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CASE SERIES

A lifestyle intervention program for successfully addressing major cardiometabolic risks in persons with SCI: a three-subject case series

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INTRODUCTION: This study is a prospective case series analyzing the effects of a comprehensive lifestyle intervention program in three patients with chronic paraplegia having major risks for the cardiometabolic syndrome (CMS).

CASE PRESENTATION: Individuals underwent an intense 6-month program of circuit resistance exercise, nutrition using a Mediterranean diet and behavioral support, followed by a 6-month extension (maintenance) phase involving minimal support. The primary goal was a 7% reduction of body mass. Other outcomes analyzed insulin resistance using the HOMA-IR model, and plasma levels of fasting triglycerides and high-density lipoprotein cholesterol. All participants achieved the goal for 7% reduction of body mass and maintained the loss after the MP. Improvements were observed in 2/3 subjects for HOMA-IR and high-density lipoprotein cholesterol. All participants improved their risk for plasma triglycerides.

DISCUSSION: We conclude, in a three-person case series of persons with chronic paraplegia, a lifestyle intervention program involving circuit resistance training, a calorie-restrictive Mediterranean-style diet and behavioral support, results in clinically significant loss of body mass and effectively reduced component risks for CMS and diabetes. These results were for the most part maintained after a 6-month MP involving minimal supervision.

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INTRODUCTION

A growing body of research has observed an elevated prevalence of risk factors associated with all-cause cardiovascular disease and co-morbid endocrine disorders in persons with spinal cord injuries (SCI).[1–5] The clustering of these constituent risks—termed either metabolic or cardiometabolic syndrome (CMS)—is widely reported after SCI and thought to worsen the CVD risk prognosis. When identified according to guidelines, the CMS is defined by the coalescing of any three or more of five constituent risks. These risks include central obesity,[6–9] dyslipidemia[10–14]—as distinct threats posed by depressed plasma high-density lipoprotein cholesterol (HDL-C) and elevated plasma triglycerides (TG),[10–13,15,16] hypertension and insulin resistance.[16,17] The CMS diagnosis confers the same health threat as either existing coronary disease or a clinical diagnosis of diabetes,[18] and while the five constituent risks share equal weight in determining the CMS diagnosis, risks of obesity and insulin resistance are known to pose more substantial health hazards than the others.

To date, a unified cause for CMS after SCI has not been proposed, although it is highly likely that physical deconditioning coupled with a hypercaloric diet play a major role in its pathogenesis.[9,19–23] Both of these health hazards accompany the early phases of SCI and are known causes of fat mass gain and insulin resistance. Moreover, both are co-morbid with elevated proatherogenic inflammatory activity, which is now thought to be a progenitor of atherosclerosis.[24] Despite these obvious health risks, only marginal success has been realized in their prevention or resolution following SCI. While several studies have shown that moderate-to-intense (that is, 70–80% of peak capacity) upper extremity exercise[25–27] and circuit resistance training reduce individual CMS risks,[28–33] (reviewed in Nash *et al.*[22]) most of these benefits accompany short-term interventions that fail to lower body fat mass by clinically relevant levels. These findings reveal a need for more substantial lifestyle intervention incorporating population-appropriate physical activity, 'heart-healthy' nutrition at caloric levels that maintain stable body mass and behavioral support, the latter to sustain user engagement in this healthy lifestyle throughout the lifespan.

The Diabetes Prevention Program (DPP) was a landmark NIH-sponsored, 27-center randomized clinical trial that tested a lock-step lifestyle intervention program for persons who were at risk of developing type-2 diabetes mellitus. The lifestyle intervention program incorporated an exercise conditioning (walking) program, a Mediterranean-style calorie-restrictive diet and behavioral support and education, which was tested against a control condition using Metformin monotherapy. The trial targeted to achieve and maintain $\geqslant 7\%$ loss in body mass based on epidemiological data correlating diabetes risk with increased levels of body weight and body mass index (BMI).[34,35] Results showed both significant weight loss and a 58% decrease in the incidence of type-2 diabetes mellitus in the lifestyle intervention trial arm,[36] and that the lifestyle intervention program was more effective in achieving this goal than medication therapy. We report herein a three participant case series in which we

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Table 1. Description of Resistance maneuvers used in the CRT intervention

Exercise maneuver	*Description*
Military press	Shoulder abduction with scapular elevation and upward rotation starting from the fully adducted and depressed position.
Horizontal row	Shoulder horizontal abduction with scapular adduction starting from a position of maximum forward reach.
Pec Dec	Should horizontal adduction while in external rotation to the midline, from the maximum tolerated horizontal abduction in external rotation.
Preacher curl	Elbow flexion supported on an inclined pad from the fully extended position.
Latissimus pulldowns	Shoulder adduction with scapular downward rotation and depression starting from the maximal upward reach position.
Seated dips ('Rickshaw')	Shoulder flexion, scapular depression and elbow extension while maintaining arms as near the body as possible, from the fullest allowed point of shoulder joint extension, scapular elevation and elbow flexion.

