JACC Vol. 28, No. 6
November 15, 1996:1471–7

Resistance Exercise Training Restores Bone Mineral Density in Heart Transplant Recipients

RANDY W. BRAITH, PHD, ROGER M. MILLS, JR., MD, FACC, MICHAEL A. WELSCH, MS, JEFFREY W. KELLER, BS, MICHAEL L. POLLOCK, PHD, FACC

Gainesville, Florida

Objectives. This was a prospective, randomized, controlled study designed to determine the effect of resistance exercise training on bone metabolism in heart transplant recipients.

Background. Osteoporosis frequently complicates heart transplantation. No preventative strategy is generally accepted for glucocorticoid-induced bone loss.

Methods. Sixteen male heart transplant recipients were randomly assigned to a resistance exercise group that trained for 6 months (mean [±SD] age 56 ± 6 years) or a control group (mean age 52 ± 10 years) that did not perform resistance exercise. Bone mineral density (BMD) of the total body, femur neck and lumbar spine (L2 to L3) was measured by dual-energy X-ray absorptiometry before and 2 months after transplantation and after 3 and 6 months of resistance exercise or a control period. The exercise regimen consisted of lumbar extension exercise (MedX) performed 1 day/week and variable resistance exercises (Nautilus) performed 2 days/week. Each exercise consisted of one set of 10 to 15 repetitions performed to volitional fatigue.

Results. Pretransplantation baseline values for regional BMD did not differ in the control and training groups. Bone mineral density of the total body, femur neck and lumbar vertebra (L2 to L3) were significantly decreased below baseline at 2 months after transplantation in both the control (−3.3 ± 1.3%, −4.5 ± 2.8%, −12.7 ± 6.2%, respectively) and training groups (−2.9 ± 1.1%, 5.9 ± 3.2%, −14.8 ± 3.1%, respectively). Six months of resistance exercise restored BMD of the whole body, femur neck and lumbar vertebra to within 1%, 1.9% and 3.6% of pretransplantation levels, respectively. Bone mineral density of the control group remained unchanged from the 2-month posttransplantation levels.

Conclusions. Within 2 months after heart transplantation, ~3% of whole-body BMD is lost, mostly due to decreases in trabecular bone (−12% to −15% of lumbar vertebra). Six months of resistance exercise, consisting of low back exercise that isolates the lumbar spine and a regimen of variable resistance exercises, restores BMD toward pretransplantation levels. Our results suggest that resistance exercise is osteogenic and should be initiated early after heart transplantation.

(J Am Coll Cardiol 1996;28:1471–7)

Osteoporosis frequently complicates heart transplantation. Accelerated bone loss occurs early in the postoperative period and appears to be directly associated with glucocorticoid therapy (1–5). Heart transplant recipients receiving long-term glucocorticoids present a distinctive clinical picture, including centripetal obesity with peripheral subcutaneous fat atrophy, thinning of the skin with increased fragility and ecchymoses, muscle weakness and fluid retention. However, bone demineralization with resulting vertebral compression fractures is the most incapacitating sequela of steroid therapy. Significant vertebral bone loss is observed in up to 97% of heart transplant recipients (2), and radiologic evidence of fractures, occurring early in the postoperative period, is reported in up to 44% (4).

The potential reversibility of glucocorticoid-induced bone loss is an important issue. However, no preventative strategy is generally accepted. Calcium supplementation, bisphosphonate agents, estrogenic and androgenic hormones and calcitonin have all been used to prevent glucocorticoid-induced osteoporosis, but they have failed to prevent bone mineral loss after heart transplantation (3,5). Bone mineral density (BMD) in heart transplant recipients remains significantly below age-matched norms, and bone mineral levels do not indicate any recovery toward preoperative levels in patients up to 36 months after transplantation (3,5).

The purpose of this study was to determine the effect of resistance exercise training on defective bone metabolism in heart transplant recipients. Under normal circumstances, the strain or mechanical load placed on bone helps determine its structural integrity (6–8). Thus, we hypothesized that resistance exercise might effect sufficient adaptation in the adult skeleton to increase bone mass. Much of the evidence suggesting a beneficial effect of resistance exercise on the skeleton arises from abundant cross-sectional studies. Indeed, the majority of these studies show that resistance training is associated with high BMD (6–8). We previously found (9) that 6 months of resistance exercise increased BMD of the lumbar spine in the elderly, and another recent longitudinal study (10)

From the Center for Exercise Science, College of Health and Human Performance and College of Medicine, University of Florida, Gainesville, Florida.

