Body Composition and Athletic Performance

Wayne E. Sinning
Kent State University

Considerable effort has been expended to develop methods for measuring the body composition of athletes, but very little research effort has been focused on the significance of body composition relative to athletic performance. Several questions must be answered. For example, what is the ideal combination of fat and fat free mass (FFM) for optimum performance in different sports? What is the absolute minimum weight for athletes who participate in sports in which weight cutting is practiced? What are the implications of weight control practices for immediate and long-term health? Such issues are dealt with here relative to current literature.

RECOMMENDING WEIGHTS TO ATHLETES

A primary concern in athletics is the recommendation of ideal weight for peak performance in a chosen sport. The common use of the term ideal weight is unfortunate in that it implies a known optimum combination of body fat (BF) and FFM. Unfortunately, the ideal relative fat content for performance or health is not known. Such recommendations are usually based on average relative fat (%BF) and FFW values derived from samples of athletes who participate in the same sport as the person being tested. Wilmore (1983) has reviewed the literature to develop extensive body composition profiles on male and female athletes in numerous sports.

Assumptions must be made when using such profiles to set target weights. It must be accepted that the average %BF reflects a desirable value relative to the physiological and biomechanical requirements of the sport. It is also accepted that averages reflect the genetic endowment for the sport and the effects of an acceptable training program. Variability of the reference sample must also be considered.

American football provides a suitable model for illustrating this concept in that the game requires a high level of specialization at different player positions. Data on professional football from Wilmore, Parr, Haskell, Costill, Milburn, and Kerlan (1976) were used in formulating Figure 1. Other investigators have presented similar data on college players (Forsyth & Sinning, 1973; Mayhew, Piper, & Holmes, 1981; Novak, Hyatt, & Alexander, 1968; White, Mayhew, & Piper, 1980; Wickkiser & Kelly, 1975;
Wilmore & Haskell, 1972). However, professional athletes should reflect the highest competency level in a sport and thereby best reflect the assumptions.

Figure 1 shows that defensive and offensive backs tend to have lower relative fat content than players in other positions. These athletes must have speed and agility to execute assignments requiring quick, precise movements, as well as endurance to perform repeated sprints. The lower %BF provides a lower weight-to-strength ratio, which would be advantageous.

The positions of linebacker, offensive lineman, and tight end all involve extensive physical contact. Linebackers must react to movements of the offensive team. Their relative fat content is slightly lower than that of offensive linemen, while their weight is lower by 10.4 kg. The larger FFM and total weight of offensive linemen would be advantageous in that they are frequently involved in contests of strength with defensive linemen who tend to weigh 4.5 kg more. For the defensive linemen, the additional weight would be helpful since they must frequently react to contact by a moving offensive player. It might also be argued that the higher fat content provides some protection for the musculoskeletal system.

The relationship between body composition and the performance of runners is shown by their low %BF. Pollock, Gettman, Jackson, Ayers, Ward, and Lennerud (1977) found elite, middle-distance male runners to have an average 5.0 ± 3.5% BF, while elite marathoners were 4.3 ± 3.0% and good college runners were 6.1 ± 4.0%. The fat content of 94 average young men tested by the same investigators was 13.4 ± 6.0%. The elite middle-distance runners fell 1.4 SD below that mean while the marathoners and good runners were 1.5 and 1.2 SD below, respectively.

Sprinters also tend to be very lean. Barnes (1981) reported a relative fat content of 4.39 ± 1.87% for six international caliber sprinters and hurdlers. The range was from 3.79% to 8.55%. Leanness in sprinters would enhance the power output-to-body-
weight ratio, an important factor when accelerating the body mass as rapidly as possible.

