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# Diving pattern of Tsushima male breath-hold divers (Katsugi)

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Shiraki K, Konda N, Sagawa S, Park YS, Komatsu T, Hong SK. Diving pattern of Tsushima male breath-hold divers (Katsugi). Undersea Biomed Res 1985; 12(4):439–452.—The present study was undertaken to investigate the diving pattern, buoyancy-mass relationship, and some respiratory functions in professional male breath-hold divers in Tsushima Island, Japan. These divers always wear neoprene wet suits and use fins and 4-kg counterweights. They usually dive to 3–10 m depths. The rate of descent was 1.12 m/s for deeper dives (>10 m), which is nearly twofold greater than that of Korean female divers also wearing wet suits and fins. However, the rate of ascent (0.8 m/s) was comparable to that of Korean women divers. On a typical summer day, they spend nearly 4 h in the water and perform 175 dives. The average dive and surface time were 39 and 42 s, respectively. The total bottom time was estimated to be 67 min/d, nearly twice that of Korean women divers. These divers do not adjust the counterweight and all are using a 4-kg weight. Nevertheless, the buoyancy-mass relationship revealed that they maintain the same degree of positive buoyancy (~10% above the neutral level) at surface as do Korean women divers who adjust counterweights. The vital capacity was significantly greater in the diver than in the control ($P < 0.05$), which was largely due to the greater expiratory reserve volume in the diver. The end-tidal $O_2$ and $CO_2$ pressures of the diver resting in air were not different from those of the control. These results indicate that, while the basic diving pattern is similar in both male and female breath-hold divers, the overall efficiency of diving (in terms of the rate of descent and the bottom time) appears to be superior in male divers.

breath-hold diving
male
wet suits
time-depth profile
lung volumes
buoyancy

Along the coast and islands of South Korea and Japan there live more than 30,000 breath-hold divers who harvest professionally the ocean floor, gathering abalones, snails, sea urchins, and sea weeds. While this profession belongs exclusively to females in Korea (Hae-Nyo), in Japan, both males and females are engaged in diving work. According to the statistics compiled in 1977 by the Ministry of Agriculture, Forestry and Fisheries of the Japanese government, there are approximately 13,000

full-time divers in Japan, of whom 8500 (65%) are male; moreover, the number of male divers remained the same whereas that of females decreased by 20% since 1965. It is also significant that male divers are responsible for 75% of the annual harvest by all divers in Japan. Since these divers usually start their profession at approximately 15 yr old and continue until they reach more than 60 yr, they have been the subject of many physiological studies. However, most of these studies have been focused on female divers in whom diving pattern and cardiovascular, respiratory, and thermoregulatory functions have been extensively investigated (1–3). In contrast, male divers have received little attention from physiologists despite their dominance in numbers and the quantity of harvest over their female counterparts. Hence this investigation was undertaken to study the diving velocity and daily diving patterns in male divers in Tsushima Island, located between the island of Kyushu, Japan, and the Korean peninsula (24°20′N and 129°20′E). These results are compared with those obtained from earlier studies of Korean women divers.

## METHODS

This study was conducted in August 1984 in the village of Hiruga-ura on Tsushima Island, Nagasaki Prefecture, where 10 professional male breath-hold divers were engaged in diving work daily during harvesting seasons. Although a small number of woman divers were also present in this village until some years ago, they are no longer found.

In accordance with the union rule, diving activities are permitted during two periods a year, one from July 1 to October 31, and the other from December 1 to March 31. All divers in the village served as subjects in this study and their physical characteristics are shown in Table 1. All divers wore neoprene wet suits throughout their diving careers even during summer (27°C water in August).

Six control subjects from the same locale were also used in this study to compare the lung volumes and respiratory gas pressures with divers. These control subjects were professional fishermen with a socioeconomic status comparable to that of the divers. Although attempts were made to match the age and physical characteristics of control subjects with those of the divers, our effort was not too successful because of the limitation in the number of available candidates. On the average, the control group was slightly older and taller than the divers (Table 1). Since these small differences in age and height would influence the level of the vital capacity, the latter values were compared with those predicted on the basis of age and height of individual subjects (*see* below).

*A. Depth-time profile.* Depth-time profiles were determined in 4 randomly selected divers (Subjects 1, 2, 3, 4) by the same method described for previous studies on Korean women divers (ama) (1, 5). The depth of submergence was continuously recorded on a strip chart recorder (model U-228, Nippon Denshi Kagaku Co., Kyoto, Japan) via a strain gauge (USP-100 series pressure sensor, Nishino Manufacturing Co., Osaka, Japan) to a rubber balloon inflated to 500 ml by way of a 50-m nylon tubing. The lag between balloon compression and gauge response in terms of the observed diving velocities was 0.5 s. The balloon was protected by a perforated cylinder made of stainless steel and Plexiglas and attached to the belt of the diver.