Manuscript received April 19, 1996; revised manuscript received July 8, 1996, accepted July 12, 1996.

Address for correspondence: Dr. Randy W. Braith, P.O. Box 118206, Center for Exercise Science, University of Florida, Gainesville, Florida 32611.

0735-1097/96 $15.00
PII S0735-1097(96)00357-5

JACC Vol. 28, No. 6
November 15, 1996:1471–7

Abbreviations and Acronyms

BMD = bone mineral density
DXA = dual-energy X-ray absorptiometer
ISHLT = International Society for Heart and Lung Transplantation
PTH = parathyroid hormone

also reported that 4 months of resistance exercise in middle-aged and older men was associated with increased BMD and bone remodeling. However, these relations have not been studied in organ transplant recipients receiving long-term glucocorticoids. In the present study, we prospectively determined BMD in heart transplant candidates before transplantation and longitudinally tracked their changes in BMD at intervals after transplantation.

Methods

Subjects. The descriptive characteristics of the heart transplant recipients are presented in Table 1. Sixteen male patients listed with the United Network for Organ Sharing as orthotopic heart transplant candidates were recruited. The patients were randomly and prospectively assigned either to a training group that would participate in a program of resistance exercise after transplantation or to a control group that would not perform specific resistance exercises. All the heart transplant recipients participated in postoperative walking programs that were comparable in intensity and duration, but only the training group performed specific resistance exercises.

All the heart transplant recipients had biatrial anastomosis at the time of transplantation and were receiving standard triple-drug immunosuppressive therapy with cyclosporine, prednisone and azathioprine. Whole-blood cyclosporine trough levels, calculated as an average of four determinations over 8 months after transplantation, were similar in the training ([mean ±SD] 249 ± 18 ng/ml) and control (256 ± 26 ng/ml) groups. Three transplant recipients in the training group and three in the control group were receiving supplemental calcium throughout the study (900 ± 225 mg/24 h). Serum creatinine and blood urea nitrogen (BUN), indexes of renal function, were similar in both groups (training group: 1.5 ± 0.3 and 26 ± 8 mg/dl, respectively; control group: 1.7 ± 0.4 and 29 ± 9 mg/dl, respectively) at 6 months after transplantation. No heart transplant recipient had evidence of atherosclerotic disease, and none had any evidence of cardiac allograft vascular disease. The protocol was approved by the institutional review board for the protection of human subjects at the University of Florida College of Medicine, and all subjects provided written informed consent to participate in the study.

Table 1. Descriptive Characteristics of Heart Transplant Recipients in Control and Training Groups*

	Control Group (n = 8) (mean ± SD)	Training Group (n = 8) (mean ± SD)
Age (yr)	52 ± 10	56 ± 6
Height (cm)	173 ± 9	172 ± 5
Weight (kg)†	85 ± 11	78 ± 8
Waiting list (wk)	26 ± 17	21 ± 13

*There were no significant differences between groups at baseline. †Body weight at pretransplantation bone scan.

Glucocorticoid therapy. Heart transplant recipients at our institution receive 1,000 mg of methylprednisolone (Solu-Medrol) intravenously during the transplantation surgery and 375 mg/24 h of methylprednisolone intravenously on the first postoperative day. Methylprednisolone is reduced to 250 mg/24 h on the second postoperative day and to 125 mg/24 h on the third postoperative day. Oral prednisone (1 mg/kg body weight per day) is initiated on the fourth postoperative day. During the first 6 weeks after transplantation, the daily prednisone dose is tapered by 10 mg each week in transplant recipients who remain rejection free. The daily prednisone dose is further reduced by 5 mg after the 6-week biopsy and by 5 mg after the 8-week biopsy. Thereafter, in the absence of rejection, the daily prednisone dose is decreased by 2.5 mg every 2 weeks to a target dose of 10 mg/day at 20 weeks after transplantation. Further prednisone reduction is not attempted until 1 year after transplantation. Episodes of acute rejection, as determined by routine surveillance endomyocardial biopsy, are treated with enhanced immunosuppression, including increased doses of intravenous methylprednisolone or oral prednisone.