Female runners also present a very lean configuration. Wilmore, Brown, and Davis (1977) reported body composition data on 70 distance runners as well as 8 sprinters and middle-distance runners. Distance runners averaged 16.8 ± 5.5% BF, while sprinters and middle-distance runners averaged 10.9 ± 3.6%. In both groups there was essentially no difference between young (9 to 16 yr) and mature (17 to 51 yr) athletes. Other female athletes also tend to be very lean. Reported values for gymnasts range from 10.1 to 17% BF (Parizkova & Poupa, 1963; Sinning, 1978; Sinning & Lindberg, 1972; Sprynarova & Parizkova, 1969). Classical ballet dancers were 16.9% BF (Calabrese, Kirkendall, Floyd, Rapoport, Williams, Weiker, & Bergfeld, 1983). Snyder, Wenderoth, Baker, and Johnston (1984) found approximately 12.5% BF in elite, lightweight oarswomen. World-class female pentathletes were reported to be 11.0% BF (Krahenbuhl, Wells, Brown, & Ward, 1979).

Wilmore, Brown, and Davis (1977) noted that, in comparison to the average male distance runner, females tended to be 13 kg lighter in body weight and 16 kg lighter in FFW but 6% to 7% higher in BF content. This additional fat is an added burden that the female must carry while running. Of interest, 8 of their middle-distance runners and 7 of the 70 distance runners were comparable to their male counterparts in that they were less than 10% BF. All of these were elite athletes! Two distance runners who were only 6% BF were also the best runners in the sample.

The relationship between weight and energy expenditure has long been recognized. Margaria, Ceretelli, and Mangili (1964) found that the net energy requirement per kilogram of body weight per kilometer run was independent of speed when it was within the aerobic capacity of the athletes they tested. For level running, the cost was approximately 1 kcal/kg • min⁻¹. For a marathoner, an extra kilogram would require an additional oxygen uptake of about 65 ml • min⁻¹ while running at a world-record pace.

Studies on locomotion show that added energy expenditure for carrying additional fat is the same as for carrying an external load while walking (Goldman & Iampietro, 1962). Hanson (1973) found that changes in the energy expenditure of locomotion with experimentally induced obesity and weight loss followed normal prediction values based on total weight, including an external load.

Cureton and Sparling (1980) took advantage of such observations to develop a model to study the significance of body composition relative to the difference between males and females in running performance. They measured O₂ uptake during maximal and submaximal exercise as well as performance in the 12-min run. Males were tested under two conditions: first, without added weight and then with extra weight. The weight for a runner was equal to his body fat plus enough additional weight to give him the same proportional contribution of excess weight to total body weight as that of the proportional fat content of a paired female subject. The added weight reduced the gender difference in treadmill run time and 12-min run by about 30%, which suggests that about one-third of the gender difference in running performance could be accounted for by the relative fat content. The difference in VO₂ max in milliliters per kilogram of weight was reduced by 65%. The use of added weight to study the effects of gender differences can easily be criticized. However, this is one of the few attempts to develop a model of experimentally altered body composition. More efforts are needed to develop acceptable models if we are to truly understand the role of body composition in performance.
THE PROBLEMS OF LEANNESS

The high volume training program of distance runners readily explains their leanness. However, there are other sports in which participants are typically lean, but the training routines do not require the high energy expenditure found in distance running. Barnes (1981) noted that the sprinters he studied incorporated only 2.2 miles of running per week in their training routines. He suggested that their leanness (4.39% BF) may be due to natural selection rather than training.

Sports such as gymnastics and dance, which require the controlled movement of the body through space, also typically have lean athletes. Novak, Hyatt, and Alexander (1968) reported a 4.3% BF in male college gymnasts, while we found an average of 6.5% BF (Sinning, Dolny, Little, Cunningham, Recaniello, Siconolfi, & Sholes, 1984). Reported values for female gymnasts range from 10.1% to 15.7% BF (Parizkova & Poupa, 1963; Sinning, 1978; Sprynarova & Parizkova, 1969) while classical ballet dancers averaged 16.9% (Calabrese et al., 1983). For both gymnasts and dancers, a low fat content would be beneficial from both aesthetic and performance considerations. Ballet dancers are required to have a lithe appearance (Calabrese et al., 1983).

Gymnasts and dancers follow very rigorous training routines but still need to diet to control weight. Calabrese et al. (1983) reported that ballet dancers spend over 40 hours a week in exercise. Nutritional surveys taken during the working week revealed that ballet dancers were consuming only 71.6% of the RDA in calories and were deficient in minerals and vitamins as well.