**TABLE 1**
PHYSICAL CHARACTERISTICS OF SUBJECTS

| Subjects | Age, yr | Wt, kg | Ht, cm | SA, $m^2$ | Body Fat,* % | Diving Experience, yr | Remarks |
|---|---|---|---|---|---|---|---|
| | | | | A. Divers | | | |
| 1. K.M.O. | 29 | 56.8 | 161.9 | 1.612 | 16.6 | 2 | |
| 2. K.K.O. | 27 | 55.1 | 158.7 | 1.569 | 16.5 | 6 | smoker |
| 3. K.W.O. | 31 | 57.2 | 168.7 | 1.666 | 10.7 | 10 | smoker |
| 4. K.H.A. | 24 | 70.3 | 174.6 | 1.864 | 15.1 | 5 | smoker |
| 5. K.K.Y. | 34 | 66.4 | 165.0 | 1.747 | 14.4 | 6 | smoker |
| 6. S.M.Y. | 31 | 56.1 | 157.2 | 1.570 | 13.4 | 6 | smoker |
| 7. K.T.O. | 33 | 56.7 | 162.8 | 1.617 | 18.5 | 6 | |
| 8. K.F.A. | 23 | 63.3 | 167.9 | 1.733 | 12.4 | 6 | smoker |
| 9. K.K.M. | 30 | 61.0 | 166.0 | 1.692 | 17.1 | 6 | |
| 10. M.N.J. | 33 | 47.9 | 156.2 | 1.461 | 10.2 | 0.25 | smoker |
| Mean | 29.5 | 59.1 | 163.9 | 1.653 | 14.5 | 5.3 | |
| SE | 1.3 | 2.1 | 1.9 | 0.036 | 0.9 | 0.8 | |
| | | | | B. Control (Occasional Divers) | | | |
| 1. S.M.G. | 35 | 55.8 | 162.0 | 1.601 | 19.4 | | |
| 2. K.H.J. | 24 | 54.2 | 172.2 | 1.653 | 15.1 | | smoker |
| 3. S.S.M. | 36 | 71.4 | 168.6 | 1.830 | 25.4 | | smoker |
| 4. M.T.U. | 42 | 55.7 | 158.6 | 1.575 | 20.3 | | |
| 5. I.T.A. | 47 | 61.5 | 169.7 | 1.725 | 16.5 | | smoker |
| 6. H.M.G. | 34 | 60.9 | 172.9 | 1.742 | 10.5 | | smoker |
| Mean | 36.3 | 59.9 | 167.3 | 1.687 | 17.9 | | |
| SE | 3.5 | 2.8 | 2.6 | 0.039 | 2.3 | | |

*Based on measurements of skinfold thickness using the Durnin and Rahaman formula (4).

These measurements were made under two conditions: (a) with wet suits, goggles, fins, and counter weights; and (b) with swimming trunks and goggles.

*B. Diving time and work shifts.* The duration of each dive and the interval between two successive dives (surface time) were measured during their natural work shifts in all 10 divers. An investigator accompanied one assigned diver to the diving area on the same boat and took a complete record of his diving and surface times throughout the entire day. Each diver was specifically instructed to follow his normal pattern and no restriction was imposed on his activity.

*C. Buoyancy-mass relationship.* Mass and buoyancy were determined in 6 randomly selected divers by a method described by Park et al. (5), with a minor modification. Briefly, each subject was first weighed in the air, inspired 80% of his vital capacity via a mouth-piece connected to the respirometer (27°C), then completely

submersed in a cylindrical water tank (diameter 56 cm, height 85 cm), and the water level was readjusted to a predetermined mark. After the subject came out of the water tank, the volume of water displaced by the subject was determined by measuring the volume of water (27°C) needed to refill the tank to the predetermined mark, with the precision of 0.2 liter. The buoyancy was calculated by multiplying the displacement volume by the density of sea water (1.03 kg/l). These measurements were also made under the same two conditions employed for measurements of depth-time profile (*see* above).

*D. Lung volumes and end-tidal gas pressures.* The vital capacity and its subdivisions were determined while standing in air by a Fukuda 13.5 l respirometer (Type R-1300 N, Fukuda Sangyo Co., Tokyo, Japan). Triplicate measurements were made and the largest vital capacity value was used. For the measurement of end-tidal $O_2$ and $CO_2$ concentrations, each subject expired through a mouth-piece into a Hans Rudolph valve, and a portion of the expired gas was led continuously through a thin polyethylene tube to a gas analyzer (Model IH21A Type, Sanei Sokki Co., Tokyo, Japan) until the gas concentrations were steady for 5 s. Duplicate measurements were made and the results averaged. The gas pressure was calculated by multiplying the fractional concentration of respective gas with the barometric pressure (corrected for the water vapor pressure at 37°C). All divers and control subjects were used for this study.

*E. Statistics.* The mean and standard error were calculated for various measured items, and the lung volumes and end-tidal gas pressures obtained from the divers and controls were compared using Student's *t* tests. A difference was considered significant if $P < 0.05$.