Bone mineral density. Total body and regional BMD, bone mineral content and total body calcium were assessed noninvasively using a dual-energy X-ray absorptiometer (DXA) (Lunar Radiation). Subjects were placed in a supine position or on their side while the X-ray scanner performed a series of transverse scans, moving from top to bottom of the region being measured at 1-cm intervals. Three separate DXA scans were performed: 1) total body scan with the subject supine; 2) lateral lumbar spine scan with the subject lying on the left side against a cushion that kept the hips flexed at a 90° angle while the scanner moved from the top of the L2 vertebra to the bottom of the L3 vertebra; 3) hip scan with the subject supine while the scanner moved across the right hip, providing information on the femur neck. Quality control of the DXA machine was performed daily by scanning an anthropomorphic phantom supplied by the manufacturer. We previously demonstrated (11) that regional BMD, bone mineral content and total body calcium measurements with this technique are highly reliable and are associated with <5% variability when subject positioning is carefully standardized.

All subjects completed a total of four DXA scans. A pretransplantation DXA scan was performed while subjects were heart transplant candidates. The second DXA scan was performed 2 months after transplantation and just before initiation of a resistance training program. The DXA bone scans were repeated after 3 and 6 months of resistance exercise

or a control period. Thus, the final DXA scan was performed 8 months after cardiac transplantation.

Resistance exercise training. The training group began supervised resistance exercise at 2 months after transplantation and continued to exercise for a 6-month period. The training regimen consisted of two components: 1) lumbar extensor training 1 day/week on a MedX lumbar extension machine; and 2) upper and lower body resistance training 2 days/week using Nautilus and MedX variable resistance machines. All training sessions involved one transplant recipient supervised by at least two exercise specialists. Before resistance exercise sessions, seated blood pressure and pulse rate measurements were recorded and were followed by 5 min of low intensity walking on a treadmill. A single set consisting of 10 to 15 repetitions was completed for each exercise. The initial training resistance represented 50% of one repetition maximum. The subjects were not permitted to exceed 15 repetitions. Rather, when 15 repetitions were successfully achieved, the resistance was increased by 5% to 10% at the next training session. Thus, the exercise prescription strived to have subjects use the greatest resistance possible to complete 15 repetitions. The following exercises were performed in order: lumbar extension, duo-decline chest press, knee extension, pullover, knee flexion, triceps extension, biceps flexion, shoulder press and abdominals. Special precautions were taken to ensure adequate maintenance of blood pressure in preload-dependent cardiac denervated heart transplant recipients. Upper body exercises were alternated with lower body exercises in an attempt to prevent blood pooling. Symptomatic subjects walked 2 min between exercises or performed standing calf raises. All subjects concluded each training session with a 5 min cool-down walk at low intensity on the treadmill.

The frequency of lumbar training for this study was based on previous research (12) that demonstrated that MedX lumbar training once a week is as effective as training two or three times a week for increasing lumbar extension strength. Lumbar extension training required subjects to sit in the lumbar extension machine with their knees positioned so that the femurs were parallel to the seat. The subjects were secured in place by femur, pelvic and thigh restraints that stabilized the pelvis. A head rest was adjusted to the level of the occipital bone for comfort and support. This stabilization procedure has been previously described (12).

Statistical analysis. Descriptive characteristics were compared between groups using analysis of variance. Analysis of covariance with repeated measures was used to analyze the temporal pattern of BMD, body mineral content and total bone calcium before and after transplantation. When a significant group by time interaction was observed, within-group comparisons between time points and between-group comparisons at each time point were done using analysis of covariance with contrast analysis for obtaining appropriate post hoc custom hypothesis tests. All statistical analyses were performed using the SAS statistical program (SAS Institute Inc.). An alpha level of $p \leq 0.05$ was required for statistical significance.

Table 2. Incidence of Acute Rejection and Glucocorticoid Treatment in Control and Resistance Training Groups

	Control Group (n = 8)	Training Group (n = 8)
Methylprednisolone, IV		
1 g QD × 3 days	6	6
500 mg QD × 3 days	1	0
Prednisone, oral; 100 mg × 3 days with rapid taper	4	3
Total treated episodes*	11	9

*$p \geq 0.05$, control versus trained group. IV = intravenous; QD = every day.