The extreme leanness of female body builders (13.2% BF, Freedson, Mihevic, Loucks, & Girandola, 1983) is of interest. Weight lifting programs do not have the high caloric expenditures associated with low body fat content. The leanness is apparently due to dietary control and aerobics exercise (Cushing, 1984), perhaps to reduce the fat covering in order to reveal the muscle definition needed in competition.

The advantage of a low fat content for successful performance in these female athletes is evident. But what about the health implications of extreme weight cutting? The frequency of secondary amenorrhea in women athletes, a condition often referred to as sports or athletic amenorrhea, is of concern. In last year’s Academy meeting, Drinkwater (1984) presented an excellent review on this topic. It has been suggested that reduced body fat is a causative factor. This hypothesis, which was developed by Frisch (1976a), is very appealing. It is suggested the menstruation starts when the weight is 22% to 24% BF, and it will be maintained as long as the fat content exceeds 17% of the weight (Frisch, 1976b). Sports amenorrhea could thereby be attributed to the reduced BF.

Frisch’s theory has been challenged both on the methodology of measuring body composition and on the statistical analyses used (Johnston, Malina, & Galbraith, 1971; Reeves, 1979; Trussell, 1980). Research on athletes has not consistently supported Frisch’s theory (Feicht, Johnston, Martin, Sparkes, & Wagner, 1978; Wakat, Sweeney, & Rogol, 1982; Warren, 1980). Preliminary analyses of data from our laboratory on women from eight different sports showed no apparent differences between amenorrheic (N = 10), oligomenorrheic (N = 14), and normally cyclic (N = 45) subjects. Respective relative BF contents were 18.8 ± 3.88%, 19.7 ± 5.07%, and 20.0 ± 5.82%.

It is time to accept that low BF content may be related to sports amenorrhea, although this is almost surely not the causative factor.
Very recently, another concern about intensive training and low body weight has developed because of research suggesting significant loss of bone mineral in amenorrheic women. Cann, Martin, Genant, and Jaffe (1984) found that subjects who served as an experimental group representing hypothalamic amenorrhea were all involved in vigorous training. Spinal trabecular bone mass was decreased 20% to 30% while cortical bone was unchanged. These subjects were also very lean. Subsequently, Drinkwater, Nilson, Chestnut, Bremmer, Shainholz, and Southworth (1984) found significant decreases in trabecular bone mineral in 14 amenorrheic women who averaged 41.8 miles of running per week, compared to 14 eumenorrheic women who averaged 24.9. Respective relative BF contents were 15.8% and 16.9%.

Marcus, Madvig, Minkoff, Cann, Genant, Goddard, and Haskell (1984) also found reduced spinal bone mass in 11 amenorrheic runners when they were compared to 6 cyclic runners. However, the bone mineral content was higher in the amenorrheic runners than it was in nonexercising amenorrheic women. Respective fat content values were 10.0 ± 1.0% and 11.1 ± 2% BF. Snyder et al. (1984) found no evidence of bone loss in amenorrheic or oligomenorrheic elite lightweight oarswomen who were 11.6% BF. Loss of bone mineral content has not been shown during training in males (Aloia, Cohn, Babu, Abesamis, Kalici, & Ellis, 1978; Montoye, Smith, Fardon, & Howley, 1980; Williams, Wagner, Wasnich, & Heilbrum, 1984).

Concern about low fat content in male athletes centers around sports in which participants must “make weight.” Examples are jockeys, boxers, and wrestlers. The latter group has generated the most research interest because wrestling is a popular sport in high schools and colleges. Wrestlers tend to be quite lean, but not extremely so. They tend to maintain approximately 8% to 9% BF during the season (Kelly, Gorney, & Kalm, 1978; Sinning, 1974). They then dehydrate drastically to make weight by exercising in a warm environment in an impervious garment while restricting food and fluid intake over the last 24 to 48 hours before a match, sometimes losing 10 or more pounds.

