
Body Composition in Aging: Adverse Changes in Able-Bodied Persons and in Those with Spinal Cord Injury

William A. Bauman and Ann M. Spungen

Advancing age in the able-bodied population is associated with loss of lean tissue and gain of fat tissue. Initially, immobilization from spinal cord injury results in rapid loss of muscle and bone tissues and a relative gain in adiposity. A more gradual but persistent loss of muscle and bone occurs at a rate exceeding that of normal aging. In addition to immobilization, reductions in endogenous anabolic hormones may be partially responsible for these body composition changes. Strategies must be sought to preserve skeletal muscle with aging to maintain function and independence as well as to reduce the risk of several chronic illnesses associated with advancing age. Key words: *anabolic hormones, body composition, bone mineral density, fat, growth hormone, immobilization, muscle, sarcopenia, soft tissue, testosterone*

Several studies have addressed the effects of advancing age on body composition in able-bodied individuals.¹⁻³ It is beyond the scope of this article to review that literature in detail. However, certain findings and concepts will be discussed that broadly outline the changes in muscle mass and strength that will assist understanding of the normal physiology of aging. A more accurate awareness of the aging process in those who are paralyzed may be accomplished once body composition changes with advancing age are appreciated.

Novak² assessed body composition in more than 500 men and women between the ages of 18 and 85 years. Body adiposity doubled from 18% to 36% by their eighth decade of life, with men having 33% and women 44%. Skeletal muscle is the predominant site of protein in the body. Cohn et al.³ noted that the main loss in fat-free mass was in muscle mass. Furthermore, these investigators found that there was a strong association between total body nitrogen as a measure of body lean tissue and total body calcium as a measure of skeletal mass, suggesting that sarcopenia is linked to

osteopenia. Chronic inadequate protein intake and the maintenance of negative nitrogen balance may exacerbate muscle losses in older persons. After attaining a peak bone mass in the second decade of life, bone mass is maintained fairly constant. In women, there is an accelerated loss of bone after the menopause.⁴ In men, bone mineral mass remains fairly constant until the seventh decade of life, when gradual losses occur.⁵

There are direct quantitative relationships

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that exist between muscle mass and muscle strength. A reduction in strength, a major finding in older persons, accompanies sarcopenia. Larsson et al.⁶ reported that strength of the quadriceps in men decreased approximately 15% per decade from 50 to 70 years. Danneskoild-Samsoe et al.⁷ found that even in older men and women in their 80s, knee extensor strength was 30% lower than that reported in a previous study of persons in their 70s. Muscle function is related to muscle strength, which is reduced with advancing age.⁸ The loss of function may be correlated with morbidity and a reduction in independence and quality of life.

Anabolic Hormonal Changes Associated with Normal Aging

The two predominant anabolic hormones are growth hormone and testosterone and both generally decrease with advancing age. It has been demonstrated that growth hormone is necessary for linear growth in children. More recently, it has been shown that low levels of growth hormone and its second messenger, insulin-like growth factor, are closely associated with adverse body composition changes in adults. In adult men, low testosterone levels have been associated with a loss in lean body tissue, as well as reduced libido and perhaps sexual function, whereas the restoration of physiologic levels has been correlated with improved lean tissue.^{9,10}

The secretion of growth hormone in older persons has been extensively studied. Earlier studies had shown unchanged basal levels of growth hormone.¹¹ However, more sophisticated studies with frequent sampling over a 24-hour period have demonstrated a reduction in secretion with aging. One such study in healthy men who were 20 to 70 years old

showed that growth hormone production fell by 14% per decade.¹² Growth hormone stimulates the production of a second messenger of its action, serum insulin-like growth factor I, predominantly in the liver. In a population study of men and women, serum insulin-like growth factor I levels declined with age.¹³ Adiposity and carbohydrate intolerance are associated with reductions in growth hormone secretion and serum insulin-like growth factor I levels.