Abbreviation: CRT, circuit resistance training.

refashioned and administered the DPP for persons with SCI who satisfied diagnostic criteria for CMS or type-2 diabetes. Unlike other studies, we evaluated both the effectiveness of a 6-month supervised lifestyle intervention and then a 6-month extension of minimal contact and support.

COMPREHENSIVE LIFESTYLE INTERVENTION

Six-month supervised exercise intervention

Three participants underwent circuit resistance training three times weekly on non-consecutive days for 24 weeks (6 months). Each session lasted approximately 40–45 min and employed resistance training (weight lifting) and endurance activities (rapid, reciprocal arm exercise with interposed periods of incomplete recovery, that is, heart rate not falling to baseline). Full range bilateral resistance maneuvers were performed on an Equalizer 7000 multi-station exercise system (Helm; Bozeman, MT, USA) as we have previously described.[28,37] Each training session was preceded by a 2-min warm-up on a Colorado Cycle arm ergometer. Resistance exercises were performed in pairs (two maneuvers in succession) each incorporating 10 repetitions of each maneuver (6 s movement; 3 s concentric (lifting) and 3 s eccentric (lowering)). Two minutes of endurance exercise was then interposed without applied resistance. Then, two more resistance maneuvers were performed. These activities were alternated until subjects rotated through each resistance station three times. Resistive loads for training during weeks 1 and 2 of each month were set at 50% of the 1-Repetition Maximal (1-RM) values calculated during initial isoinertial strength testing, as we have previously reported.[28,37] We increased these loads to 55% and 60% of the 1-RM during training weeks three and four of each month, respectively. The 1-RM for each maneuver was re-computed during the last training session every 4r weeks, to correct for training effects. Resistance maneuvers are summarized in Table 1.

Six-month nutritional intervention

The nutritional plan—administered to participants one-on-one by a registered dietician (RD) at the onset of the study—consisted of a 24-week energy-restricted Mediterranean-style diet. By DPP protocol, we measured daily energy consumption using a 4-day dietary recall (two representative weekdays and two weekend days) performed by the RD, and dietary targets were made following adjustments for measured total energy expenditure—including basal/resting and physical activity energy expenditure. Daily energy intake was reduced to achieve a 500–1000 kcal per day deficit, sufficient to result in a weight loss of 0.45–0.91 kg per week and ~7% of baseline body mass by the end of the 24-week intervention. The DPP report that this rate of weight loss was (i) a safe and effective target over a 24-week time-frame and (ii) achieved long-term compliance,[36,38] and this is currently the weight loss guideline outlined by the US Department of Health and Human Services through the NHLBI,[39] the CDC and the Mayo Clinic. Targeted daily energy intakes prior to adjustment for physical activity were 1200 kcal per day for subjects weighing 54.5–77 kg at baseline, 1500 kcal per day for subjects weighing 79.5–98 kg at baseline, 1800 kcal per day for subjects weighing 100–111 kg at baseline and 2000 kcal per day for subjects weighing >114 kg at baseline. The nutritional plan emphasized fruits, vegetables, whole grains and olive oil, while animal sources of protein were restricted to poultry and fish. The daily energy intake of the diet was composed of 50% carbohydrate, 15% protein and 35% fat. We note that the percentage of fat recommendations are specific to the Mediterranean-style diet. The daily fat intake consisted primarily of monounsaturated fats (18–20% of daily energy intake) with only a small portion of saturated fats ($<7\%$) and the balance of polyunsaturated fats (10–13%). This macronutrient composition closely resembles those used by several recent investigations of Mediterranean-style diets.[40–42] Fiber intake was targeted to achieve 14 g per 1000 kcal consumed. To monitor adherence to the nutritional intervention—both target daily energy intake and Mediterranean-style diet—participants were tasked with daily food logs, which were evaluated during each of the behavioral intervention sessions interspersed within the intervention period.