## RESULTS AND DISCUSSION

*A. Depth-time relationship.* Actual depth-time profiles of repeated shallow (<10 m) and deep (>10 m) dives of one diver (Subject 2) wearing wet suit and fins are shown in Fig. 1. The diver was first asked to make long, shallow dives, in which he descended to a depth of approximately 5 m in 9–10 s with a remarkable uniformity in repeated trials. Once the diver reached the bottom, he stayed at this depth for about 20 s and then slowly ascended over a period of 30–50 s. This ascent pattern is attributed to the terrain of the sea bottom which was not flat but sloped in this particular diving spot. According to the diver, once he reached the bottom he slowly swam toward the shallower region of the bottom to prolong the dive time. Unfortunately, therefore, the rate of ascent as determined under the present condition is not real. In the next series, the diver was asked to make deep dives to the best of his ability. In this case, both the descent and ascent were carried out at uniformly high rates.

All data obtained from subjects wearing wet suits and fins are tabulated in Table 2 *(left)*. The average rate of descent for shallow dives, obtained from only two subjects, was 0.63 m/s, which is similar to that reported for unassisted Korean women divers wearing either cotton suits (1, 5) or wet suits (and fins) (5). However, the rate of descent increased almost twofold to 1.12 m/s for deeper dives. The latter value is

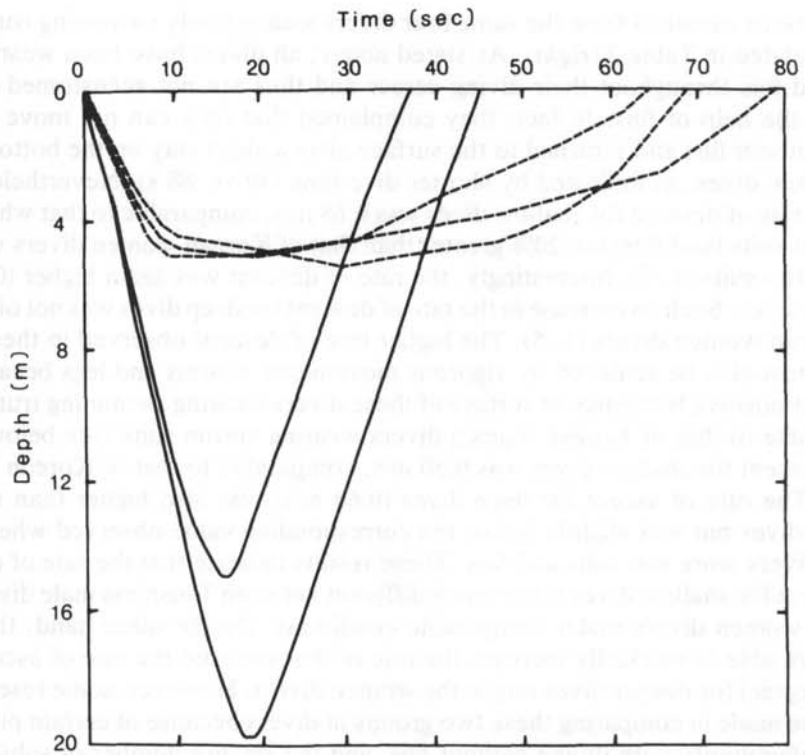


Fig. 1. Actual tracings of records showing depth-time profiles of repeated shallow *(broken lines)* and deep *(solid lines)* dives of one diver (Subject 2) wearing wet suits, goggles, fins, and counterweights (4 kg). Dive profiles shown in this figure do not necessarily represent the typical pattern. The slow ascending pattern for shallow dives was attributed to the terrain of the sea bottom (*see* text). Moreover, usual depths of dive are 3–10 m, although these divers are capable of reaching deeper depths as shown in this figure.

comparable to 1.2 m/s reported by Teruoka (6) for the assisted ama of Japan, who descends with a 15-kg weight. On the other hand, the wet-suit divers in the present study use rather light counterweights (4 kg), which can not account for their high rate of descent. Actual underwater observations of their descending pattern indicated vigorous movements of their legs and fins for deep (but not shallow) dives. As described below, the male divers maintain the same degree of positive buoyancy at the surface as Korean women divers wearing either cotton suits or wet suits (along with counterweights and fins). It is thus evident that the present divers are solely dependent on the extensive use of legs and fins to achieve a high rate of descent. The average rate of ascent for deep dives was 0.77 m/s, comparable to that by Korean women divers wearing wet suits (5). The rate of ascent was quite uniform in all divers, as indicated by a rather small value of the coefficient of variance (CV). The lower value of the ascent rate as compared to the descent rate in the wet-suit male divers indicates that they are not vigorously using their legs and fins for ascent as they do for descent. It is possible that their $O_2$ stores may be markedly depleted by the time they start ascent and thus they elect to ascent conservatively. A maximal dive time of 115 s (Subject 3) and a maximal diving depth of 25.7 m (Subject 4) observed in this series are also comparable to those reported in women divers (1, 5, 6).