Similarities in body composition have been noted between older persons and adults with growth hormone deficiency. It has been speculated that the age-related fall in growth hormone secretion may contribute to the insidious negative nitrogen balance and increase in adiposity. Indeed, studies have shown that short-term growth hormone administration in older persons resulted in nitrogen retention and protein synthesis, as well as increased fat oxidation, resulting in favorable body composition changes.¹⁴

There has been some controversy as to whether serum testosterone levels decrease with normal aging in adult men. In a cross-sectional study, Harman and Tsitouras¹⁵ reported that aging per se may not be associated with reduced testosterone levels. Rather, these investigators hypothesized that a sedentary lifestyle, medications, diet, and anthropometric factors may be at least as important as the aging process itself. However, more recent studies have suggested that sex steroids fall with age. In an epidemiological study (Massachusetts Male Aging Study, a population-based cross-sectional survey of men aged 39 to 70 years), Gray et al.¹⁶ addressed the question of the effect of aging on serum testosterone and sex steroid levels independent of the effects of obesity, chronic illness, and/or prescription medications in

men. Total and free serum testosterone levels declined with age, regardless of confounding factors, at a rate of 0.4% and 1.2% per year, respectively; associated sex steroids also fell with age.¹⁶

Because elderly men have reduced levels of serum testosterone and muscle loss, it was hypothesized that a relative testosterone deficiency was at least partially responsible. Several studies have confirmed the beneficial effect of replacement levels of testosterone on body composition in hypogonadal and in older men.^{17,18} In a study by Snyder et al.,¹⁹ in men over 65 years who wore a testosterone patch for 36 months, lean mass increased about 2 kg and fat mass decreased by 3 kg. It is of note that if testosterone levels are reduced to below physiologic levels in young healthy men, a decrease in protein synthesis and strength and an increase in adiposity ensues in as short a period as 10 weeks.¹⁰

It should also be noted that there appears to be an interaction between testosterone and growth hormone. Ulloa-Aquirre et al.²⁰ have reported that in boys with constitutionally impaired growth and/or development either testosterone or oxandrolone (a nonaromatizable synthetic oral androgen) increased growth hormone production rate without any change in metabolic clearance rate. In rodent models, growth hormone has been shown to enhance testosterone secretion.²¹ Thus, it would appear that endogenous anabolic hormones play a contributory role in the determination of body composition in the adult. Replacement therapy with testosterone in older men is being routinely considered after appropriate screening for prostatic cancer and other potential contraindications.⁹ At this time, because of its expense and the somewhat inconclusive nature of the studies to

date, growth hormone therapy is only an investigational modality for improving body composition.

Soft Tissue Body Composition Changes in Persons with Spinal Cord Injury

Spinal cord injury (SCI) predisposes the individual to medical complications and secondary disabilities such as obesity, lipid abnormalities, carbohydrate intolerance, and cardiovascular disease. One hypothesis for these secondary disabilities is that they are the result of adverse body composition. Persons with SCI have body compositional changes that are similar to those in aged humans, including loss of lean tissue and increase of fat tissue mass. Longitudinal studies that have measured body composition immediately after SCI and continued to investigate changes in body composition are limited in the experimental design and in the number of participants studied. Using baseline measurements that were performed several weeks after acute SCI, Wilmet et al.²² reported on bone mineral and soft tissue changes in 31 participants over the course of 1 year. In all participants, lean soft tissue decreased dramatically in regions of the body that were paralyzed, but these reductions were less pronounced in those regions that had evidence of spasticity.²² Fat content tended to increase in the paralyzed areas as well.²² Rossier et al.²³ studied 17 participants with SCI within 1 month after injury and then again 2–12 months postinjury, demonstrating that within the first year after injury there was a significant amount of total body potassium depletion and weight loss of lean body mass. By using cross-sectional designs that compared age- and height-matched reference populations, previous investigators

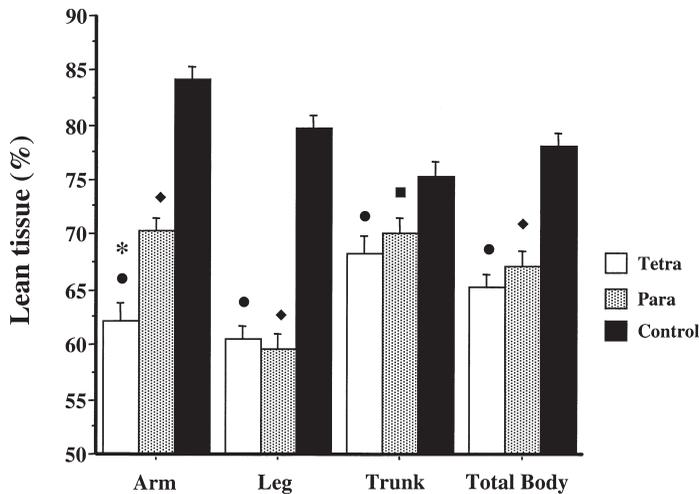


Fig 1. Regional and total body lean tissue percent comparisons among controls and persons with tetraplegia (Tetra) and paraplegia (Para). Asterisk, $p < .0001$ for Tetra vs. Para; filled circle, $p < .0001$ for Tetra vs. Control; filled diamond, $p < .0001$ for Para vs. Control; filled square, $p < .01$ for Para vs. Control. (Unpublished data provided by Drs. William A. Bauman and Ann M. Spungen.)

