

Loss of muscle mass is poorly reflected in grip strength performance in healthy young men

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ABSTRACT

JOHNSON, M. J., K. E. FRIEDL, P. N. FRYKMAN, and R. J. MOORE. Loss of muscle mass is poorly reflected in grip strength performance in healthy young men. *Med. Sci. Sports Exerc.*, Vol. 26, No. 2, pp. 235-240, 1994. Isometric maximal handgrip strength (GS_{max}) has been used as an expedient test of overall muscle strength and index of fat-free mass (FFM). We tested this relationship in 55 fit young men undergoing high rates of FFM loss in an 8.5-wk military training course involving multiple stressors including nutritionally uncomplicated energy deficit. GS_{max} was measured by a hand dynamometer interfaced with a computer providing visual feedback; another strength test, measuring dynamic strength of larger muscle groups ($Clean_{sim}$), was also performed. GS_{max} did not change (530 ± 57 vs 529 ± 63 N) in the face of a 15.6% loss of body weight (12.1 ± 3.4 (SD) kg), including 6.9% loss of FFM (4.6 ± 2.6 kg), but $Clean_{sim}$ decremented significantly (77.4 ± 9.6 to 58.7 ± 8.9 kg) and changes were significantly correlated with ΔFFM for GS_{max} ($r = 0.31$) and $Clean_{sim}$ ($r = 0.49$). We conclude that GS_{max} is not a good representation of changes in total FFM in healthy young men even though it appears to be useful in more severely catabolic patients with extreme losses of FFM and in pubertal boys making large gains in FFM. Other aspects of physical performance are clearly affected by high rates of weight loss, as demonstrated by decrements in the $Clean_{sim}$ and its stronger relationship to ΔFFM .

ISOMETRIC HANDGRIP STRENGTH, BODY COMPOSITION,
MILITARY PERSONNEL, LIFT CAPACITY, CLEAN LIFT,
WEIGHT REDUCTION

Maximal voluntary grip strength (GS_{max}) has been promoted as a convenient marker of nutritional status in hospitalized patients, where it has been generally assumed to be a marker of protein balance and whole body muscle mass. In such settings, where the reduction in muscle mass is large enough to compromise health, GS_{max} has been repeatedly demonstrated to predict severe postsurgical complications (6,22) and relates to protein loss (24). Similarly, a loss of 25% of body weight in healthy men in the Minnesota

study was accompanied by a significant decline in grip strength, and a parallel recovery of these two parameters was observed over several months of refeeding and weight regain (5). Other studies of healthy populations have suggested a connection between fat-free mass (FFM) and GS_{max} on the basis of age-related increases in GS_{max} (8) that parallel increased muscularity in adolescent boys (17) and age-related decreases in GS_{max} in the elderly when there is a downward trend in average FFM (4,7). Such trends suggest a stronger connection between strength of the hand and changes in FFM than more detailed physiological studies substantiate. Thus, Stolz and Stolz (17) found a correlation of 0.64 ($N = 67$) between GS_{max} and body weight in pubertal boys even though there is a well-established delay of 6-12 months to the peak increase in a variety of strength measures (including GS_{max}) after the peak weight gain in boys (17,18). A more detailed analysis of the relationship between FFM and GS_{max} in elderly subjects also suggests that changes in FFM account for only a portion of the decline in strength (4,7). These studies suggest grip strength may be a useful marker of FFM and changes in FFM, but with some limitations.

Sharp et al. (14) found that in male and female soldiers GS_{max} and a maximal lift test were both well correlated with FFM. However, the strength of the relationship between FFM and GS_{max} has not been clearly defined in healthy young men undergoing rapid weight loss, especially when the weight loss involves more than an acute dehydration such as that observed with wrestlers (13). The present study evaluated the effect of FFM change produced by long duration but low intensity exercise with an energy deficit on the commonly used expedient test of muscle strength (GS_{max}). A second and substantially different strength index, a dynamic test involving major muscle groups (a simulated clean lift, $Clean_{sim}$), was also compared in order to establish strength performance decrements associated with such a regimen.

