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Insulative power of body fat on deep muscle temperatures and isometric endurance

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PETROFSKY, JERROLD SCOTT, AND ALEXANDER R. LIND. *Insulative power of body fat on deep muscle temperatures and isometric endurance.* J. Appl. Physiol. 39(4): 639–642. 1975.—Four male subjects were examined to assess the relationship of body fat content to deep muscle temperature and the endurance of a fatiguing isometric handgrip contraction at a tension set at 40% MVC. Muscle temperature was altered by the immersion of the forearm in water at temperatures varying from 7.5 to 40°C. In all subjects, there was a water bath temperature above and below which isometric endurance decreased markedly; the difference among individuals was solely accounted for by the individual's body fat content. Thus, subjects with higher body fat content required lower bath temperatures to cool the forearm musculature to its optimum temperature, which we found to always be approximately 27°C measured 2 cm perpendicularly to the skin in the belly of the brachioradialis muscle. Further, in one subject, we found that a reduction in this subject's body fat content resulted in a corresponding increase in the water bath temperature necessary to cool his muscles to their optimum isometric performance. These data demonstrate the striking insulative power of the thin layer of fat around the forearm in man in protecting shell tissues from cold exposure.

adipose tissue; isometric exercise; thermoregulation; shell tissues

THE ENDURANCE of fatiguing isometric exercise is related to the temperature of the forearm musculature. Clarke, Hellon, and Lind (5) demonstrated that there was an optimum temperature of the muscles of the forearm above and below which isometric endurance fell markedly. This temperature was about 27°C measured halfway between the skin and the bone in the belly of the brachioradialis muscle. However, the temperature of the resting forearm muscle of man in a comfortable environment has been reported to be considerably above this optimum temperature (2, 5, 9). More recent evidence shows that forearm muscle temperature can vary quite widely under normal physiological circumstances. For example, Petrofsky and Lind (9) have demonstrated that the deep muscle temperature of the forearm of both male and female subjects is directly related to the body fat content, causing an elevation of some 1.5°C in muscle temperature for every 10% increase in body fat content over the "ideal" weight (10–15% of body weight as fat in males).

Body fat has long been known to provide a potent insulation against cold ambient environments (1, 3, 4, 6, 7). It seems reasonable, then, that the isometric endurance measured after exposure to cold or to heat should be related to the body fat content of the individual, but so far, no study has examined this relationship. Therefore, in the present investigation, muscle temperature and isometric endurance were measured following immersion of the forearm in water at various temperatures in men with different known body fat content and in one subject before and after weight loss.

METHODS

Subjects. The subjects in this study were four male volunteers whose ages, heights, weights, and calculated body fat content are listed in Table 1.

All procedures and potential hazards were carefully explained to each subject who then signed a statement of informed consent before participating. In addition, all potential subjects were medically examined, including a treadmill stress test and a pulmonary function test. All procedures were approved by the Committee on Human Experimentation.

Training. The subjects were first trained in isometric exercise. At the start of each experiment, the subiect exerted two brief (<3 s) maximum voluntary contractions (MVC) on a portable handgrip dynamometer similar to one described previously (5). The interval between those contractions was 1 min; the MVC was taken to be the stronger of the two contractions. Isometric endurance (measured with the subject sitting) was assessed as the duration (to the nearest second) of a sustained isometric handgrip contraction held to fatigue at a tension of 40% MVC calculated from the MVC recorded each day. On each training day, the maximal voluntary contraction and the endurance of five successive fatiguing contractions exerted at a tension of 40% MVC were measured; 3 min were allowed between the successive contractions. This procedure was repeated each Monday, Wednesday, and Friday of successive weeks until the coefficient of variation of the duration of the first fatiguing contraction was reduced to not more than ±5%; using that criterion, the training period ranged from 3 to 6 wk. During the period when the body fat content of one subject was altered, isometric training was maintained by repeating the training regimen once per week.

Measurement of isometric strength and endurance during immersion. Following the measurement of isometric strength in air, the seated subject immersed his forearm in water. The handgrip was also placed in the bath and after 30 min of immersion the subject performed a single 40% MVC contraction. A vigorous flow of water over the forearm was maintained by two pumps placed in opposite corners of the

TABLE 1. *Ages, heights, and weights of subjects*

Subj	Age, yr	Ht, cm	Wt, kg	Body Fat Content
JP	24	188.0	145.0	28%
CJ	26	188.0	68.2	16%
RB	38	193.0	79.5	18%
GS	25	185.4	97.0	26%

bath. Water temperature ranged from 7.5 to 40.0°C, maintained at ±0.1°C. The series of water temperatures was presented at random for each subject and was separately randomized for replicate immersions. In any one set of experiments, some or all those water temperatures were chosen to obtain the required data. A minimum of 72 h was allowed between any two experiments.

Body fat content. The body fat content (the % of body weight which is fat) was assessed by the underwater body density method described by Keys and Brozek (8).

