suits, goggles, fins, and the counterweight. In all three conditions, the buoyancy was directly and linearly proportional to the mass. In all cases, however, divers were in a state of positive buoyancy. From the regression lines shown in Fig. 6 the positive buoyancy force at the surface for a 50-kg diver was calculated to be 3.6 kg for cotton suit divers, 7.9 kg for wet suit divers without counterweight, and 4.7 kg for wet suit divers with counterweight. This indicates that wet suit divers regulate the counterweight to maintain a slightly (3%) greater positive buoyance force than when wearing the cotton suit.

In order to generalize the magnitude of counterweight of divers, we next compared the counterweight of each subject (counter wt-actual) with the theoretical counterweight to give her a neutral buoyancy (counter wt-neutral). As shown in Fig. 7, most divers adjusted the counterweight to the level of approximately 40% of counterweight-neutral. However, some divers who do not routinely wear fins (closed symbols) tended to use relatively greater counterweights. We observed that one such diver used different counterweights, depending on the suits she wore. She adjusted the weight to a high level with new wet suits (point "new suit," Fig. 7) and to a low level with old suits (point "old suit"), but in each case the counterweight corresponded to about 70% of the counterweight-neutral. In this connection it should be pointed

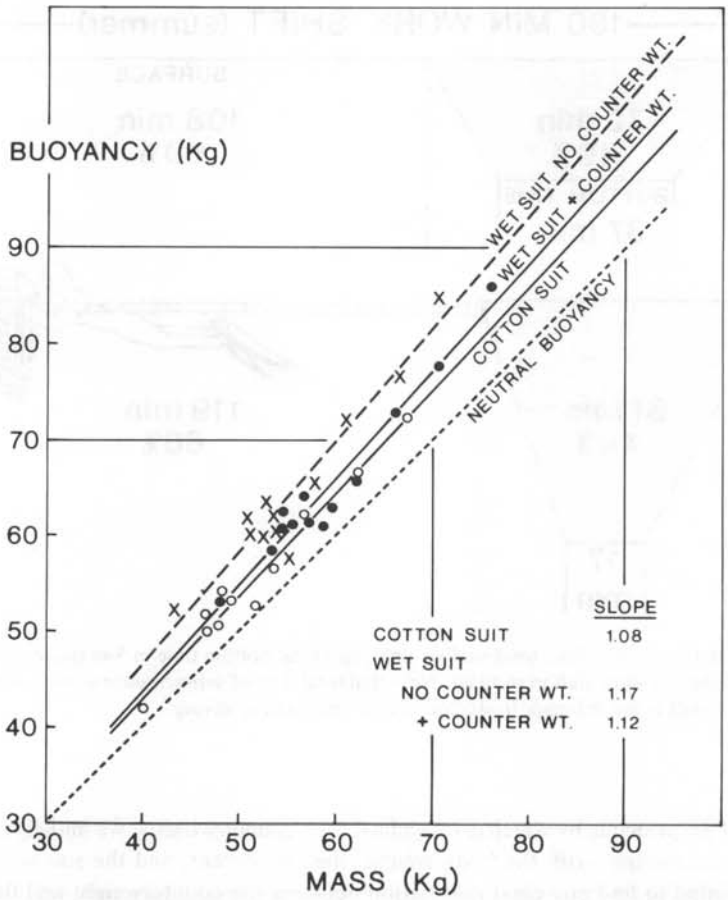

Fig. 6. Buoyancy-mass relationship in 13 divers. Buoyancy was calculated by multiplying volume of water displaced in subject by density of sea water (1.03 kg/liter). Regression equations for cotton suits: buoyancy = 1.08 mass − 0.353 (r = 0.977); wet suits without counterweight: buoyancy = 1.17 mass − 0.577 (r = 0.954); wet suits + counterweight: buoyancy = 1.12 mass − 1.340 (r = 0.977).

out that fins greatly reduce the energy requirements for diving (6), which may have a bearing on the selection of the counterweight.

The fact that present divers have slightly more positive buoyancy than previous divers, and that divers who do not use fins use a relatively greater counterweight, may explain why the rate of ascent, but not the rate of descent, has selectively increased in contemporary divers. It may be that the high buoyancy itself would reduce the rate of descent, but the effect is compensated by the action of fins, such that the rate is not changed. During ascent, however, both the combined positive buoyancy and action of fins would increase the rate of movement. In divers without fins, the effect of excessive positive buoyancy on descent can be compensated only by increasing the counterweight, but in this case the rate of ascent may not be different from that of descent.