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METHODS

Subjects. Participation in this study was strictly voluntary and written informed consent was obtained from each subject before the start of the study; participation in Ranger training is also voluntary and soldiers may withdraw and be returned to their regular military unit at any time. One hundred and ninety healthy young male soldiers enrolled in the U.S. Army Ranger training course volunteered for this study from a class of 261 soldiers; 55 were present at the end of the course ("finishers") and were available for both pre- and poststudy measurements. The remainder dropped out of the training class for reasons unrelated to the study procedures (80 failed military skills and patrolling technique, 38 were removed for medical problems, 4 failed peer evaluations, 4 were caught with unauthorized food, 4 withdrew from the course, and 5 were removed for administrative reasons). The average ($\pm$ SD) age, height, and weight of the finishers was 23.6 ± 2.8 yr, 176.6 ± 6.2 cm, and 75.9 ± 8.9 kg. These characteristics were not significantly different for the soldiers not completing the experiment, and no initial strength or body composition measurements were different between finishers and nonfinishers. The soldiers who volunteer for Ranger training and are recommended for the course by their Army unit represent a physically elite group of young men in excellent health and at a high level of fitness. The Clean_{sim} test used in this study demonstrates the superior strength of these men over the typical young Army male: the lowest measurement obtained at the start of this study was the average measurement (61.0 ± 12.4 kg; $N = 2061$) for Army men, with measurements taken by some of the same observers using the same equipment (15).

Ranger course description. The U.S. Army Ranger course is a demanding 62-d training program designed to teach and evaluate individual leadership and small unit tactics under physically and mentally demanding conditions. The course exposes trainees to multiple stressors including restricted availability of food, sleep deprivation, and four periods of sustained physical exertion (as 7–10 d of simulated combat patrols). The average daily energy expenditure of our volunteers estimated from known energy intakes and body composition changes was 4000 kcal; this was confirmed in a subset of men using the doubly labeled water technique (11). Only issued food rations were authorized and in the setting of this course this was generally the only food that soldiers could reasonably obtain; the discovery of unauthorized food led to immediate dismissal from the course. Since the men consumed only 2800 kcal, this resulted in a 1200 kcal·d⁻¹ energy deficit. This energy deficit was primarily the result of limited food intakes during four patrolling exercises when soldiers received one or fewer Meal-Ready-to-Eat rations (approximately 1300 kcal) daily (35 d total separated by three periods of refeeding). Except

for energy intake, intake of all nutrients met or exceeded the recommended daily allowances. Thus, unlike malnourished patients (16), the weight loss was the result of an uncomplicated energy deficit, since evidence of frank nutritional deficiency was not detected during physical examination of the subjects for signs of nutritional deficiencies and biochemical markers of nutritional status remained within normal limits throughout the course (11).

The primary work performed involved prolonged walking with a backpack load for distances between patrol bases that were typically 10–12 km·d⁻¹; except for an average of 3.6 h of sleep·24 h⁻¹, assessed by wrist activity monitors (Kathryn Popp, unpublished results, 1991, 1992) soldiers were continuously active in military tasks and training such as setting up patrol bases, preparing ambushes, performing reconnaissance and raid patrols, fording rivers, rappelling from helicopters, and training in hand-to-hand combat. The loaded backpack and pistol belt assemblies averaged 32.5 ± 7.8 kg (without water and ammunition) (total weights carried were usually ~50% of body weight). Arm exercise consisted of carrying a weapon (3.5–10.4 kg), usually partially supported by a sling and/or resting in a waist belt throughout the day. Considerable arm work was performed during the 3rd and 4th wk of the 8.5-wk course when mountaineering techniques were learned and used, but for most of the course, arm work consisted primarily of carrying a weapon.

Testing procedures. Body composition (measured by dual energy x-ray absorptiometry, DEXA) and three performance tests (maximal handgrip strength, handgrip endurance, and the one repetition maximal lift determined by a machine that simulates the Olympic clean lift) were all performed at the beginning and end of the study. These timepoints relative to the Ranger course were -5 d to +1 day of the start of the course (beginning), and on the last day of the evaluative portion of the course and before any refeeding began (end). The stability of these three physical performance measures over time has been previously demonstrated in soldiers (20).