have demonstrated lean tissue loss and/or fat tissue gain in individuals after SCI.²⁴⁻²⁶ Rasmann Nuhlicek et al.²⁴ studied 37 participants with SCI who were classified into four levels of lesion subgroups and 10 controls. Total body water, intracellular water, and lean body tissue were significantly decreased.²⁴ Fat mass increased as the level of neurological deficit increased.²⁴ In a cross-sectional study, Bauman and Spungen²⁷ reported significant decreases in percent of regional and total body lean tissue in male participants with tetraplegia ($n = 66$) or paraplegia ($n = 66$) with a mean age of 39 ± 1.5 years (range 20–71) compared with gender-, age-, height-, and weight-matched controls ($n = 66$) (Fig. 1). These differences were most pronounced in the arms and legs and less so in the trunk. It is of particular interest that the arms of persons with paraplegia had significantly less percent lean tissue com-

pared with controls (67.3 ± 1.26 vs. $79.9 \pm 1.03\%$, $p < .0001$) (Fig. 1). The slope of change across age for total body lean tissue was steeper in participants with SCI than in controls (-0.306 ± 0.073 vs. -0.093 ± 0.89 , $p < .07$) (Fig. 2). No differences in this cross-sectional rate of loss were observed between participants with tetraplegia and paraplegia. Male participants with SCI can be expected to lose about 3.2% per decade of their total body lean tissue versus 1% per decade in able-bodied males (Fig. 2).

A cross-sectional design, due to the individual variability in body composition, limits the ability to determine the precise amount of lean tissue loss and fat tissue gain that is attributable exclusively to paralysis. Longitudinal studies are relatively expensive and pose enormous logistic problems, including the performance of measurements before body composition changes have occurred

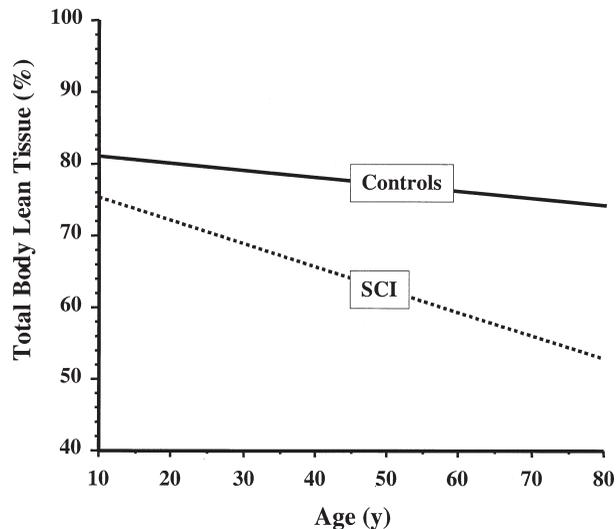


Fig 2. The slopes across age for total body percent lean tissue (excluding bone). (Unpublished data provided by Drs. William A. Bauman and Ann M. Spungen.)

after immobilization. It is quite difficult to capture a baseline measurement immediately after SCI, which is a time of stress for the patient. It is also difficult, if not impossible, to enlist participants to perform these intermittent body composition measurements over 10 to 30 years after acute injury. Thus, a creative solution to defining these changes in body composition, independent of genetic variability and aging, is the use of a cross-sectional monozygotic twin model. In an identical twin study, with one co-twin in each of the eight pairs having SCI, Spungen et al.²⁸ reported a loss of total body and extremity muscle mass that was continuous and directly related to duration of injury: 3.9 ± 0.2 kg of total body lean tissue lost per 5-year period of injury (Fig. 3). Additionally, total body and leg lean tissue losses were significantly related to total body ($r = .80, p < .02$) and leg bone mineral content losses ($r = .81, p < .01$), respectively (Fig. 4). Possibly

related to these adverse body compositional changes and reduced levels of activity, individuals with SCI have a pattern of metabolic alteration that is atherogenic, with adverse lipid changes, glucose intolerance, insulin resistance, and a reduction in metabolic rate.