Lung volume

It was previously observed that the Korean divers inhaled to a lung volume of approximately 84% of the vital capacity before diving (1). The reason for this initial incomplete filling of the

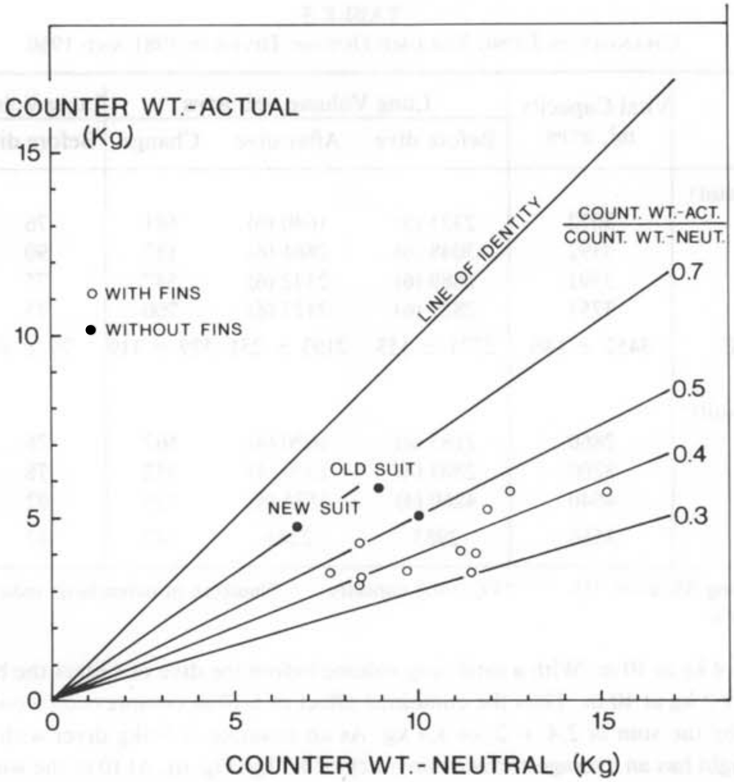

Fig. 7. Relationship between counterweight of diver *(counter wt-actual)* and theoretical counterweight required to give neutral buoyancy *(counter wt-neutral)* in 13 divers. In each diver the counterweight-neutral was calculated by subtracting mass from buoyancy. *Open circles*, divers who routinely wear fins; *solid circles*, divers wearing no fins. The points "old suit" and "new suit" represent the same diver when she wore old wet suits and new wet suits, respectively.

lung was thought to reduce excessive intrapulmonary pressure and buoyancy. If the lung is completely filled, it is either too uncomfortable because of high intrapulmonary pressure, which would exceed 30 cmH_2O under such conditions, or it requires more energy to submerge against excessive buoyancy.

In view of the fact that present divers experience more positive buoyancy than before, it was interesting to examine whether their lung volumes were different from those of previous divers. Table 5 summarizes the lung volumes at the beginning and at the end of each dive along with vital capacities measured immediately before the diver entered the water. For the purpose of comparison the values obtained in a previous study (1) are also included. The average lung volume before a dive was 79% (range 75%–90%) and that after a dive was 64% (range 54%–84%) of the vital capacity. These values are exactly comparable to those of previous divers, suggesting that the diving lung volumes are not altered by wearing wet suits.

Buoyancy changes during descent

We can now consider the effect of compression of not only the lung volume but also the neoprene wet suit during a dive, and the resulting change in buoyancy. In a preliminary test of buoyancy a 4.7-kg neoprene suit (5 mm thick, weight 2.6 kg in air) decreased by 1.5 kg at 5

TABLE 5
CHANGES IN LUNG VOLUME DURING DIVES IN 1981 AND 1960

Diver	Vital Capacity, ml, BTPS	Lung Volume, ml, BTPS			Lung Volume, % VC**	
		Before dive	After dive	Change	Before dive	After dive
1981 (Wet suit)						
Park KJ	3072	2321 (5)	1640 (6)	681	76	53
Kim CW	3392	3048 (6)	2861 (6)	187	90	84
Yang SS	3591	2689 (6)	2142 (6)	547	75	60
Yang OB	3751	2827 (6)	2127 (6)	700	75	57
Mean ± SE	3452 ± 146	2721 ± 153	2193 ± 251	529 ± 119	79 ± 4	64 ± 7
1960 (Cotton suit)*						
Kang	2860	2185 (4)	1620 (4)	567	76	57
Koh	3200	2503 (4)	1570 (4)	932	78	49
Song	4640	4260 (4)	3535 (4)	725	92	76
Mean	3566	2983	2241	742	82	61