Fat-free mass (FFM) was measured using DEXA (DPX-Plus, Lunar Corp, Madison, WI). The relative and absolute attenuation of two low level energy x-rays produced in a rectilinear scan of the whole body were used to measure the mass of tissue and the percentage of fat (9). Absorptiometry measurements were made at the beginning and end of the study. Precision of the measurement is better than $\pm 0.5\%$ percent body fat (2).

Maximal isometric handgrip force was measured using a customized hand dynamometer that included a BLH electronic load cell transducer interfaced with a Hewlett-Packard series 300 computer for real time display. The grip dominant hand was tested in three to four trials, alternating between test subjects to encourage competition and permit muscular recovery between replicate tri-

als (Fig. 1). The grip device was adjusted to fit each individual's hand before each trial. Subjects were instructed to keep their elbows in contact with the table and to position their shoulder over the elbow, keeping the elbow joint at approximately 90°. If the elbow was lifted from the table the trial was not used. Because the grip device was not anchored to the table, the test only measured the force provided by the forearm muscles attempting to close the gap between the fingers and thumb of the hand. Force was plotted in real time on a screen display to provide feedback for the subject and each subject was verbally encouraged to produce his best effort. This level of both visual and verbal feedback has been reported to increase maximal voluntary contractions by 10% over nonfeedback (12). Peak force values were recorded and the highest two values from three trials were averaged (23) to obtain a representation of the best effort from sleep deprived men. Only values that were within 10% of each other were used, and an additional trial was conducted in cases where adequate agreement between measurements was not achieved in three trials.

Handgrip endurance was measured by determining the holding time at 60% of maximal handgrip force. A screen display of the target force plotted over time gave subjects two horizontal lines at 57.5% and 62.5% of maximal handgrip force and produced a real-time plot of the subject's holding performance. Each subject was instructed to maintain a force within these limits, and when his grip force fell below 57.5% of the maximum for over 2 s, the computer stopped the test and displayed holding time in seconds.

The maximal lift capacity was measured with a weight stack machine that simulates the Olympic clean lift (1,10). This device was originally developed to classify individuals for military occupations requiring heavy lifting (10). A carriage with attached handles slides on two guide rods in the vertical direction. The handles were designed to simulate the feel of a free weight bar.

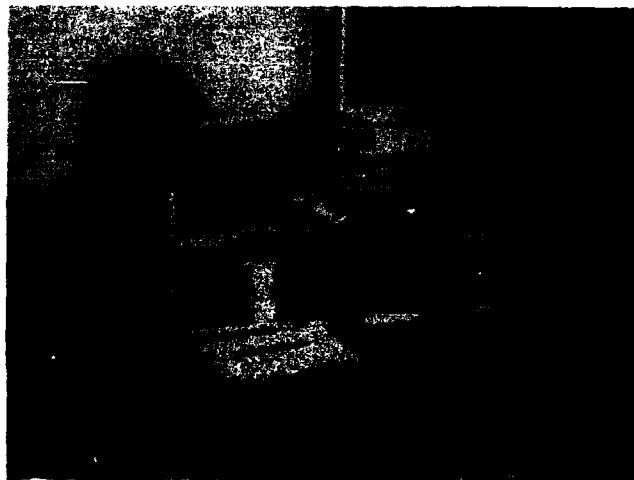


Figure 1—The testing arrangement for GS_{max} and handgrip holding time.

The exercise simulates the clean lift in Olympic lifting where the goal is to raise a weight from the floor to shoulder height. The individual explodes upward, extending at the knee and hip. He then racks the weight by dropping under and supporting it with the hands at shoulder level, and finishes the lift by standing up straight. To allow for proper warm-up the subjects began by lifting 36.3 kg (80 lbs) followed by the addition of weight in increments of 9.1 kg (20 lbs) or 4.6 kg (10 lbs) until a maximum lift ability was achieved. If the volunteer missed two attempts, a third one was not allowed because of the high probability that exercise technique could not be maintained. The test-retest reliability of this technique is $r = 0.91$ (15), and the measurement has been demonstrated to be highly stable over time in soldiers with heavy work in the absence of weight loss (20).