The losses in lean body tissue are directly reflected in the metabolic rate. In 12 participants with SCI, Spungen et al.²⁹ demonstrated a strong relationship ($r = .803, p < .002$) between metabolic rate and fat-free mass in persons with SCI. The greater the reduction in lean body tissue, the greater the decrease in resting metabolic rate (Fig. 5).²⁹ Supporting the findings of Spungen et al., Mollinger et al.³⁰ described a 12% to 29% reduction from predicted values for basal energy expenditure in 48 participants with SCI, with those participants who had higher levels of injury and presumably less lean tissue mass having the greater reductions in basal energy expenditure.

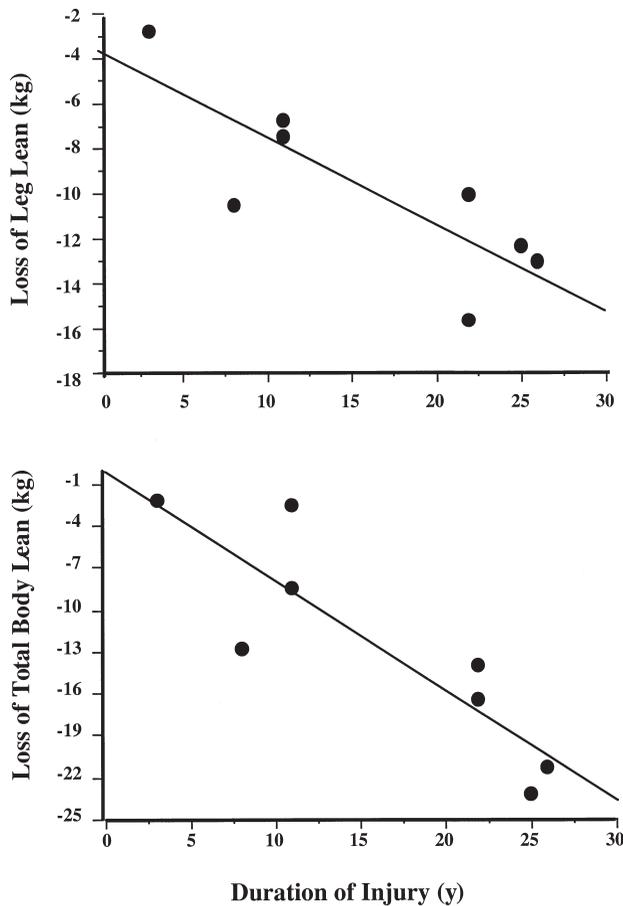


Fig 3. Linear regression analyses of intrapair difference scores (noninjured minus spinal cord-injured twin) of leg lean (top) or total body lean (bottom) versus duration of injury. (Modified from Spungen et al. Soft tissue body composition differences in monozygotic twins discordant for immobilization. *J Appl Physiol.* 2000;88:1310–1315. Copyright © 2000 by American Physiological Society.)

Skeletal Changes and Associated Metabolic Considerations in Persons with SCI

SCI produces immediate and permanent unloading (or absence of normal gravitational forces) of the involved skeletal regions with structural and metabolic consequences.

After acute immobilization, urine calcium excretion, as a marker of skeletal bone resorption, increases in 10 days and becomes maximal between 1 and 6 months after injury. The maximum urinary calcium in those with SCI was between two and four times that of able-bodied participants who were voluntarily placed at prolonged bed rest. The