The consequences of such weight cutting may be immediate or long range. Severe, short-term starvation and dehydration has been shown to reduce isometric (Bosco, Greenleaf, Bernauer, & Card, 1974) and dynamic strength (Houston, Marrin, Green, & Thompson, 1981). Muscle glycogen stores are also reduced (Houston et al., 1981). Starvation over a 2 1/2 to 5-day period with up to 7.8% weight loss adversely affects the capacity to work at submaximal intensities (Henschel, Taylor, & Keys, 1954). However, Houston et al. (1981) did not find adverse effects on aerobic and anaerobic capacity.

The effect of weight cutting on the kidney function of wrestlers was examined in a series of studies at the University of Iowa. Zambraski, Tipton, Jordon, Palmer, and Tcheng (1974) compared urine samples of high school nonwrestlers and state finalists at weigh-in. They found the wrestlers’ urine to be significantly higher in specific gravity, creatinine, osmolality, and potassium but lower in pH (i.e., more acidic) and sodium. For the wrestlers, 76% demonstrated some degree of proteinuria. Later, Zambraski, Foster, Gross, and Tipton (1976) found similar results in college wrestlers. In another project, Zambraski, Tipton, Tcheng, Jordan, Vailis, and Callahan (1975) studied an NCAA championship team before a major match, collecting urine specimens over 2 days before the match and at weigh-in. Again, urine changes reflected extreme dehydration at weigh-in. Changes in the enzyme leucine amino peptidase suggested the possibility
of renal ischemia. Vaccaro, Zauner, and Cade (1976) reported increases in hematocrit and serum protein showing reduced plasma volume over the 2 days before competition. Strauss, Lanese, and Malarkey (1984) found four cases of reduced serum testosterone levels in varsity wrestlers who were estimated to have an average 7.7% BF.

Smith (1980) expressed concern about anorexia nervosa and anorexic behavior in athletes. He presents a case study of a male rower who, in an attempt to weigh 155 lbs to make the lightweight rowing team, developed a food aversion and dropped from 182 lbs to 140 lbs in 6 weeks. Sinning (1978) found similar anorexic behavior in a woman gymnast. On making a college team, she weighed 56.2 kg and was 14.9% BF with a FFW of 48 kg. Two years later, after severe dieting for about 7 months, she weighed 47.7 kg with an 8.1% BF content and a FFW of 43.8 kg. Her total weight after dieting was equal to her FFW at the beginning of her career. The reduction in blood testosterone found in wrestlers by Strauss et al. (1984) was similar to reduced levels observed in male anorexics by Andersen and Mickalide (1983). The latter observed that anorexia nervosa is underdiagnosed in males.

THE CASE FOR A LITTLE FAT

Extreme leanness may be advantageous in many sports, but a higher fat content may be advantageous in swimming in that it improves buoyancy. Pendergast, diPrampero, Craig, and Rennie (1978) observed that swimming velocity is determined by two factors: the potential aerobic and anaerobic power (É) and the ratio of net mechanical energy (e) per unit of drag (D). The latter is also a measure of technical skill. They also noted that the ratio of oxygen uptake (VO₂) per unit of distance (d) is equivalent to D/e. By comparing VO₂/d values, it is apparent that female swimmers are much more proficient than their male counterparts.

Pendergast et al. (1978) attribute this superiority to the higher buoyancy in females due to their higher fat content. With more buoyancy, females tend to swim higher in the water, which reduces D. Also, Pendergast and Craig (1974) have shown that the lower density in the lower limbs of females allows them to float more horizontally in the water. Consequently, the female swimmer can devote less energy of the leg kick to counteract the vertical component and more to a propulsive forward component.

Pendergast et al. (1978) observed that record times in pool competition shows males to be superior to females, while in marathon swimming females dominate. They attribute males' better performance at shorter distances to their capacity to develop much higher aerobic and anaerobic power. In marathon swimming, technical competency is more important than power; therefore females dominate. In fact, females hold many speed records for swimming the English Channel (McWhirter & Cook, 1980).