Results

Allograft rejection. Table 2 details the incidence of acute rejection episodes during the study and the glucocorticoid treatment regimens. Acute allograft rejection was determined by endomyocardial biopsy and graded using the International Society for Heart and Lung Transplantation (ISHLT) system. We enhanced immunosuppression only for ISHLT grade 3A or 3B rejection (Table 2). No patient failed to respond to corticosteroid therapy, and none had evidence of "humoral rejection," or hemodynamic compromise. There were 11 episodes of acute rejection in the control group and 9 in the training group ($p \geq 0.05$).

Bone mineral density. Absolute values for regional BMD in the control and training groups are presented in Table 3. Results of the BMD scans are expressed as grams hydroxyapatite divided by the projected area in square centimeters (g/cm^2). Pretransplantation values for total body BMD, femur neck BMD, lumbar vertebral body BMD (L2 to L3) and lumbar vertebra middle BMD (L2 to L3) were not significantly different ($p \geq 0.05$) between the control and training groups.

The temporal pattern of relative changes in total body BMD and femur neck BMD (percent change from pretransplant baseline) is shown in Figure 1. Total body BMD decreased significantly below pretransplantation values at 2 months after transplantation in both the control ($-3.3 \pm 1.3\%$) and training groups ($-2.9 \pm 1.1\%$). Six months of resistance exercise training restored total body BMD to within 1% of pretransplantation levels in the training group; the control group continued to lose total body BMD at 3 ($-5.8 \pm 2.5\%$) and 6 months ($-6.9 \pm 3.7\%$). Femur neck BMD was significantly diminished below baseline at 2 months after transplantation in both the control ($-4.5 \pm 2.8\%$) and training groups ($-5.9 \pm 3.2\%$). However, femur neck BMD was restored to within 1.9% of pretransplantation levels after 6 months of resistance exercise in the training group. In contrast, BMD diminished further at 3 ($-6.3 \pm 2.5\%$ below baseline) and 6 months ($-7.2 \pm 3.7\%$) in the control group.

The evolution of relative changes in BMD for the lumbar vertebral body and lumbar vertebral middle are shown in Figure 2. At 2 months after transplantation, lumbar BMD (L2 and L3) was markedly decreased in the vertebral body and the

Table 3. Bone Mineral Density Values of Total Body, Femur Neck, Lumbar Vertebral Body and Lumbar Vertebral Midsection and Bone Mineral Content and Total Bone Calcium Values for Resistance Training and Control Groups

	Bone Mineral Density (g/cm²)*					
Group	Total Body	Femur Neck	Lumbar Vertebral Body (L2 to L3)	Lumbar Vertebral Midsection (L2 to L3)	Bone Mineral Content (g)	Total Bone Calcium (g)
Control (n = 8)						
PreTx	1.204 ± 0.023	0.965 ± 0.081	0.817 ± 0.099	0.778 ± 0.099	2978.3 ± 144.5	1162.9 ± 67.8
PostTx	1.164 ± 0.032†	0.921 ± 0.078†	0.716 ± 0.087†	0.677 ± 0.082†	2827.9 ± 149.9†	1093.8 ± 61.2†
3 mo	1.134 ± 0.045†	0.904 ± 0.082†	0.667 ± 0.061†	0.631 ± 0.065†	2797.9 ± 135.8†	1075.4 ± 65.5†
6 mo	1.120 ± 0.056†	0.895 ± 0.084†	0.683 ± 0.070†	0.648 ± 0.078†	2809.1 ± 138.4†	1084.8 ± 67.9†
Training (n = 8)						
PreTx	1.228 ± 0.080	1.031 ± 0.079	0.828 ± 0.111	0.768 ± 0.109	3109.4 ± 201.5	1171.0 ± 63.8
PostTx	1.193 ± 0.077†	0.972 ± 0.085†	0.701 ± 0.064†	0.652 ± 0.069†	2940.9 ± 236.5†	1103.1 ± 76.6†
3 mo	1.196 ± 0.079†‡	0.980 ± 0.094†	0.728 ± 0.088†‡	0.672 ± 0.086†‡	2945.6 ± 196.8*‡	1112.5 ± 47.9†‡
6 mo	1.216 ± 0.084‡	1.012 ± 0.074‡	0.809 ± 0.085‡	0.740 ± 0.073‡	3030.6 ± 181.6†‡	1140.4 ± 49.4†‡