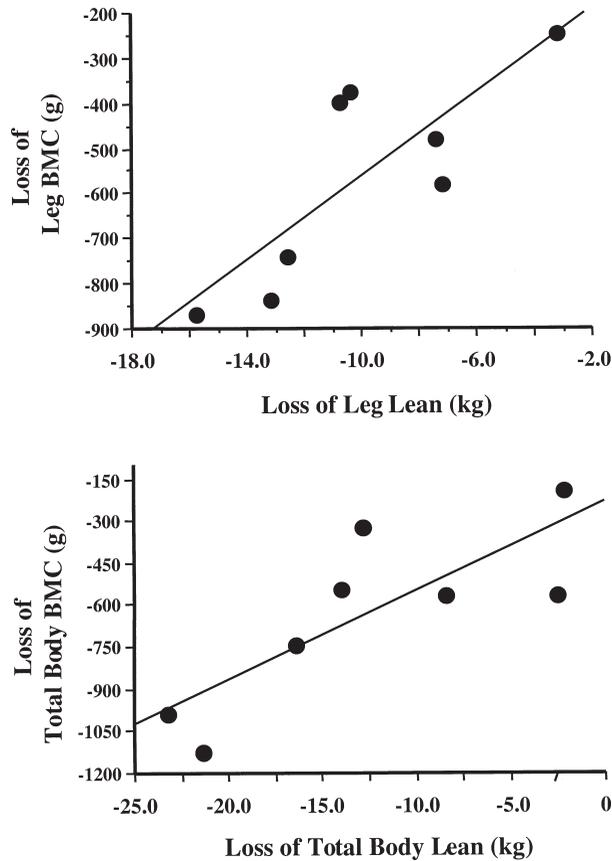


Fig 4. Linear regression analyses of intrapair difference scores (noninjured minus spinal cord-injured twin) of leg bone mineral content (BMC) (top) or total body BMC (bottom) versus the intrapair difference scores for leg lean (top) or total body lean (bottom). (Modified from data from Spungen et al. Soft tissue body composition differences in monozygotic twins discordant for immobilization. *J Appl Physiol.* 2000;88:1310–1315. Copyright © 2000 by American Physiological Society.)

finding of hypercalciuria and hypercalcemia after acute SCI results from increased bone resorption and has led to the misguided clinical practice of dietary restriction of calcium and vitamin D.

The occurrence of bone loss in persons with chronic SCI has been well documented. Osteoporosis generally involves the pelvis and lower extremities in persons with

paraplegia, while those with tetraplegia experience bone loss in the upper extremities as well. Individuals with incomplete SCI tend to have greater bone mineral density than those with complete lesions, with muscle strength and bone density moderately correlated. Bauman et al.³¹ have studied eight pairs of male identical twins, one of whom had paraplegia (average duration of injury of 16

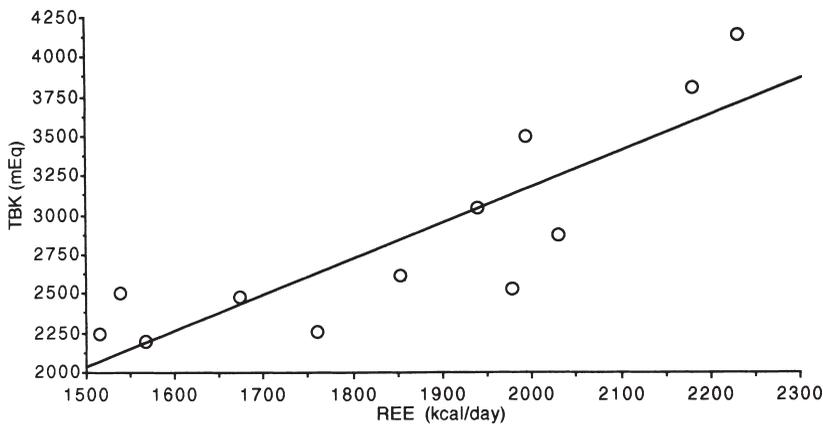


Fig 5. Linear regression analysis between total body potassium (TBK) and resting energy expenditure (REE). (Reprinted with permission from Spungen AM, et al. The relationship between total body potassium and resting energy expenditure in individuals with paraplegia. *Arch Phys Med Rehabil.* 1993;73:965–968. Copyright © 1993 by WB Saunders.)

± 9 years with a range of 3 to 26 years). In the twins with paraplegia compared with their co-twins, there was a loss of bone content and density in the pelvis and lower extremities (Fig. 6). The depletion of bone mineral content and density appeared to be progressive over decades after injury (Fig. 7).³¹

Although disuse may be the primary cause of osteopenia in persons with SCI, there is reason to believe that nutritional deficiencies may be contributory, particularly involving calcium and vitamin D. Because of the tendency for calcium nephrolithiasis soon after acute SCI, individuals with SCI are often instructed to restrict calcium intake indefinitely, chiefly by reducing their consumption of dairy products. Reduced dietary calcium consumption may also result in vitamin D deprivation, since fortified dairy products serve as a substantial source of vitamin D. In addition, individuals may have reduced sunlight exposure and may receive anticonvulsants and other medications that increase

vitamin D degradation. The combination of reduced calcium and vitamin D supply may lower the serum calcium concentration and stimulate the parathyroid glands, resulting in increased bone resorption and accentuation of osteopenia. Bauman et al.³² studied calcium and vitamin D metabolism in 100 participants with chronic SCI compared with 50 normal control participants. Participants with SCI had significantly lower 25-hydroxyvitamin D levels, the major storage form of vitamin D, which was negatively correlated with serum parathyroid hormone.³² It may be postulated that the subgroup of participants with reduced vitamin D levels had increased bone turnover and, hence, accelerated bone loss.