Data were analyzed by paired t -test comparisons between measurements collected at baseline and 8 wk. Pearson's correlation coefficients (r) were obtained between body weight, FFM, and strength measures and for changes (baseline to 8 wk) in these parameters. Statistical tests with $\alpha < 0.05$ were accepted as significant. Data were analyzed using SPSSx statistical software (SPSS, Chicago, IL).

RESULTS

The men in this study lost 12.1 ± 3.4 kg body weight, representing 15.6% of initial body weight. FFM declined with body weight ($r = 0.44$; $P < 0.01$), averaging 4.6 ± 2.6 kg or 6.9% of initial FFM (Table 1). This is an underestimate of the true loss because of the increased hydration of the FFM that occurs in semistarvation (5). The subset of men tested with doubly labeled water demonstrated a normal hydration at the start of the study (based on total body water estimates from ^{18}O dilution and FFM measurements) but at all later time-points yielded variable FFM hydration values but all in excess of 80%; there was no overt edema at the end of the study.

Clean_{sim} declined significantly (-18.7 ± 8.3 kg) but there was no mean change in GS_{max} or in grip hold time (Table 1; Fig. 2). GS_{max} and Clean_{sim} were both significantly correlated with initial weight and FFM (Table 2). Using all available measurements from volunteers starting the course, the correlation coefficients were similar

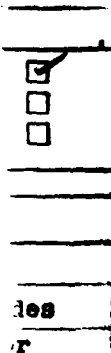
TABLE 1. Mean ($\pm$ SD) values of body composition and physical performance measurements

Variable	Baseline	8 wk	Change	Paired t -Test
Body wt (kg)	75.9 $\pm$ 9.0	63.8 $\pm$ 6.7	-12.1 $\pm$ 3.4	$P < 0.01$
FFM (kg)*	64.6 $\pm$ 6.4	60.0 $\pm$ 5.8	-4.6 $\pm$ 2.6	$P < 0.01$
Clean _{sim} (kg)	77.4 $\pm$ 9.6	58.7 $\pm$ 8.9	-18.7 $\pm$ 8.3	$P < 0.01$
GS_{max} (N)	530 $\pm$ 57	529 $\pm$ 63	-0.5 $\pm$ 51	NS
Hold time (s)	66.2 $\pm$ 14.1	66.3 $\pm$ 16.7	-0.2 $\pm$ 17.8	NS

* FFM calculated from % body fat by dual-energy x-ray absorptiometry.

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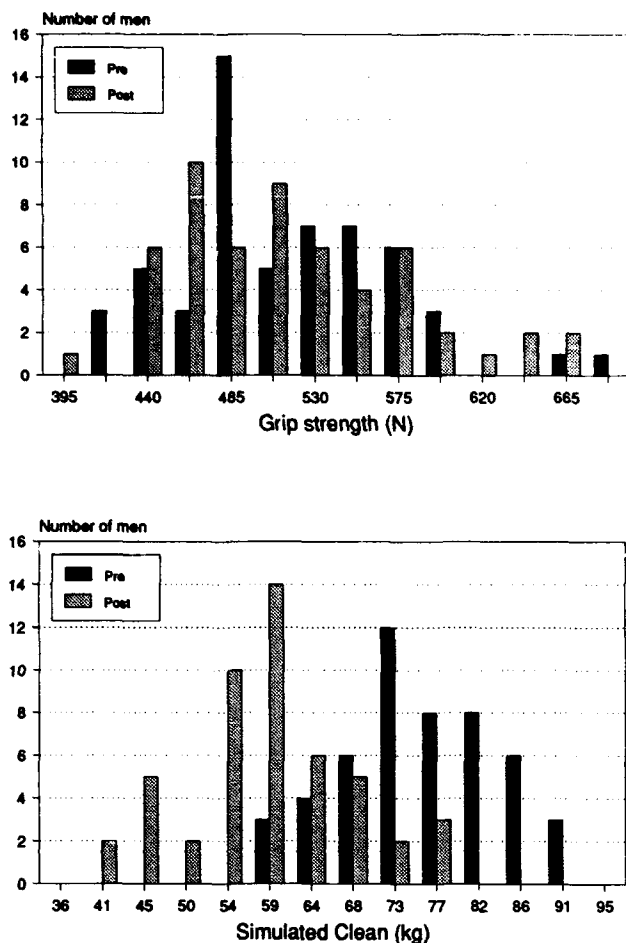