*Scans are expressed as grams hydroxyapatite divided by projected area in square centimeters (g/cm²). †$p \leq 0.05$ versus before transplantation when patient was placed on donor organ waiting list (PreTx). ‡$p \leq 0.05$. Training versus Control group. Data presented are mean value ± SD. Lumbar Vertebral Body = entire vertebral perimeter; PostTx = 2 months after transplantation; 3 mo = after 3 months of resistance training; 6 mo = after 6 months of resistance training.

vertebral middle in both the control (−12.2 ± 5.5% and −12.7 ± 6.2%) and training groups (−14.9 ± 4.4% and −14.8 ± 3.1%). The control group had further significant ($p \leq 0.05$) reductions in lumbar vertebral BMD at 3 months and demonstrated little remineralization at the conclusion of the study. Indeed, lumbar BMD levels at 3 and 6 months of the control period were not significantly different in the control group and appeared to plateau at levels that were 16% below pretransplantation baseline levels. In contrast, specific lumbar extension exercise 1 day/week for 6 months was singularly effective in promoting remineralization of the lumbar vertebra in the training group. The BMD of the lumbar vertebral body and the lumbar vertebral middle were restored to within 2.0% and 3.6%, respectively, of pretransplantation levels.

Body mineral content and total bone calcium. Absolute values for body mineral content (g) and total bone calcium (g) in the control and training groups are presented in Table 3. Pretransplantation values for body mineral content and total bone calcium were not significantly different ($p \geq 0.05$) between the control and training groups.

The relative changes in body mineral content and total bone calcium after transplantation (percent change from pretransplant baseline) are presented in Figure 3. Similar decreases in body mineral content were recorded at 2 months after transplantation in the control (−5.1 ± 1.2% from baseline) and training groups (−5.4 ± 2.4% from baseline). Body mineral content levels remained suppressed in the control group (−6.9 ± 3.3%) but returned to within 2.4% of baseline levels in the training group after 6 months of resistance exercise. Total bone calcium also decreased dramatically in the early postoperative period in both the control (−5.9 ± 1.1% from baseline) and training groups (−5.8 ± 1.9% from baseline), but improvement in total bone calcium was observed only in the group that trained. Body mineral content and total bone calcium in the control group were not significantly different between 3 and 6 months of the control period.

Discussion

Principal findings. To our knowledge, this prospective, controlled study is the first to provide quantitative data on the efficacy of resistance exercise training as a therapy for defective bone metabolism in heart transplant recipients. The evolution of axial and appendicular bone mass was determined from DXA scans performed before transplantation, 2 months after transplantation and after 3 and 6 months of a resistance exercise program or a control period. Our results demonstrate that regional bone demineralization occurs within 2 months of heart transplantation and is characterized by a rapid early phase and a plateau phase after ~5 months. Our results also indicate that BMD losses from compartments with trabecular bone, such as the clinically important lumbar spine, are proportionately greater than BMD losses from regions with cortical bone. The BMD of the lumbar vertebral body was diminished by 12.2% and 14.9% in the control and training groups, respectively, at only 2 months after transplantation.

The main finding of this study is that a 6-month program of monitored resistance exercise, consisting of a specific low back exercise that isolates the lumbar spine and a regimen of variable resistance exercises for the total body, restores regional BMD toward pretransplantation levels in heart transplant recipients despite continued immunosuppression with glucocorticoids. In contrast, regional BMD in the control group did not indicate any statistically significant recovery toward preoperative levels by 8 months after transplantation.

Bone mineral density in heart transplant candidates. Other studies have reported diminished BMD in heart transplant recipients, but it was unclear whether postoperative osteoporosis was a consequence of heart transplantation and immunosuppressive agents or simply a continuation of preexisting osteopenia engendered by chronic heart failure (4,5). Our results suggest that regional BMD is reasonably well preserved in heart transplant candidates before heart trans-