Anabolic Hormonal Changes in Persons with SCI

A deficiency state of testosterone or growth hormone has the potential for adverse

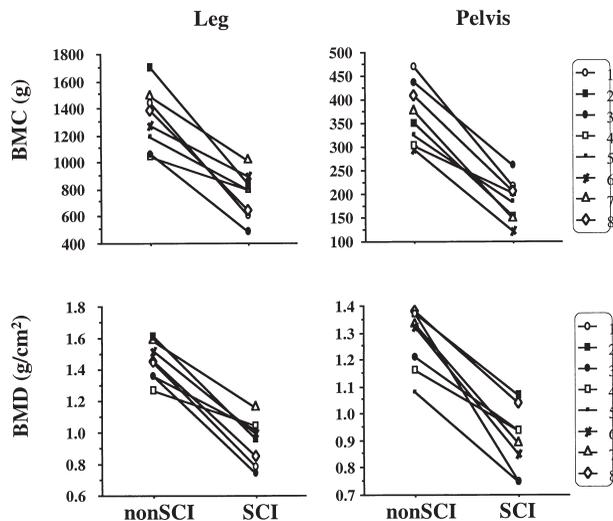


Fig 6. Leg and pelvic losses of bone mineral content (BMC) (top figures) or bone mineral density (BMD) (bottom figures) in twins with spinal cord injury (SCI). Individual paired comparisons between noninjured and spinal cord-injured twins are shown for leg and pelvic BMC and BMD. (Reprinted with permission from Bauman WA, et al. Continuous loss of bone in chronic immobilization: A monozygotic twin study. *Osteoporosis Int.* 1999;10:123–127. Copyright © 1999 by Springer-Verlag.)

consequences. Although the literature on persons with SCI presents conflicting results, there are undoubtedly subsets of individuals with a relative or absolute androgen deficiency state. The etiology of a relative deficiency of testosterone in persons with SCI has not been elucidated. However, it is conceivable that prolonged sitting and eutheria of the scrotal sac and testis may itself have a deleterious local effect on testosterone production. In a group of 20 healthy participants with SCI, 12 with paraplegia and 8 with tetraplegia, Tsitouras et al.³³ reported that a subset had reduced serum total and free testosterone levels without a significant increase in serum gonadotropin concentrations. Of note, serum testosterone levels were already low in younger individuals with SCI; therefore, a decrease with age was not

observed as it was in the able-bodied controls. However, serum testosterone levels significantly decreased with duration of injury (Fig. 8). A nonlinear regression between free testosterone and serum insulin-like growth factor I was evident (Fig. 9). Wang et al.³⁴ also reported on a subset of participants with SCI who had low serum testosterone levels, but none had increased serum gonadotropin levels. In one report, direct stimulation of the testes with pharmacological levels of chorionic gonadotropin produced normal testosterone release.³⁵ These studies suggest that hypogonadism in healthy individuals with SCI may be of hypothalamic-pituitary origin. It should be noted that acute or chronic illness has adverse effects on serum testosterone levels. Furthermore, persons with SCI are often prescribed medications