Such observations suggest that swimmers would tend toward fatness. However, body composition studies on swimmers other than marathoners suggest that good swimmers tend to be lean. A summary of relative BF values for female swimmers is given in Table 1. For less skilled swimmers, the values fall within the range of 21.5% to 29.1% BF reported in various studies on college women as summarized by Katch and McArdle (1973). Values for more proficient swimmers range from 14.6% for the sprinters reported by Wilmore et al. (1977) to 19.7% reported by Thorland, Johnston, Housh, and Refsell (1983) for Junior Olympic swimmers. Men swimmers, for whom reported values are summarized in Table 2, tend to be quite lean. With the exception
Table 1

Body Composition Characteristics of Female Swimmers*

<table>
<thead>
<tr>
<th>Source</th>
<th>N</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Fat (%)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meleski et al. (1982)</td>
<td>41</td>
<td>17.1</td>
<td>168.2</td>
<td>56.0</td>
<td>16.2</td>
<td>Age range 11-20 yrs. Some world class.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 2.4</td>
<td>± 6.3</td>
<td>± 4.7</td>
<td>± 3.7</td>
<td></td>
</tr>
<tr>
<td>Thorland et al. (1983)</td>
<td>67</td>
<td>15.8</td>
<td>168.2</td>
<td>58.5</td>
<td>19.7</td>
<td>Junior Olympic swimmers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 1.4</td>
<td>± 6.6</td>
<td>± 5.9</td>
<td>± 12.8</td>
<td></td>
</tr>
<tr>
<td>Sprynarova &amp; Parizkova</td>
<td>10</td>
<td>19.54</td>
<td>166.22</td>
<td>63.85</td>
<td>19.2</td>
<td>International caliber</td>
</tr>
<tr>
<td>(1969)</td>
<td></td>
<td>± 3.21</td>
<td>± 5.65</td>
<td>± 5.56</td>
<td>± 3.13</td>
<td></td>
</tr>
<tr>
<td>Katch et al. (1969)</td>
<td>5</td>
<td>60.30</td>
<td></td>
<td></td>
<td>23.2</td>
<td>College team</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 4.25</td>
<td></td>
<td></td>
<td>± 2.0</td>
<td></td>
</tr>
<tr>
<td>Tittel &amp; Wutscherk (1972)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freestyle</td>
<td></td>
<td></td>
<td>166.8</td>
<td>58.8</td>
<td>16.3</td>
<td>International caliber</td>
</tr>
<tr>
<td>Dolphin butterfly</td>
<td></td>
<td></td>
<td>165.6</td>
<td>60.7</td>
<td>18.2</td>
<td></td>
</tr>
<tr>
<td>Breast stroke</td>
<td></td>
<td></td>
<td>163.5</td>
<td>56.2</td>
<td>16.7</td>
<td></td>
</tr>
<tr>
<td>Back stroke</td>
<td></td>
<td></td>
<td>168.2</td>
<td>60.2</td>
<td>17.3</td>
<td></td>
</tr>
<tr>
<td>Relay</td>
<td></td>
<td></td>
<td>165.5</td>
<td>58.7</td>
<td>17.2</td>
<td></td>
</tr>
<tr>
<td>Wilmore et al. (1977)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprinters</td>
<td>4</td>
<td>165.1</td>
<td>57.1</td>
<td></td>
<td>14.6</td>
<td>Level not noted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 4.3</td>
<td>± 4.7</td>
<td></td>
<td>± 5.9</td>
<td></td>
</tr>
<tr>
<td>Middle distance</td>
<td>7</td>
<td>166.6</td>
<td>66.8</td>
<td></td>
<td>24.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 3.0</td>
<td>± 6.3</td>
<td></td>
<td>± 5.6</td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>4</td>
<td>168.3</td>
<td>50.4</td>
<td></td>
<td>17.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>± 5.3</td>
<td>± 4.4</td>
<td></td>
<td>± 2.6</td>
<td></td>
</tr>
</tbody>
</table>

*Values are means ± SD.

of the Junior Olympic swimmers studied by Thorland et al. (1983), the means ranged from 4.95% (Novak et al., 1968) to 8.8% BF (Sinning et al., 1984), values not uncommon for distance runners.