Weight loss. Weight loss on one subject was achieved by a ketogenic diet (15% carbohydrates, 40% protein, and 45% fat) maintained for a period of 3 mo. The experiments on this subject occurred just before and 1 mo after weight loss; during the month after dieting, a mixed food intake was used to keep his body weight stable.

Muscle temperature. Muscle temperatures were measured on a separate occasion from endurance determinations. Temperatures were measured with a BC32L1 thermistor (Fenwall Instrument) implanted in a 23-gauge stainless steel needle. The resistance of the thermistor was measured with a digital ohmmeter accurate to ±0.1 Ω (Weston Instrument). The thermistor was calibrated before and after each experiment. Fully sterile procedures were followed and the needle was inserted into the brachioradialis muscle distal to the olecranon process approximately one-third of the distance to the ulnar process. The puncture was protected by collodion before immersion in the water.

After the first experiment on each subject, a tattoo mark was placed at the puncture site so that the muscle temperature in repeated experiments could be assessed at the same spot; a minimum of 3 days was allowed between muscle temperature recordings.

RESULTS

Each point in Fig. 1 represents the mean of four endurance contractions (2 for each subject) for two subjects who were overweight (closed circles) and two subjects of normal weight (open circles). Obviously, two discreet curves were obtained. While isometric endurance was similar for all the subjects after immersion in water at 40°C the longest endurance recorded for the overweight subjects (mean body fat content, 27%) was found when the forearm was immersed in water at 17.5°C, while that of the normal subjects (mean body fat content, 17%) was found in water at 25°C. Here, as in training, for any one subject, replicate endurance determinations at any temperature differed by no more than 10 s.

In overweight *subject JP* (whose body fat content was 27%) and normal weight *subject RB* (whose body fat content was 18%) the muscle temperature in the brachioradialis muscle was measured under these same conditions. Muscle temperatures were recorded before immersion and every 5 min up to 30 min following immersion of the forearm in water at 10, 15, 20, and 34°C. In all experiments, the deep-muscle temperature before immersion was about 1.5°C greater in the overweight subject (Fig. 2). Following immersion of the forearm in water at 34°C, this difference in deep-muscle temperature between the two subjects remained quite steady; muscle temperature increased to 34.5 and 36°C, respectively, for the normal and the overweight subject. But, after immersion of the forearm in the three colder water baths, this difference in the deep-muscle temperature between these subjects was accentuated. For example, after 30 min immersion of the forearm in water at 10°C the muscle temperatures were, respectively, about 18 and 22°C for the normal and overweight subjects. Figure 3 shows the duration of the sustained contractions at 40% MVC plotted against the muscle temperatures recorded after immersion of the forearm in water at 10, 15, 20, 25, and 34°C for these two subjects. While the absolute magnitude of the endurance response differed in the two subjects, the longest recorded endurance occurred at a muscle temperature of about 28°C for both subjects. Above and below this temperature, muscular endurance fell markedly.

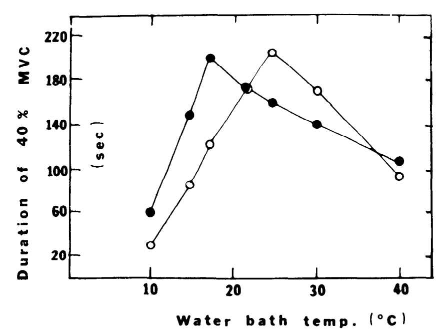

FIG. 1. Average duration of fatiguing isometric contractions at 40% MVC after 30 min immersion in water at 10, 15, 17.5, 22, 25, 30, and 40°C for two overweight subjects (●) and two subjects of normal weight (○). Each point illustrates the mean of four endurance determinations. Both pairs of subjects had the same mean endurance in the 22°C water.

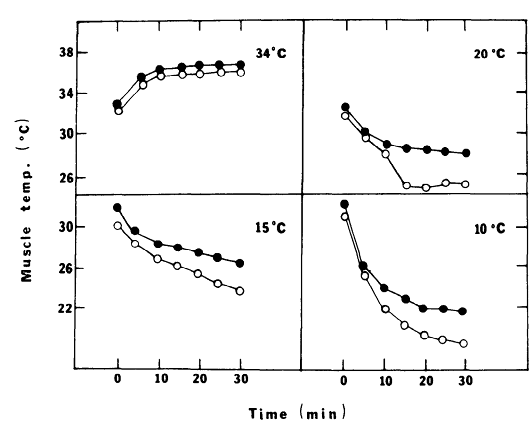

FIG. 2. Illustrating muscle temperature at vertical depth of 2 cm into the forearm of normal *subject RB* (○) and overweight *subject JP* (●) after immersion of the forearm in water at 10, 15, 20, and 34°C. Each point shows the mean of two determinations.