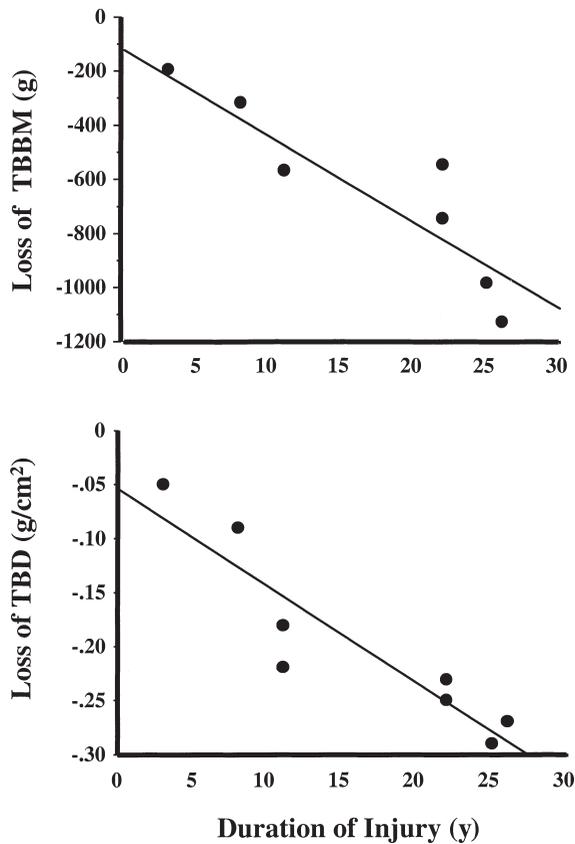


Fig 7. Linear regression analyses of intrapair difference scores (noninjured minus spinal cord-injured twin) of total body bone mineral (TBBM) (top figure) and total bone density (TBD) (bottom figure) versus duration of injury. (Modified from data from Bauman WA, et al. Continuous loss of bone in chronic immobilization: A monozygotic twin study. *Osteoporosis Int.* 1999;10:123–127. Copyright © 1999 by Springer-Verlag.)

that have been shown to affect pituitary and/or testicular secretory function in able-bodied persons, such as benzodiazepams, anticholinergics, γ amino butyric acid and adenergic agonists.

Growth hormone and insulin-like growth factor I have been reported to be depressed in individuals with SCI. In a group of 16 participants with SCI, Bauman et al.³⁶ reported a blunted growth hormone release to provocative stimulation with intravenous arginine

(Fig. 10). The average serum insulin-like growth factor I level was lower in younger individuals with SCI than that in younger able-bodied controls. Similarly, Shetty et al.³⁷ reported that the average serum insulin-like growth factor I level in persons with tetraplegia was depressed compared with ambulatory controls. In a study of persons with post-poliomyelitis syndrome, lower serum insulin-like growth factor I levels were found to be a potent discriminator of those

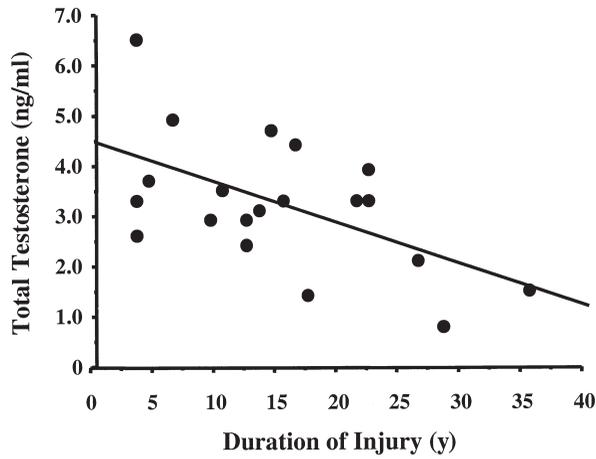


Fig 8. Linear regression of serum total testosterone versus duration of spinal cord injury. (Reprinted with permission from Tsitouras PD, et al. Serum testosterone and insulin-like growth factor-I/growth hormone in adults with spinal cord injury. *Horm Metab Res.* 1995;27:287–292. Copyright © 1995 by Georg Thieme Verlag.)

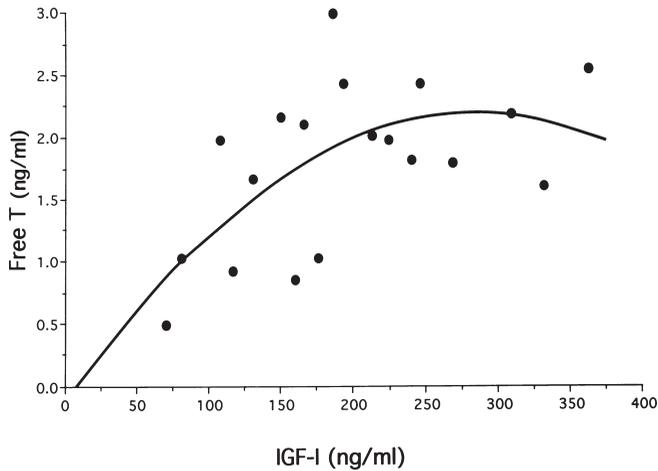


Fig 9. Polynomial regression of serum free testosterone (Free T) versus insulin-like growth factor-I (IGF-I). (Reprinted with permission from Tsitouras PD, et al. Serum testosterone and insulin-like growth factor-I/growth hormone in adults with spinal cord injury. *Horm Metab Res.* 1995;27:287–292. Copyright © 1995 by Georg Thieme Verlag.)