Six-month behavioral intervention

The core intervention involved an SCI-specific, 16-session protocol during the initial 24-week intervention period, which targeted behavior through education, problem-solving skills training and cognitive restructuring. Modifications were tailored from the generalized DPP intervention. The complete curriculum is summarized in Table 2. Eight teaching sessions focused on education, diet and exercise, outlining of goals and self-monitoring of food intake and physical activity. Nutritional sessions were performed one-on-one by the RD and they expand on and develop the principals of the dietary plan outlined at study onset (such as providing exemplars of sample menus). The other eight sessions provided information and strategies addressing the psychological, social and behavioral challenges to the maintenance of behavior change. Each training session was approximately 30–60 min in length. Each participant was given a personalized Lifestyle Intervention Manual containing their data from the screening and pre-intervention assessments, goals, key elements of training and motivational messages. A photograph was taken of the participant, and the internet freeware Weight-Mirror (Modiface, Inc., Toronto, ON, Canada) was used to create a 'virtual image' that was 7% lighter. This photo was included in the manual as a motivational tool.

Six-month Self-care Extension-Phase Maintenance Program

The fifth month of the clinical training phase was used to identify and train participants in the extension phase of the intervention.

Table 2. Curriculum summary for behavioral intervention

	Core intervention training curriculum	
	Session	*Topic*
Focus is on diet and exercise goals and education	1	Introduction to lifestyle intervention. Explain study goals.
	2	Introduce self-monitoring of weight at home.
	3	Teach 3 ways to eat less fat.
	4	Educate about healthy eating. Recommend alternate foods.
	5	Introduce physical activity modules.
	6	Tailor physical activity regimen to needs of the individual.
	7	Teach principles of energy balance between calories and exercise. Teach principles of health maintenance from exercise.
	8	Introduce principles of stimulus control as a method to prevent unhealthy eating. Introduce principles of stimulus control as a method to maintain exercise adherence.
Focus is on psychosocial and behavioral strategies	9	Present five-step model of problem solving.
	10	Introduce basic skills for eating and exercising away from home. Introduce basic skills for exercising away from home.
	11	Practice identifying negative thoughts and how to counter them.
	12	Introduce concept that slips are part of lifestyle change and provide tips for behavioral change maintenance.
	13	Introduce principles of aerobic fitness and coping with boredom.
	14	Provide strategies for managing social cues, both stressful and supportive.
	15	Summarize stress management principles presented over the course of the intervention.
	16	Focus on enhancing motivation and maintaining behavioral change post-lifestyle intervention.

Lifestyle coaches worked with participants to test, select and master a training mode that they found appealing, and set intensity thresholds that simulated those undertaken in the clinical phase of training. Bi-monthly behavioral support was provided, which involved 1 h for data collection, review of self-monitoring records, review of competencies, introduction of new topics, completion of action plans and scheduling of the next meeting.

PARTICIPANT TESTING

Statement of ethics

Written and verbal informed consent was obtained from all participants. The protocol was approved by the Human Subjects Research Office, Miller School of Medicine, University of Miami.

The following data were obtained at baseline, the end of the 6-month supervised LI and the end of the 6-month minimally supervised extension phase:

Body mass and BMI—body mass was expressed as the average of two measurements on a calibrated wheelchair scale. BMI was addressed using an adjusted BMI-scale for SCI with the surrogate measure of overweight as $\geqslant 22\ kg\ m^{-2}$ and obesity as $\geqslant 25\ kg\ m^{-2}$ [43,44]—now the target recommendation for BMI in SCI.[23]

Lipids and glucose levels were assayed in blood plasma as previously described.[4] Briefly, subjects refrained from caffeine and alcohol intake for 24 h before testing. Antecubital venous blood samples were taken under sterile conditions in the post-absorptive state after an overnight (10-h) fast. Ten milliliters whole blood was drawn into ethylenediaminetetraacetic acid and gel and lysis activator tubes between 8:00 and 10:00 AM. Tubes were centrifuged at 3000 r.p.m. for 30 min to isolate platelet poor plasma. Fasting glucose was determined on an auto-analyzer using the glucose oxidase method. HDL-C and TG were assayed by automated methods utilizing commercially available kits according to manufacturer's instructions and run procedures.[28] Polyanion precipitation was undertaken before HDL-C assay to separate the apoB-containing lipoproteins.[45] Fasting insulin was measured by electrochemiluminescence immunoassay (Roche Diagnostics USA, Indianapolis, IN, USA).