The results obtained from the same four divers wearing only swimming trunks are also tabulated in Table 2 *(right)*. As stated above, all divers have been wearing wet suits and fins throughout their diving career and thus are not accustomed to dive without the help of fins. In fact, they complained that they can not move around easily without fins and returned to the surface after a short stay on the bottom even for shallow dives, as indicated by shorter dive time (49 vs. 88 s). Nevertheless, the average rate of descent for shallow dives was 0.68 m/s, comparable to that when they wear wet suits (and fins) but 20% greater than that of Korean women divers wearing only cotton suits (1, 5). Interestingly, the rate of descent was again higher (0.8 m/s) for deep dives. Such an increase in the rate of descent for deep dives was not observed for Korean women divers (1, 5). The higher rate of descent observed in these male divers must also be achieved by vigorous movements of arms and legs because the degree of positive buoyancy at surface of these divers wearing swimming trunks was comparable to that of Korean women divers wearing cotton suits (*see* below). The rate of ascent for shallow dives was 0.50 m/s, comparable to that of Korean women divers. The rate of ascent for deep dives (0.68 m/s) was also higher than that for shallow dives but was slightly below the corresponding value observed when these (male) divers wore wet suits and fins. These results indicate that the rate of descent and ascent for shallow dives is not much different between Tsushima male divers and Korean women divers under comparable conditions. On the other hand, the male divers are able to markedly increase the rate of descent (and the rate of ascent to a lesser degree) for deeper dives unlike the women divers. However, some reservation should be made in comparing these two groups of divers because of certain problems (e.g., unfamiliarity with diving without fins, and the smaller number of subjects for shallow dives with wet suits) associated with the present study.

*B. Diving pattern.* Daily diving-related activity for a typical summer day is shown in Table 3. Typically, they take two shifts a day, one in the morning and the other in the afternoon. Between two shifts, they take a 1.5-h lunch break. Overall, they spend 285 min/d working in the sea, during which each diver makes 175 dives on the average. The depth of dive in this survey was 3–10 m. The average dive time, surface time (interval between two successive dives), and the ratio of surface time to (immediately preceding) dive time are computed for individual divers and shown in Table 4. Frequency distributions of these parameters for 1752 dives performed by all divers are shown in Fig. 2 to indicate the actual degree of variations for the entire group. The dive time in a given diver is relatively uniform as indicated by small coefficients of variance but there were marked individual variations. Although the shortest dive time (22.5 s on the average) was noted in Subject 10 who has the shortest diving history (*see* Table 1), there was no correlation between the average dive time and the diving experience in the rest of divers. The longest average dive time of 57 s was observed in Subject 2 who has been diving for 6 yr. The average dive time for all divers was 39 s which is longer than that for Korean women wet-suit divers (5) but is shorter than that for assisted women divers of Japan (6). The surface time showed intraindividual variations twofold greater (the mean CV 0.56) than those for the diving time (the mean CV 0.30). The same phenomenon was observed in Korean women wet-suit divers (5) and was attributed to fatigue, search for a new diving spot, recovery of the float carried away by wind or by currents while submerged, or a combination of these factors. The same arguments can be made for the present study, although

**TABLE 2**
RATES OF DESCENT AND ASCENT WITH OR WITHOUT WET SUITS

| Subject No. | With Wet Suits | | | | With Swimming Trunks | | | |
|---|---|---|---|---|---|---|---|---|
| | Descent, m/s | Ascent, m/s | Depth, m | Dive Time, s | Descent, m/s | Ascent, m/s | Depth, m | Dive Time, s |
| | A. *Shallow Dives* (depth <10 m) | | | | | | | |
| 1 | | | | | 0.65 | 0.43 | 6.7 | 42 |
| | | | | | 0.61 | 0.48 | 4.6 | 45 |
| | | | | | 0.67 | 0.51 | 3.5 | 54 |
| | | | | | 0.77 | 0.54 | 6.5 | 59 |
| | | | | | 0.67 | 0.56 | 8.7 | 51 |
| Mean | | | | | 0.67 | 0.51 | 6.0 | 50 |
| 2 | 0.62 | 0.13 | 5.0 | 62 | 0.76 | 0.49 | 5.7 | 54 |
| | 0.51 | 0.32 | 5.4 | 68 | 0.51 | 0.29 | 5.0 | 42 |
| | 0.71 | 0.18 | 5.1 | 77 | 0.56 | 0.28 | 4.5 | 56 |
| Mean | 0.61 | 0.21 | 5.2 | 69 | 0.61 | 0.36 | 5.1 | 51 |
| 3 | 0.69 | 0.28 | 7.8 | 99 | 0.66 | 0.60 | 9.3 | 51 |
| | 0.59 | 0.33 | 6.5 | 115 | 0.73 | 0.58 | 7.2 | 38 |
| | 0.68 | 0.35 | 7.1 | 106 | 0.49 | 0.41 | 4.8 | 63 |
| Mean | 0.65 | 0.32 | 7.1 | 107 | 0.63 | 0.53 | 7.1 | 51 |
| 4 | | | | | 0.90 | 0.58 | 8.8 | 42 |
| | | | | | 0.82 | 0.69 | 8.4 | 40 |
| | | | | | 0.78 | 0.44 | 4.4 | 39 |
| | | | | | 0.56 | 0.57 | 6.2 | 57 |
| Mean | | | | | 0.77 | 0.57 | 7.0 | 45 |
| Grand Mean | 0.63 | 0.27** | 6.2 | 88 | 0.68 | 0.50 | 6.3 | 49 |
| CV* | 0.12 | 0.34 | 0.19 | 0.25 | 0.18 | 0.23 | 0.30 | 0.17 |
| | B. *Deep Dives* (depth >10 m) | | | | | | | |
| 1 | 0.96 | 0.83 | 16.6 | 41 | 0.65 | 0.54 | 11.3 | 42 |
| | 1.24 | 0.84 | 18.6 | 59 | 0.80 | 0.62 | 14.0 | 41 |
| | 0.97 | 0.88 | 14.3 | 70 | 0.78 | 0.59 | 16.1 | 62 |
| | 1.12 | 0.82 | 14.6 | 64 | 0.85 | 0.86 | 15.9 | 44 |
| | 0.99 | 0.74 | 14.4 | 57 | 0.82 | 0.80 | 16.0 | 48 |
| Mean | 1.06 | 0.82 | 15.7 | 58 | 0.78 | 0.68 | 14.7 | 47 |
| 2 | 1.29 | 0.79 | 19.7 | 45 | 0.92 | 0.72 | 16.1 | 49 |
| | 1.24 | 0.75 | 14.9 | 38 | 0.81 | 0.77 | 12.7 | 37 |