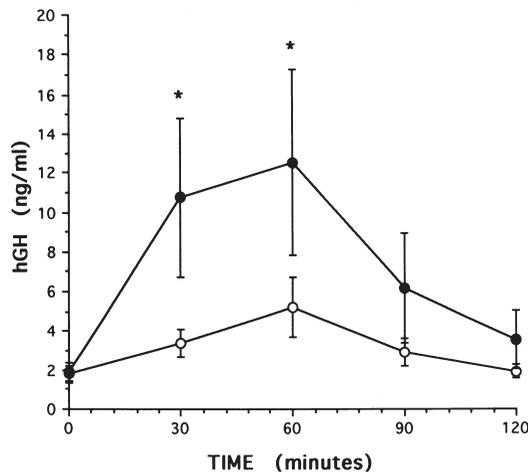


Fig 10. The human growth hormone (hGH) response to intravenous arginine. The open circles are the participants with spinal cord injury and the closed circles are the control participants. An asterisk (*) above the time point displays significant differences ($p < .05$) between the groups. (Reprinted with permission from Bauman, WA, et al. Blunted growth hormone response to intravenous arginine in participants with a spinal cord injury. *Horm Metab Res.* 1994;26:149-153. Copyright © 1994 by Georg Thieme Verlag.)

who had decreased capacity to perform activities of daily living, reduced functional independence, and increased pain.³⁸ Although it is not possible from this investigation to determine cause or effect, it would appear that depression in serum insulin-like growth factor I in persons with SCI may be related to reductions in muscle mass and strength and, hence, in functional capacity. Furthermore, there seems to be a significant nonlinear relationship between serum insulin-like growth factor I and serum total testosterone concentrations in healthy individuals with SCI.³³ It is possible that growth hormone/serum insulin-like growth factor I enhances testosterone secretion, as has been shown in animals.²¹ Testosterone may increase growth hormone release, as has been demonstrated in adolescent males and adults.²⁰ A frequently prescribed antispas-

modic medication in persons with SCI, baclofen, is associated with increases in growth hormone release to provocative stimulation and normalizes serum insulin-like growth factor I levels, presumably by central mechanisms, thus counteracting some of the adverse effects of SCI.³⁹

In addition to attempts at physiological replacement of endogenous anabolic hormones, another potential consideration is the limited administration of anabolic steroids for specific indications in persons with SCI. A recent report demonstrated that oxandrolone was associated with increased parameters of inspiratory and expiratory pulmonary function in participants with tetraplegia.⁴⁰ Changes in diaphragm mass after the administration of this anabolic steroid have been directly correlated with changes in maximal inspiratory effort; after therapy,

breathlessness significantly decreased.⁴¹ Because total body lean tissue is depleted before intercurrent illness in persons with SCI and the level of depletion is correlated with the level of neurological deficit, serious illness may result in nitrogen wasting and muscle losses that may more rapidly lead to catastrophic respiratory events. Thus, when there is pulmonary compromise due to infection in persons with higher cord lesions, the administration of oral anabolic steroids may be efficacious for circumscribed therapeutic interventions to prevent the acute loss of lean body mass, especially in those muscles related to respiration. In persons with weight loss and pressure ulcers refractory to healing despite optimum medical and surgical care, a trial with anabolic agents may prove beneficial, although at present the therapeutic efficacy is unproven.⁴²

Summary

In the older able-bodied persons, it may be postulated that reduction in the level of activity and in anabolic hormones is associated with adverse body compositional changes. Inadequate protein intake in older persons may also play a significant role in loss of lean body tissue, predominantly muscle mass. The depletion of muscle mass with advancing age has been referred to as sarcopenia.

In persons with SCI, there is an initial, dramatic loss of muscle mass after acute paralysis. However, even decades after injury, there is a continuous loss of lean body tissue compared to that observed in able-bodied persons. The superimposition of on-

going, age-related loss in muscle mass on an already reduced lean body mass places persons with SCI at increased risk of adverse consequences, such as an increased risk of diabetes mellitus, increased rate of infection, reduced tissue repair, decreased pulmonary function, and further impaired mobility.

In both older persons and persons with SCI, there is a relative increase in adiposity, especially intraabdominal, that may increase the risk of cardiovascular disease. A relative increase in adiposity would be expected to impact the pharmacokinetics of fat-soluble medications, as has been well appreciated in the able-bodied population. It is conceivable that an unfavorable hormonal environment with depressions of the endogenous anabolic hormones, testosterone and growth hormone/insulin-like growth factor, may worsen body composition in individuals who are partially or completely immobilized. Reversal of this catabolic hormonal milieu with physiological replacement therapy may help preserve muscle mass, strength, and function and preserve a more rewarding and independent quality of life. In addition, a reduction in relative or absolute adiposity may lower the risk of cardiovascular disease.

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