*From Hong SK et al. (1). **VC, vital capacity. Numbers in parenthesis indicate number of measurements.

m and by 2.4 kg at 10 m. With a total lung volume before the dive of 4 liters the buoyancy will decrease by 2 kg at 10 m. Thus the combined effect of a 10-m compression would reduce the buoyancy by the sum of 2.4 + 2, or 4.4 kg. As an example, a 50-kg diver with wet suit and counterweight has an average surface buoyancy of 4.7 kg (Fig. 6). At 10 m she would therefore become essentially neutral.

This investigation was carried out as a project under the United States–Republic of Korea cooperative science program and was supported by grants from NSF (INT-79-18378), KOSEF (1981), and USPHS (HL-14414). The authors gratefully acknowledge all subjects for their splendid cooperation. We are also greatly indebted to Mr. Richard A. Morin for the design and construction of a depth gauge and to Mrs. Elizabeth Miranda for typing the manuscript. Special thanks are due to Dr. C. E. G. Lundgren for determining the buoyancy changes in a neoprene wet suit at simulated depths.—*Manuscript received for publication September 1982; revision received December 1982.*

Park YS, Rahn H, Lee IS, Lee SI, Kang DH, Hong SY, Hong SK. Genres de plongée avec habit de néoprène chez les plongeuses en apnée coréennes. Undersea Biomed Res 1983; 10(3):203–215.—Les périodes de travail, genres de plongées, volumes pulmonaires de plongée, et contrepoids furent étudiés chez des plongeuses en apnée professionnelles coréennes portant des habits de plongée en néoprène. Une des différences principales, comparativement à leurs genres de plongées d'il y a quelques années lorsqu'elles portaient des habits de coton, est la prolongation des périodes de plongée de 70 min à 180 min en été et de 10 min à 120 min en hiver. Au cours d'activités soutenues de plongée, les temps moyens sous l'eau et en surface sont de 32 s et 46 s, respectivement, pour les plongées de 5 m et de 43 s et 85 s, respectivement, pour celles de 10 m. Durant une période de 3 h le temps total passé au fond pour la récolte est de 37 min pour les plongées de 5 m et de 17 min pour celles de 10 m. Les vitesses de descente et de remontée sont de 0.55 m/s et de 0.84 m/s, respectivement. Les plongeuses vêtues d'habits de néoprène ajustent leurs contrepoids afin d'obtenir un taux de flottabilité positive de 12% à la surface de l'eau salée, en comparaison à un taux de 8% pour les plongeuses portant des habits de coton. Les volumes pulmonaires moyens avant et après une plongée sont de 79% et 64% de leurs capacités vitales. Ces valeurs sont semblables à celles obtenues antérieurement au cours de plongées avec vêtements de coton.

plongée en apnée
habits de plongée en néoprène
contrepoids

REFERENCES

1. Hong SK, Rahn H, Kang DH, Song SH, Kang BS. Diving pattern, lung volumes, and alveolar gas of the Korean diving woman (ama). J Appl Physiol 1963; 18:457–465.
2. Kang BS, Song SH, Suh CS, Hong SK. Changes in body temperature and basal metabolic rate of the ama. J Appl Physiol 1963; 18:483–488.
3. Yokoyama T, Iwasaki S. Ecology of the Japanese ama. In: Yoshimura H, Kobayashi S, eds. Human adaptability. Vol. 3 Physiological adaptability and nutritional status of the Japanese. Tokyo: University of Tokyo Press, 1975: 199–209.
4. Hong SK, Rahn H. The diving women of Korea and Japan. Sci Am 1967; 210:34–43.
5. Teruoka T. Die Ama und ihre Arbeit. Arbeitsphysiologie 1932; 5:239–251.
6. Craig AB Jr, Medd WL. Oxygen consumption and carbon dioxide production during breath-hold diving. J Appl Physiol 1968; 24:190–202.