**TABLE 2 (continued)**

| Subject No. | With Wet Suits | | | | With Swimming Trunks | | | |
|---|---|---|---|---|---|---|---|---|
| | Descent, m/s | Ascent, m/s | Depth, m | Dive Time, s | Descent, m/s | Ascent, m/s | Depth, m | Dive Time, s |
| Mean | 1.27 | 0.77 | 17.3 | 42 | 0.87 | 0.74 | 14.4 | 43 |
| 3 | 1.39 | 0.70 | 23.1 | 64 | 0.68 | 0.61 | 15.9 | 58 |
| | 1.41 | 0.67 | 19.7 | 50 | 0.80 | 0.58 | 13.5 | 47 |
| Mean | 1.40 | 0.69 | 21.4 | 57 | 0.74 | 0.60 | 14.7 | 53 |
| 4 | 0.98 | 0.69 | 17.0 | 73 | 0.87 | 0.75 | 15.9 | 43 |
| | 1.07 | 0.77 | 14.4 | 56 | | | | |
| | 0.82 | 0.69 | 14.9 | 53 | | | | |
| | 1.16 | 0.84 | 25.7 | 65 | | | | |
| | 1.07 | 0.75 | 16.7 | 42 | | | | |
| Mean | 1.02 | 0.75 | 17.7 | 58 | 0.87 | 0.75 | 15.9 | 43 |
| Grand Mean | 1.12 | 0.77 | 17.5 | 56 | 0.80 | 0.68 | 14.7 | 47 |
| CV* | 0.16 | 0.09 | 0.20 | 0.20 | 0.10 | 0.16 | 0.12 | 0.16 |

*Coefficient of variance. **This slow rate of ascent is attributed to the terrain of the sea bottom and does not reflect the typical rate (*see* text).

**TABLE 3**
DAILY DIVING-RELATED ACTIVITY ON A TYPICAL SUMMER DAY

| Time, h | Activity |
|---|---|
| 0600–0700 | Rise from bed |
| 0700–0800 | Breakfast |
| 0845 | Leave the village by boat for diving area |
| 0900 | Arrive at diving area; change to wet suits |
| 0915 | Start diving work |
| 1145 | Terminate the morning shift; lunch |
| 1315 | Start the afternoon shift |
| 1530 | Terminate the afternoon shift |
| 1600 | Return to the village |

Total working time in water = 150 min (morning) + 135 min (afternoon) = 285 min (4 h 45 min).

we excluded exceptionally long surface times during which the diver returned to the boat to move to a new diving spot (a total of 48 min, *see* Table 4).

Although it was anticipated that the surface time may become progressively longer toward the end of 4.5 h intensive diving work, due to fatigue, no such trend was