If low density is advantageous, why are swimmers relatively lean? Their body composition is probably a trade-off between the ideal mechanics of swimming and the training routine followed to develop the aerobic and anaerobic power so necessary to compete successfully at the shorter distances. It is not unusual for swimmers to train over 10,000 meters or more per day. In addition, swimmers lift weights to develop upper body strength for the generation of power which is important in competition (Sharp, Troup, & Costill, 1983).

There is no doubt that long-distance swimmers benefit from a high fat content. In addition to the efficiency factor, fat serves as thermal insulation which is so impor-
Table 2

Body Composition Characteristics of Male Swimmers*

<table>
<thead>
<tr>
<th>Source</th>
<th>N</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Fat (%)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorland et al.</td>
<td>39</td>
<td>17.3</td>
<td>180.7</td>
<td>72.7</td>
<td>12.1</td>
<td>Junior Olympic</td>
</tr>
<tr>
<td>(1982)</td>
<td></td>
<td>± 0.9</td>
<td>± 7.6</td>
<td>± 7.4</td>
<td>± 1.6</td>
<td>swimmers</td>
</tr>
<tr>
<td>Novak et al.</td>
<td>7</td>
<td>20.6</td>
<td>182.87</td>
<td>78.89</td>
<td>4.95</td>
<td>University</td>
</tr>
<tr>
<td>(1968)</td>
<td></td>
<td>± 1.19</td>
<td>± 5.016</td>
<td>± 7.22</td>
<td>± 4.48</td>
<td>team</td>
</tr>
<tr>
<td>Sprynarova &amp;</td>
<td>13</td>
<td>21.8</td>
<td>182.27</td>
<td>79.08</td>
<td>8.45</td>
<td>International</td>
</tr>
<tr>
<td>Parizkova</td>
<td></td>
<td>± 2.24</td>
<td>± 4.06</td>
<td>± 4.75</td>
<td>± 2.93</td>
<td>caliber</td>
</tr>
<tr>
<td>(1969)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinning et al.</td>
<td>27</td>
<td>19.80</td>
<td>178.32</td>
<td>79.9</td>
<td>8.8</td>
<td>College</td>
</tr>
<tr>
<td>(1984)</td>
<td></td>
<td>± 1.15</td>
<td>± 6.41</td>
<td>± 6.7</td>
<td>± 3.2</td>
<td>team</td>
</tr>
</tbody>
</table>

*Values are means ± SD.

tant because water stores 3700 times more heat than an equal volume of air and transfers it 25 times more rapidly. Pugh, Edholm, Fox, Wolff, Hervey, Hammond, Tanner, and Whitehouse (1955) did an extensive study of swimmers participating in the 1955 race across the English Channel. Fat content ranged from 17% to 31% on 11 male participants; the mean was 25.2 ± 4.04%. Interestingly, the competitors who finished the swim tended to have the lower fat content. It was suggested that the better swimmers could maintain a higher heat production. Consequently, they did not need as much fat to maintain core temperature.

Cold stress is accommodated by the vasoconstriction of skin blood vessels forcing the blood internally, as well as by an increase in metabolic rate. When the skin vasoconstricts, the fat acts as an insulator to preserve body heat. Pugh et al. (1955) computed that a fat thickness of 1 cm would support a difference of 1.67°C between core and water temperature in a nude person at rest. When heat production is 10 times the resting level, as it is in swimming, the same layer becomes more effective and would support a difference of 16.7°C, showing that fat is a more effective insulator at high rates of heat flow.

CONCLUSIONS

Body composition is an important concern relative to performance in athletics. However, the exact role of body composition for optimum performance has not been researched extensively. A major problem is that body composition cannot be easily manipulated, as shown in the studies on experimental obesity (Hanson, 1973). Consequently, suitable experimental models must be developed for a number of sports. Also, the immediate and long-term implications of extreme leanness and severe weight cutting to health need extensive study. We must learn more about how to measure body composition accurately and efficiently, but we also need to know more about what to do with the information once we have it.
REFERENCES