Figure 2—The distributions of GS_{max} and $Clean_{sim}$ performances before and after Ranger training and >10% body weight loss.

TABLE 2. Correlations of performance measures to fat-free mass (coefficients in *italics* indicate correlation to body weight and change in body weight).

Variable		Pre	8 wk	Change
Body weight (kg)		0.90**	0.98**	0.44**
$Clean_{sim}$ (kg)	FFM	0.64**	0.49**	0.49**
	<i>Body weight</i>	<i>0.66**</i>	<i>0.54**</i>	<i>0.41**</i>
GS_{max} (N)	FFM	0.37**	0.40**	0.31**
	<i>Body weight</i>	<i>0.26</i>	<i>0.43**</i>	<i>0.03</i>

** $P < 0.01$, significance of Pearson's correlation coefficient.

(GS_{max} : 0.53; $Clean_{sim}$: 0.59). Using only the data from the finishers (at the start of the course), the correlation coefficients to FFM were 0.37 (GS_{max}) and 0.64 ($Clean_{sim}$) (Fig. 3). It should be noted that this smaller sample also encompassed a narrower spread of performance and FFM measures. The changes in performance correlated with reduction in FFM but the relationship was stronger for the $Clean_{sim}$ (Table 2; Fig. 4). Correlations of performance measures to body weight and change in body weight, were similar but not as strong. There was no meaningful correlation between relative grip hold time and FFM.

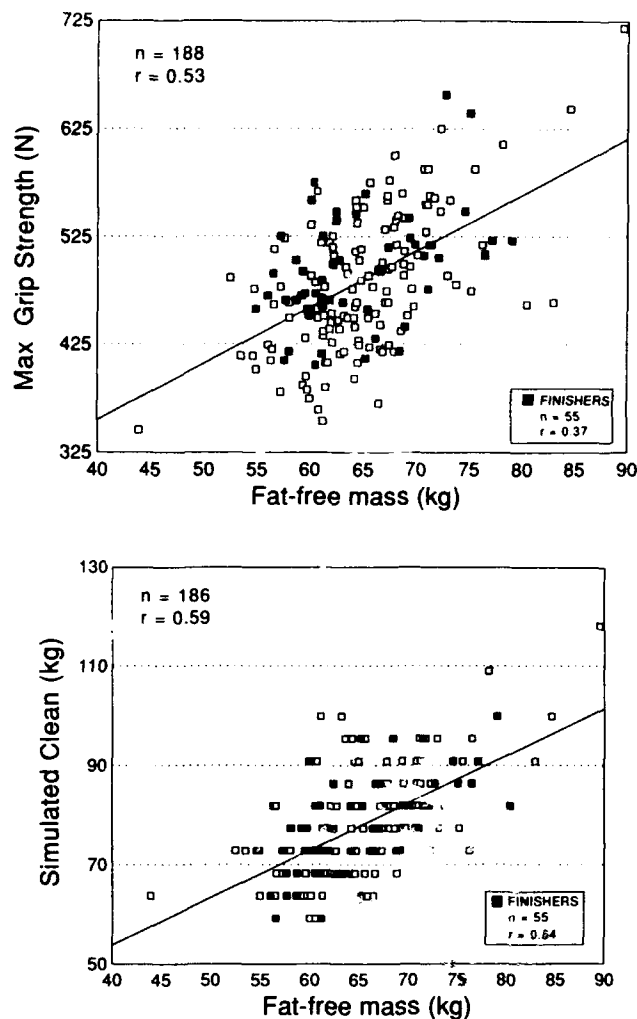


Figure 3—The relationships between FFM and GS_{max} and $Clean_{sim}$ in all subjects starting Ranger training (nonfinishers, $N = 133$, open squares; and finishers, $N = 55$, filled squares).