**TABLE 4**
AVERAGE DIVING AND SURFACE TIME (S) FOR INDIVIDUAL DIVERS

| Subject No. | Dives, $n$* | Diving Time | CV** | Surface Time | CV** | Surface Time / Dive Time | CV** |
|---|---|---|---|---|---|---|---|
| 1 | 157 | 48.2 | 0.20 | 43.1 | 0.45 | 0.94 | 0.54 |
| 2 | 167 | 56.8 | 0.20 | 37.5 | 0.43 | 0.68 | 0.46 |
| 3 | 154 | 47.7 | 0.30 | 37.7 | 0.59 | 0.82 | 0.67 |
| 4 | 198 | 32.7 | 0.38 | 38.1 | 0.77 | 1.33 | 1.06 |
| 5 | 120 | 39.1 | 0.34 | 62.0 | 0.58 | 1.73 | 0.80 |
| 6 | 202 | 27.3 | 0.34 | 36.5 | 0.42 | 1.49 | 0.84 |
| 7 | 190 | 34.2 | 0.26 | 33.2 | 0.42 | 1.02 | 0.51 |
| 8 | 197 | 34.0 | 0.37 | 38.4 | 0.64 | 1.16 | 0.57 |
| 9 | 184 | 43.4 | 0.24 | 44.4 | 0.42 | 1.05 | 0.46 |
| 10 | 183 | 22.5 | 0.38 | 52.0 | 0.84 | 2.80 | 1.67 |
| | ($\Sigma n = 1752$) | | | | | | |
| Mean | | 38.6 | 0.30 | 42.3 | 0.56 | 1.30 | 0.76 |
| SE | | 3.3 | 0.02 | 2.7 | 0.05 | 0.19 | 0.12 |

Actually, divers spent an average of 285 min in the sea, of which 48 min was spent on the boat to move to other diving spots. Average depth of dive ranged from 3–10 m. *$n$, Represents the total number of dives per day (237 min of working time). **Coefficient of variance.

present in any divers. The longest average surface time was observed in Subject 10 who had the shortest diving time and history (*see* above), with the average surface-to-dive time ratio of 2.8. On the other hand, Subject 2 who had the longest average dive time showed the shortest surface time, with the average surface-to-dive time ratio of only 0.68. Overall, the average surface time for all divers was 42 s which is slightly shorter than the Korean women wet-suit divers (5). Likewise, the average ratio of surface-to-dive time was 1.30, in contrast to 1.49 for Korean women wet-suit divers (5). From a physiological point of view, Subject 2 is very unique. This diver repeatedly makes 1-min dives all day long, with only 37-s intervals between two successive dives. Obviously, he must be making up the $O_2$ debt he incurred during the dive in such a short time. It would be interesting to study energetics of diving in this subject and compare the results with those from others.

Based on the results shown in Table 4, one can calculate that these divers spend 114 min (48%) daily for diving and 123 min (52%) floating at the surface. If, for the sake of approximation, one assumes the rate of ascent to be the same as that of descent for shallow dives (0.63 m/s, *see* Table 2), the combined time for descent to and ascent from 5-m depth would be 16 s, with the average bottom time of 23 s for a single dive (Table 5). The number of dives per hour is thus 44.4. The above described diving pattern is quite similar to that of Korean women divers. On a daily basis, the divers in the present study spend 67 min (out of 237 min of working in water) on the bottom whereas the Korean female counterparts spends 37 min (out of 180 min of working time). In other words, the male divers have a daily bottom time twice as long as that of the female counterparts.

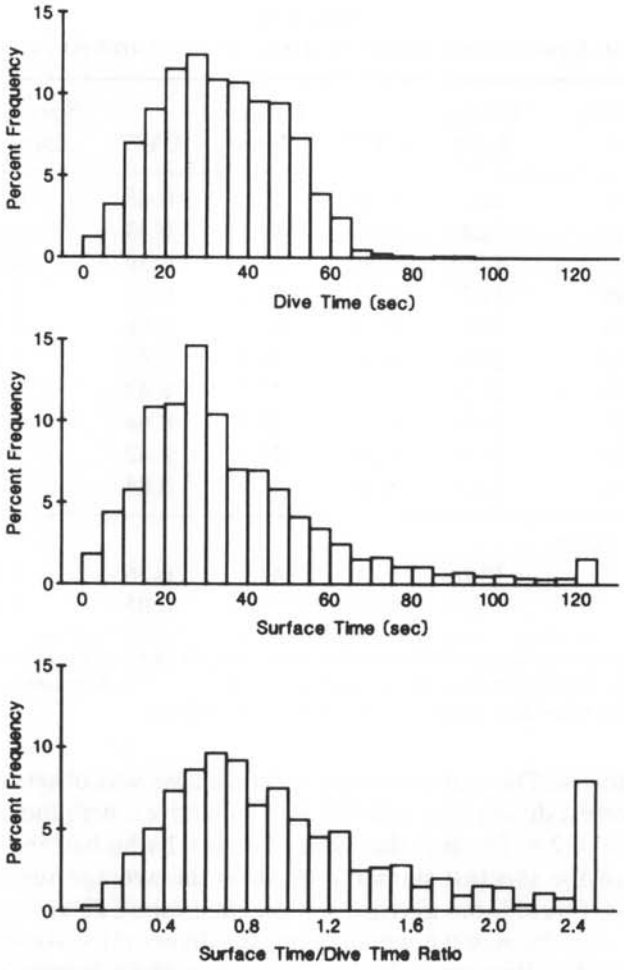


Fig. 2. Percent frequency of individual dive time (duration), surface time (interval between two successive dives), and the ratio of surface-to-dive time for 1752 dives performed by 10 divers on a typical summer day.