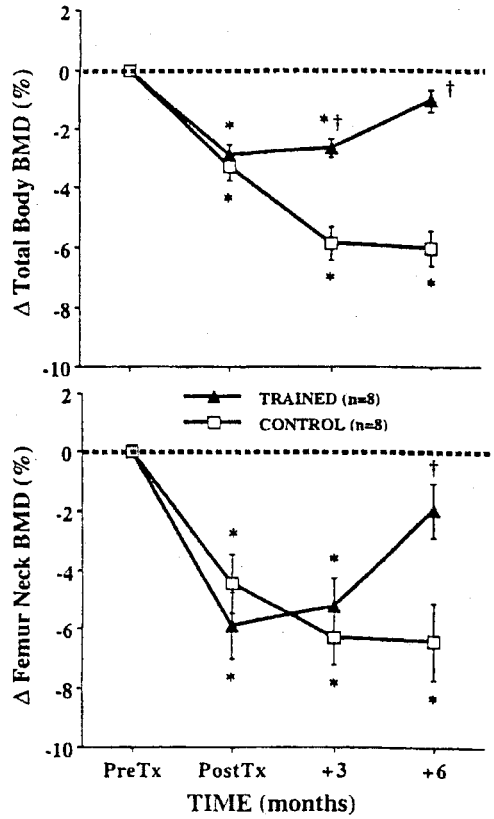

Figure 1. Changes (Δ) in total body and femur neck BMD at 2 months after heart transplantation (PostTx) and after 3 and 6 months of a resistance exercise program or a control period. Data are mean value ± SEM. *p ≤ 0.05 versus pretransplantation (PreTx) value. †p ≤ 0.05 training versus control group.

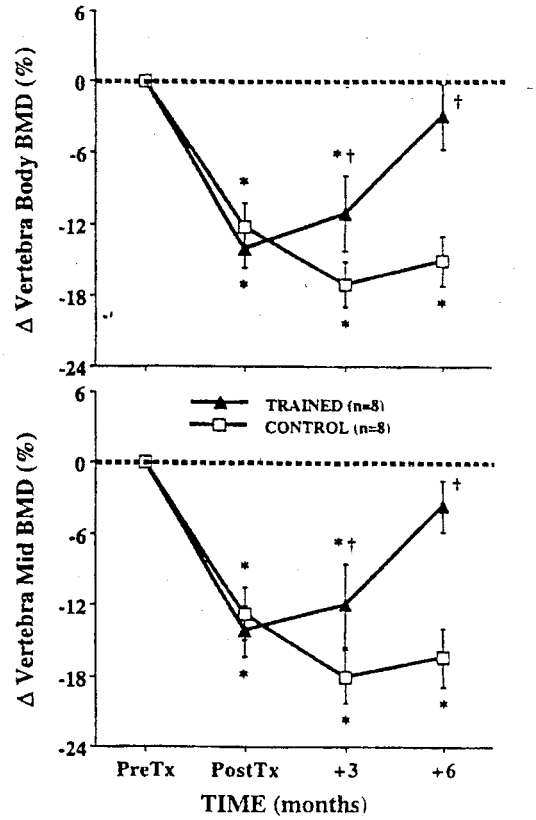

Figure 2. Changes in lumbar vertebral body and middle BMD at 2 months after heart transplantation and after 3 and 6 months of a resistance exercise program or a control period. Data are mean value ± SEM. *p ≤ 0.05 versus pretransplantation value. †p ≤ 0.05 training versus control group. Symbols and abbreviations as in Figure 1.

plantation. Whole-body BMD levels recorded before transplantation compared favorably with age-matched norms in both the control (97.3% of norm) and training groups (98.5% of norm), indicating that a relatively small amount of bone mineral loss had occurred before heart transplantation. Femur neck BMD assessed before transplantation also compared favorably with age-matched norms in both the control (96% of norm) and training groups (97% of norm). Unfortunately, age-matched norms for BMD in the lateral view of the lumbar spine were not available from the manufacturer of our DXA machine, and comparisons were not possible.

In contrast, significant bone mineral loss reportedly occurs in kidney transplant candidates before kidney transplantation (13). However, these data should not be generalized to other solid-organ transplant groups because preoperative bone loss in kidney transplant candidates is most likely related to the increases in parathyroid hormone and reductions in serum 1,25-dihydroxyvitamin D known to occur with renal failure. Although cyclosporine does cause a variable decline in renal function in most heart transplant recipients after transplantation, the relatively modest renal compromise seen in these patients does not usually lead to dramatic loss of trabecular bone.

Glucocorticoid effects. The administration of glucocorticoids (methylprednisolone, prednisone) is almost certainly the major factor in the rapid loss of BMD. Both indirect and direct indexes of skeletal metabolism implicate long-term glucocorticoid therapy in bone demineralization. Osteocalcin, an index of bone formation/bone turnover, has been shown (14–17) to be decreased by as much as 50% in patients receiving long-term glucocorticoid therapy. Direct histologic evidence of diminished bone formation is also demonstrated in glucocorticoid-treated patients (18).