DISCUSSION

GS_{max} has been widely promoted as a marker of nutritional status and/or overall muscular strength but our results call into question its usefulness as a generalized test in healthy individuals. In our study of fit young men, correlation to FFM (or body weight) was not strong. A more powerful test of such a correlation is to evaluate the relationship when one of the variables is changed; we found it remarkable that there was *no* decrement in the mean grip strength after our volunteers underwent a rapid and large weight loss which included a substantial decline in FFM. When we pursued this further with a comparison of 10 subjects from each extreme of FFM change, there was still no significant difference in the mean GS_{max} , indicating that GS_{max} is simply not a useful marker of overall FFM in healthy young men. The lack of change in grip holding time was less surprising because any relationship to FFM would be substantially weak-

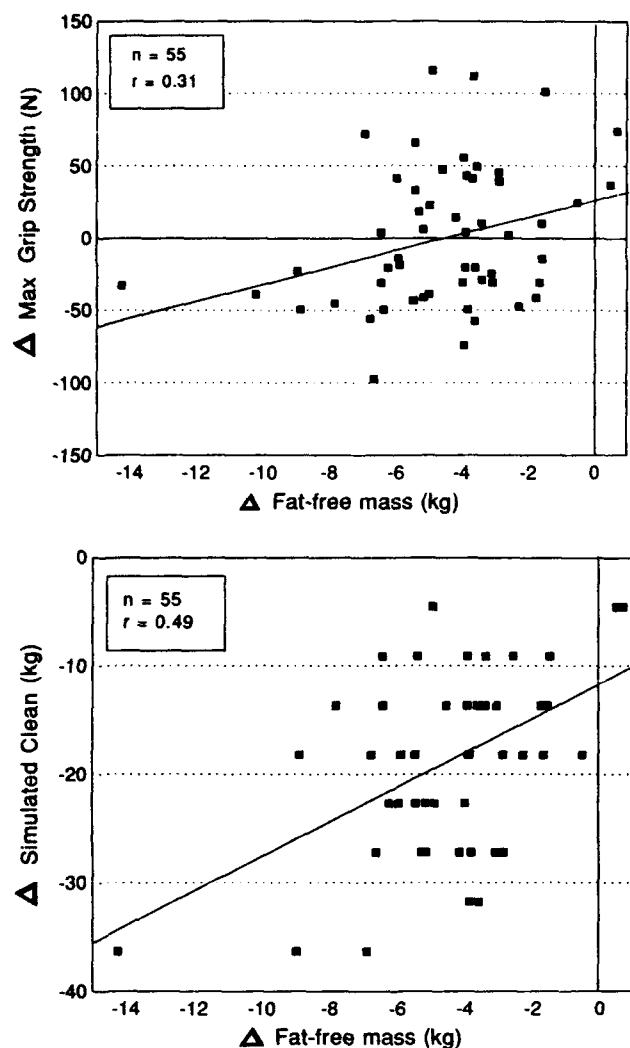


Figure 4—The relationships between change fat-free mass and GS_{max} and $Clean_{sim}$ during Ranger training.

ened by testing endurance for each individual at a force relative to the GS_{max} . In this case, we used the test to determine if there was an effect of chronic energy deficit on muscular endurance, and none was demonstrated.