*C. Buoyancy-mass relationship.* The buoyancy-mass relationship of divers wearing either swimming trunks (and goggles) or wet suits (and goggles, fins, and counterweights) is shown in Fig. 3. For comparison, the regression lines for Korean women divers wearing either cotton suits (and goggles) or wet suits (and all other accessories) are also indicated (5). Overall, all data points obtained from the present study are randomly distributed along the regression lines for Korean women divers, indicating that the male divers maintain the same degree of positive buoyancy at the surface as the Korean female counterparts, regardless of whether they wear wet suits or swimming trunks. It is, however, worth noting that Korean women divers adjust their counterweights to maintain a slightly (3%) greater positive buoyancy than when wearing cotton suits (5). On the other hand, the male divers in the present study do not make any attempt to adjust the counterweight and all divers uniformly used the same counterweight of 4.0 kg. It is perhaps more than a coincidence that the degree

**TABLE 5**
COMPARISON OF GENERAL PATTERN OF DIVING TO 5-M DEPTH BETWEEN TSUSHIMA MALE AND KOREAN FEMALE DIVERS WEARING WET SUITS

| | Male Divers | Female Divers* |
|---|---|---|
| Single dive time, s | 39 (100%) | 32 (100%) |
| Time for descent, s | 8 (20%) | 9.3 (29%) |
| Time for ascent, s | 8 (20%) | 6.0 (19%) |
| Bottom time, s | 23 (60%) | 16.5 (52%) |
| Single surface time, s | 42 | 46 |
| No. of Dives/h | 44.4 | 46.2 |

*From Park et al. (5).

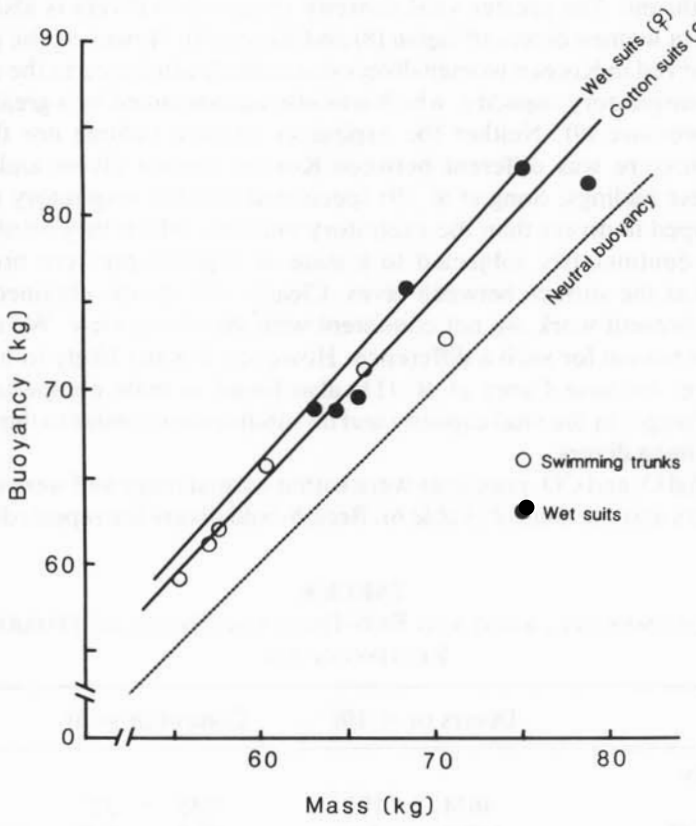


Fig. 3. Buoyancy-mass relationship in 6 divers wearing either swimming trunks (and goggles) (○) or wet suits (and goggles, fins, and 4-kg counterweights) (●). Regression lines for Korean women divers wearing cotton suits (buoyancy = 1.08 mass - 0.353) or wet suits (buoyancy = 1.12 mass - 1.340), reported by Park et al. (5), are indicated for comparison.

of positive buoyancy with wet suits (and 4 kg of counterweights) is virtually the same as with swimming trunks only. The reason why these divers elect to maintain a slightly positive buoyancy force at surface is not clear. As the diver descends to the

bottom, the lung volume as well as the degree of positive buoyancy would decrease, reaching a state of neutral buoyancy at 10-m depth according to Park et al. (5). Since these divers (both male and female) usually dive to depths shallower than 10 m, they engage in diving activities under a slightly positive buoyancy force. It is, therefore, more significant to note a high rate of descent observed in male divers (*see* above), which must be achieved at a high energy cost.