Glucocorticoids alter vitamin D metabolism and decrease net intestinal calcium absorption while increasing urinary excretion of calcium, resulting in a negative calcium balance (19). This negative balance leads to secondary hyperparathyroidism, as evidenced by elevated parathyroid hormone (PTH) levels in heart transplant recipients receiving glucocorticoids (4). However, it seems unlikely that glucocorticoid-induced osteoporosis in heart transplant recipients is due solely to secondary hyperparathyroidism. Excess PTH usually elicits increased compensatory new bone formation coupled with the increased bone resorption. In contrast, histomorphometric and calcium kinetic studies indicate that new bone forma-

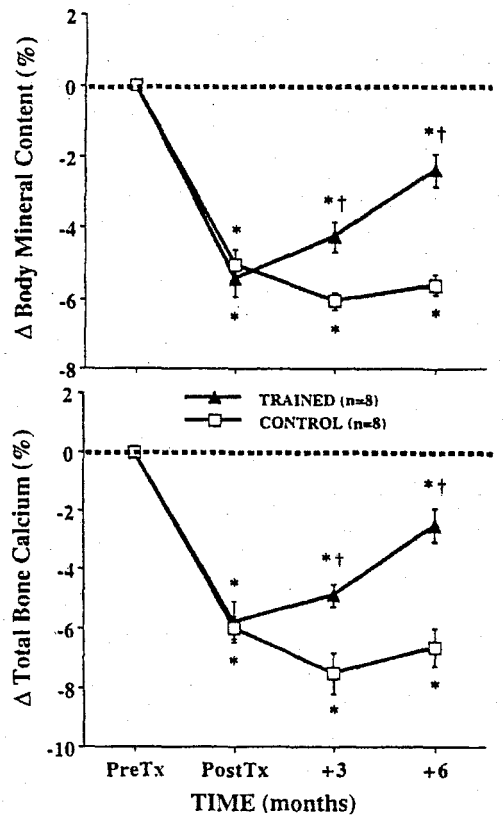

Figure 3. Changes in body mineral content and total bone calcium at 2 months after heart transplantation and after 3 and 6 months of a resistance exercise program or a control period. Data are mean value ± SEM. *p ≤ 0.05 versus pretransplantation value. †p ≤ 0.05 training group versus control group. Symbols and abbreviations as in Figure 1.

tion is decreased, whereas bone resorption is enhanced in glucocorticoid-induced osteoporosis (20). Thus, glucocorticoid-induced osteoporosis is characterized by both accelerated bone loss and inhibition of new bone formation. Additionally, excess PTH usually does not cause disproportionate losses of trabecular bone (20). However, as our data clearly demonstrate, trabecular bone loss is indeed a prominent characteristic of bone demineralization after heart transplantation, suggesting that abnormal skeletal metabolism in heart transplant recipients is mediated by glucocorticoid therapy.

Strategies to prevent osteoporosis. Dietary calcium supplements fail to prevent further loss of BMD (2,3). Intramuscular synthetic salmon calcitonin (50 to 100 IU/24 h) and testosterone (100 mg every 10 days) or estrogens (2 mg of beta-estradiol/24 h or estroderm 0.10 mg twice/week) have also been recommended for heart transplant recipients, but they failed to prevent bone mineral loss after transplantation, with further bone mineral losses ranging from 4% to 10% (2,3). BMD levels remain significantly below age-matched norms and do not indicate any recovery toward preoperative levels in patients up to 36 months after transplantation (2,3). Our results suggest that resistance exercise therapy, as part of a strategy to prevent trabecular bone loss rather than to treat established osteoporosis, should be initiated promptly after heart transplantation. This intervention was safe and not associated with any increase in rejection.

Summary. Within 2 months of successful heart transplantation, ~3% of whole-body BMD is lost, mostly due to losses in the trabecular bone compartment (12% to 15% of lumbar vertebral BMD). A 6-month program of monitored resistance exercise, consisting of a specific low back exercise that isolates the lumbar spine and a regimen of variable resistance exercises that work all major muscle groups safely, restored regional BMD toward pretransplantation levels in heart transplant recipients receiving long-term glucocorticoid therapy. However, regional BMD in the control group did not indicate any recovery toward preoperative levels. Our results suggest that resistance exercise therapy, as part of a strategy to prevent trabecular bone loss, is osteogenic and should be initiated early after heart transplantation.