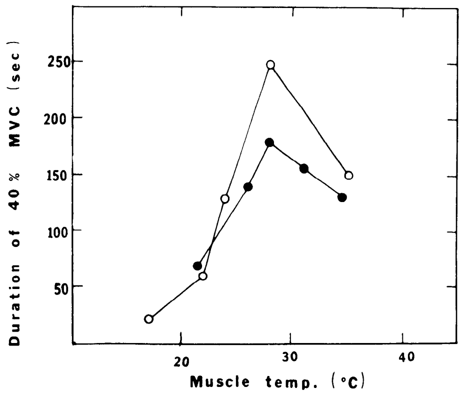

FIG. 3. Relationship of muscle temperature to the duration of a 40% MVC contraction in *subjects RB* (○) and *JP* (●). Each point illustrates the mean of two measurements.

In one subject, we had the opportunity to measure the relationship of muscle temperature to isometric endurance before and after he reduced his body fat content. The subject reduced his body fat content from 39% to 27% with an associated reduction of his forearm circumference (measured over the site of the needle insertion) of 37 mm. Before weight loss his muscle temperature was measured during a 20-min immersion in water varying in temperature from 7.5 to 40°C. Isometric endurance at 40% MVC was then recorded. One month after losing weight these procedures were repeated; during that period, his body fat content remained stable. Before he lost weight, the longest endurance time for the subject occurred in water at 12.5°C. Following weight loss, however, the curve relating endurance times to water temperature shifted to the right and the longest endurance occurred in water at 17.5°C. The relationship of muscle temperature and endurance at these water temperatures before and after weight loss are shown in Fig. 4. Peak endurance before (closed circles) and after (open circles) weight loss occurred at about the same muscle temperature, 28°C.

DISCUSSION

The intimate relationship between the body fat content and thermoregulation in man is abundantly demonstrated in the literature. For example, associated with an increased body fat content, there is a decrease in the metabolic and other thermoregulatory responses to cold air (1, 3, 6) or cold water (4, 7). However, most of these studies have dealt only with the core temperature and the regulation of that temperature in relation to body fat content. Although Wells and Buskirk (11) found higher subepidermal temperatures in the forearms of overweight than control subjects during dynamic exercise, no study has related the muscle temperature in a limb to the body fat content in subjects during exposure to heat and cold. This is particularly important to the study of fatigue during isometric exercise. Unlike dynamic exercise where the efficiency of muscular exercise appears to increase as the muscle temperature increases (10), it has been shown in earlier results (5) as well as in our present study that the peak endurance for isometric exercise occurs at a muscle temperature several degrees below the normal, resting, deep-muscle temperature

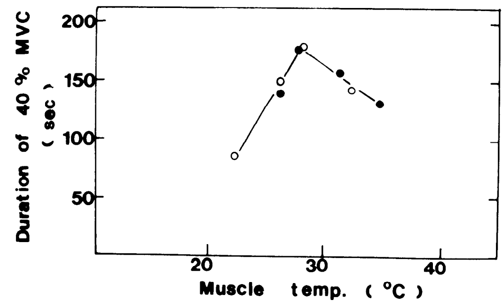

FIG. 4. Duration of an isometric contraction at 40% MVC plotted against muscle temperatures after 20 min immersion of the forearm in water of various temperatures. Data represent the mean of two determinations on *subject JP* before (●) and after (○) weight loss.

of the forearm. However, even in a controlled ambient environment, the temperature of the muscles of the forearm at rest is influenced by an individual's body fat content. We have recently demonstrated, for example, that a difference of 4.5°C may occur in the deep muscle temperature of the brachioradialis muscle measured at a perpendicular depth of 40% between the skin and center of the forearm between individuals whose body fat content differs by 30% (9). Further, we found that this dramatically higher muscle temperature in the overweight individual is easily reduced by simple weight loss. The higher resting muscle temperature in men who were overweight led to a reduction in their endurance for isometric exercise, a fact that could be accounted for solely on the basis of an elevated resting muscle temperature.

It is not surprising then, that in the present investigation, we found that the peak endurance for sustained effort occurred after immersion of the forearm in colder baths in the subjects with higher body fat contents. However, in terms of the muscle temperature, peak isometric performance occurred at the same muscle temperature irrespective of the body fat content of the subject. Thus, the causative agent for the difference in isometric endurance between the two groups of individuals (overweight and control) we studied was simply a difference in their muscle temperature. This difference illustrates the striking insulative power of the layer of fat around their forearms. For example, *subject JP*, before weight reduction, had a deep-muscle temperature of 26°C after a 20-min exposure in a 10°C water bath. Following a reduction of 12% of his body fat content, the muscle temperature measured under the same circumstances was 22°C, a reduction of 4°C. This loss of insulative power was associated with a decrease in forearm girth of 37 mm. Assuming the arm to be a cylinder and that the majority of the fat in the forearm is subcutaneous, this would represent a loss of 5.8 mm of subcutaneous fat. Thus, while the elevated muscle temperature in the resting overweight subject exposed to a thermally neutral environment compromises his isometric muscular performance, a substantial advantage is achieved for the overweight subject exposed to cold environments.

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