*D. Lung volumes and respiratory gas pressures.* Average values of the vital capacity and its subdivisions are shown in Table 6, along with values of the end-tidal $O_2$ and $CO_2$ pressures. The vital capacity of the diver group was 4674 ml (BTPS) or 17% above the value predicted by Baldwin's formula (7), and is significantly greater than that of the control group. This difference in vital capacity between the two groups is largely due to the greater expiratory reserve volume in divers. Although the inspiratory capacity was also greater in divers than in the control, the difference was not significant. The greater vital capacity observed in divers is also consistent with findings in women divers of Japan (8) and Korea (9). However, the greater vital capacity observed in Korean women divers was entirely attributed to the correspondingly greater inspiratory capacity, which was also accompanied by a greater maximal inspiratory pressure (9). Neither the expiratory reserve volume nor the maximal expiratory pressure was different between Korean women divers and nondivers. Based on these findings, Song et al. (9) speculated that the inspiratory muscles are better developed in divers than the expiratory muscles, which they attributed to the divers being continuously subjected to a state of negative-pressure breathing (10) while resting at the surface between dives. Clearly, the results obtained from male divers in the present work are not consistent with the above view. We are at a loss to explain the reason for such a difference. However, it is not likely to be due to the sex difference, because Carey et al. (11) also found in male escape-tank training instructors changes in the vital capacity and its subdivisions similar to those observed in Korean women divers.

The end-tidal $O_2$ and $CO_2$ pressures were within normal range and were not different between divers and the control (Table 6). Breath-hold divers are repeatedly subjected

**TABLE 6**
LUNG VOLUMES (ML, BTPS) AND END-TIDAL GAS PRESSURE (TORR) WHILE RESTING IN AIR

| | Divers ($n$ = 10) | Control ($n$ = 6) | |
|---|---|---|---|
| Vital Capacity | | | |
| Measured | 4674 ± 195 | 3885 ± 32' | ($P < 0.05$) |
| % Predicted* | 117.0 ± 4.3 | 97.7 ± 6.7 | ($P < 0.05$) |
| Expiratory reserve volume | 1781 ± 91 | 1241 ± 216 | ($P < 0.05$) |
| Inspiratory capacity | 2893 ± 143 | 2644 ± 199 | (NS) |
| $P_{ET_{O_2}}$ | 95.3 ± 4.0 | 89.9 ± 4.2 | (NS) |
| $P_{ET_{CO_2}}$ | 44.1 ± 1.3 | 45.9 ± 0.9 | (NS) |

Values are mean ± SE. *Based on Baldwin's formula (7).

to a state of hypercapnia (during descent and on the bottom) and hypoxia (during ascent) (1, 2, 6, 12, 13), and are known to show attenuated ventilatory responses to high $CO_2$ (8, 14) and low $O_2$ (13, 14). The latter phenomena are believed to be responsible for the higher than normal alveolar $CO_2$ pressure observed in divers during exercise (15, 16). Whether such a phenomenon is also demonstrable in resting state is still controversial. At least, in Korean women divers, both $O_2$ and $CO_2$ pressures in resting state are not different from those in the control (9). Since the end-tidal gas should reflect the alveolar gas, the results of the present study are also in agreement with the above study on Korean women divers.

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Shiraki K, Konda N, Sagawa S, Park YS, Komatsu T, Hong SK. Genre de plongée effectuée par les plongeurs (Katsugi) en apnée de Tsushima. Undersea Biomed Res 1985; 12(4):439–452.—La présente étude fut entreprise pour investiguer le genre de plongée, la relation masse-flottabilité, et quelques fonctions respiratoires chez des plongeurs professionnels en apnée de l'ile Tsushima, Japon. Ces plongeurs portent toujours des costumes de plongée en néoprène, et utilisent des palmes et des contrepoids de 4 kg. Ils plongent habituellement à des profondeurs de 3–10 m. La vitese de descente était de 1.12 m/s pour les plongées les plus profondes (> 10 m), ce qui est presque 2 fois plus vite que les plongeuses coréennes portant également un costume perméable à l'eau et des palmes. Cependant, la vitesse de remontée (0.8 m/s) était comparable à celle des plongeuses coréennes. Au cours d'une journée typique d'été, ils passent environ 4 h dans l'eau et effectuent 175 plongées. La plongée moyenne et le temps de surface furent 39 et 42 s, respectivement. Le séjour total au fond fut estimé être de 67 min par jour, presque le double de celui des plongeuses coréennes. Ces plongeurs n'ajustent pas le contre-poids et tous utilisent un poids de 4 kg. Néanmoins, la relation masse-flottabilité révéla qu'ils maintiennent le même degré de flottabilité positive (~ 10% au-dessus du point neutre) à la surface, comme dans le cas des plongeuses coréennes qui adjustent les contrepoids. La capacité vitale était significativement plus grande chez les plongeurs que chez les témoins ($P < 0.05$), ce qui était principalement du à un plus grand volume de réserve expiratoire chez les plongeurs. Les pressions d'$O_2$ et de $CO_2$ en fin d'expiration des plongeurs au repos hors de l'eau ne furent pas différentes de celles des témoins. Ces résultats indiquent que même si le genre de plongée de base est similaire pour les plongeurs et plongeuses en apnée tous les deux, l'efficacité globale de la plongée (en terme de vitesse de descente et temps de fond) apparait être supérieure chez les plongeurs mâles.

plongée en apnée
mâle
habits perméable à l'eau
profile temps-profondeur
volumes des poumons
flottabilité

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