The results of the dynamic test were substantially different from the GS_{max} . We observed a large reduction in $Clean_{sim}$, and the correlations between $Clean_{sim}$ and FFM and in change in $Clean_{sim}$ and FFM were considerably stronger than those obtained for grip strength. An earlier study produced nearly identical results to ours, with correlations for $Clean_{sim}$ and FFM of 0.61 for 802 male soldiers who were representative of an Army cross section (3) and 0.65 for 980 male soldiers starting basic training (21); however, our volunteers who competed to attend Ranger training were stronger and more muscular than the average soldier, as evidenced by a mean lift capacity *after* the substantial weight loss comparable to the normal average for young soldiers (15).

The $Clean_{sim}$ demonstrated a decline that correlated

with reductions in FFM, suggesting that a test such as the $Clean_{sim}$ that involves major muscle groups is a useful indicator of overall FFM. The absence of a change in GS_{max} suggests that manual function is better preserved and may reflect changes in FFM only in a later stage of FFM loss. In healthy and well fed young men, this decline occurs at a point beyond our average 16% body weight loss, but before the 25% of body weight lost in individuals in the Minnesota study where GS_{max} decremented by an average of 24% (5). Expressed in terms of the FFM component, decrements in grip strength performance would be expected to occur after a reduction of approximately 10% of FFM (Fig. 5) (5,19). Only our volunteers with the most extreme decrements in FFM (>8 kg and $>10\%$ of initial FFM) consistently demonstrated modest drops in GS_{max} (Fig. 4). Thus, grip strength is a useful prognostic indicator in very sick hospitalized patients who are likely to have lost greater than 10% of normal FFM, but is not likely to demonstrate changes even with fairly substantial weight losses in healthy athletic men. In pubertal boys, grip strength is also a useful marker of strength and FFM because of the very large changes in FFM that occur in the opposite direction.

These tests may also reflect loss of FFM differently because of differential effects on isometric strength compared with a dynamic test requiring explosive power; this would be better addressed with a comparison of isometric and dynamic tests involving the same muscle groups. The differences are not readily explained by differences in regional muscle loss since more muscle was lost from the arms (0.9 ± 0.8 kg, or $12 \pm 10\%$ of arm muscle mass) than from the legs (0.6 ± 1.5 kg, or $3 \pm 7\%$ of leg muscle mass) in these men (3). However, a second summer study of Ranger students has demonstrated a difference between upper and lower arm muscle volume changes using arm circumferences. Even corrected for changes in

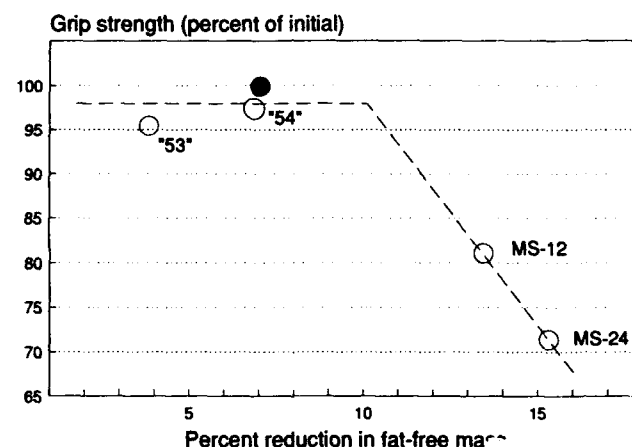


Figure 5—The relationship between change in fat-free mass and GS_{max} from four studies involving large weight losses in lean young men. Experiments "53" and "54" are from Taylor et al. (19), "MS-12" and "MS-24" represent 12- and 24-wk of semistarvation in the Minnesota study (5), and the solid point represents the data from this report.

triceps skinfold thickness, the cross sectional area of the mid upper arm decreased significantly more than the unadjusted cross sectional area of the forearm ($-9.9 \pm 5.2\%$ vs $-8.5 \pm 3.2\%$, respectively, $N = 50$, $P < 0.05$) (Bradley C. Nindl, unpublished data, 1992).

Thus, the relationship between grip strength and muscle mass is poor over an impressive range of weight loss in healthy young men and this should come as no surprise as it would be reasonable to assume from a survival adaptation point of view that the intrinsic muscles of the hand involved in grip would be well preserved even as arm muscle is catabolized.

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