References

1. Cooper DK, Muchmore JS, Welch RW. Other complications of transplantation and immunosuppressive therapy. In: Cooper DK, Novitzky D, editors. The Transplantation and Replacement of Thoracic Organs. London: Kluwer Academic Publishers, 1990:191–202.
2. Muchmore JS, Cooper DK, Ye Y, Schlegel VT, Zuhdi N. Loss of vertebral bone density in heart transplant patients. Transplant Proc 1991;23:1184–5.
3. Muchmore JS, Cooper DK, Ye Y, Schlegel V, Pribil A, Zuhdi N. Prevention and loss of vertebral bone density in heart transplant recipients. J Heart Lung Transplant 1992;11:959–64.
4. Rich GM, Mudge GH, Laffel GL, LeBoff MS. Cyclosporine A and prednisone associated osteoporosis in heart transplant recipients. J Heart Lung Transplant 1992;11:950–8.
5. Shane E, Rivas MD, Silvergerg SJ, Kim TS, Staron RB, Bilezikian JP. Osteoporosis after cardiac transplantation. Am J Med 1993;94:257–64.
6. Bell NH, Godsen RN, Henry DP, Shary J, Epstein S. The effect of muscle-building exercise on vitamin D and mineral metabolism. J Bone Miner Res 1988;3:369–73.
7. Block JE, Friedlander AL, Brooks GA, Steiger P, Stubbs HA, Genant HK. Determinants of bone density among athletes engaged in weight-bearing and non-weight-bearing activity. J Appl Physiol 1989;67:1100–5.
8. Colletti LA, Edwards J, Gordon L, Shary J, Bell NH. The effects of muscle-building exercise on bone mineral density of the radius, spine, and hip in young men. Calcif Tissue Int 1989;45:12–4.
9. Pollock ML, Garzarella L, Graves JE, et al. Effects of isolated lumbar extension resistance training on bone mineral density of the elderly [abstract]. Med Sci Sports Exerc 1992;24:S66.
10. Menkes A, Mazel S, Redmond A, et al. Strength training increases regional bone mineral density and bone remodeling in middle-aged and older men. J Appl Physiol 1993;74:2478–84.
11. Carpenter D, Tucci J, Pollock M, Graves J, Feurtado D, Mananquil R. Effect of repositioning on intraday reliability of lateral lumbar spine bone measurements using dual energy x-ray absorbtiometry [abstract]. Med Sci Sports Exerc 1992;24:S65.
12. Carpenter DM, Graves JE, Pollock ML, et al. Effect of 12 and 20 weeks of resistance training on lumbar extension torque production. Phys Ther 1991;71:580–8.
13. Horber FF, Casez JP, Steiger U, Czerniak A, Montandon A, Jaeger PH. Changes in bone mass early after kidney transplantation. J Bone Miner Res 1994;9:1–9.
14. Hahn TJ, Halstead LR, Teitelbaum SL, Hahn BH. Altered mineral metabolism in glucocorticoid-induced osteopenia. J Clin Invest 1979;64:655–65.
15. Lukert BP, Adams JS. Calcium and phosphorus homeostasis in man: effect of corticosteroids. Arch Intern Med 1976;136:1249–53.

16. Reid IR, Chapman GE, Fraser TR. Low serum osteocalcin levels in glucocorticoid-treated asthmatics. J Clin Endocrinol Metab 1986;62:379–83.
17. Epstein S. Serum and urinary markers of bone remodeling: assessment of bone turnover. Endocr Rev 1988;9:437–49.
18. Lukert BP, Raisz LG. Glucocorticoid-induced osteoporosis: pathogenesis and management. Ann Intern Med 1990;112:352–64.
19. Klein RG, Arnaud SB, Gallagher JC, DeLuca HF, Riggs BL. Intestinal calcium absorption in exogenous hypercortisonism: role of 25-hydroxyvitamin D and corticosteroid dose. J Clin Invest 1977;60:253–9.
20. Meunier PJ, Bressot C. Endocrine influences on bone cells and bone remodeling evaluated by clinical histomorphometry. In: Parsons JA, editor. Endocrinology of Calcium Metabolism. New York: Raven Press, 1982:445–65.