Insulin resistance was assessed using the Homeostatic Model-2 Assessment (HOMA2-IR) calculated as glucose ($mg\ dl^{-1}$) × insulin ($uIU\ l^{-1}$)/405.[46] HOMA2-IR is a computer-based model, derived from the original (HOMA) equation, which uses non-linear solutions to account for physiological variations not accounted for in the original equation. Available from www.OCDEM.ox.ac.uk.

Caloric intake was evaluated by using a 4-day food log,[9] including both work week and weekend food consumption. The composition was analyzed using Food Processor II Windows v. 7.6; (ESHA Research, Salem, OR, USA).

Resting energy (caloric) expenditure (REE) was calculated by indirect calorimetry: $kcal\ min^{-1} = 4.92(V)/[20.93\text{-}FEO_2/100]$, where the conversion factor of $4.92\ kcal\ l^{-1}$ of oxygen consumed was corrected for the fractional expired O_2 at rest and low-intensity work. Food, ethanol, caffeine and nicotine were restricted for 8 h before assessment, which was conducted at least 18 h following moderate or intense exercise. Subjects underwent a 20 min rest before testing, sufficient to dissipate effects of low-intensity work. Measurement duration of 30 min with the first 5 min deleted and the remaining 5 min having a coefficient of variation $< 10\%$ gives accurate readings of REE. REE comprises the majority (~70%) of total (daily) energy expenditure (TEE) and here we report and discuss calculated TEE extrapolated from measured calorimetric REE.

Peak oxygen consumption (VO_{2peak}) was determined via a maximal continuous graded exercise test on an arm crank ergometer (Monark Rehab Trainer 881E, Vansbro, Sweden). Subjects refrained from strenuous exercise 24 h before testing. Testing was conducted as previously described[47] using 10 W incremental workloads and 3-minute work stages. Expired gases were continuously analyzed by an open-circuit indirect calorimetry system (Encore Vmax229 with integrated EKG monitoring, Sensormedics, Inc., Conshohocken, PA, USA).

Upper extremity dynamic strength (1-RM) was assessed on a Helms Equalizer 7000 multi-station gym (Helms Distributing, Polson, MT, USA), using the same maneuvers adopted for training.

Table 3. Participant characteristics

Subject	*Age*	*Sex*	*Weight (kg)*	*Height (m)*	*BMI (kg m^{-2})*	*LOI*	*AIS*	*DOI (Y)*	*Cause of injury*
1	56	M	83.6	1.7	28.9	T5	A	29	MVA
2	42	M	150.5	1.85	44	T7	A	8	MVA
3	48	M	85.5	1.7	29.6	T3	A	1.5	MVA

Abbreviations: AIS, American Spinal Injury Association Impairment Scale; BMI, body mass index; LOI, level of injury; M, male; MVA, motor vehicle accident; T, thoracic; Y, years.

Table 4. Case participant outcome data

Subject	*Weight (kg)*	*BMI (kg m^{-2})*	*TEE (kcal per day)*	*Caloric intake (kcal per day)*	*Fasting glucose (mg dl^{-1})*	*Fasting TG (mg dl^{-1})*	*HOMA-IR*	*HDL-C (mg dl^{-1})*	*VO2peak (ml Kg^{-1} min^{-1})*	*1-RM Sum (kg)*	*1-RM Dip (kg)*
Baseline											
1	83.6	28.9	1680.5	1857	138	131	3.42	52	16	165.36	24.77
2	157.7	44	2545.7	1672	105	158	6.03	30	11.3	180.20	21.86
3	85.5	29.6	1317.2	1601	108	205	4.34	35	14.8	162.36	21.86
6 Months											
1	76.8	26.5	1195.2	1304	123	97	2.97	56	22.2	190.91	31.36
2	139.5	40.8	2001.6	1712	95	61	3.42	35	17.2	230.45	41.82
3	79.8	27.6	1137.6	1851	85	196	2.17	40	18.8	206.82	31.36
12 Months											
1	75.7	26.1	1008	1452	114	121	2.49	48	19.7	180.23	29.09
2	137.7	40.2	1785.6	1860	89	60	1.91	36	15.5	216.64	39.64
3	79.5	27.5	1209.6	1851	114	189	4.52	38	16.9	200.91	32.73

Abbreviations: HOMA2-IR, homeostatic assessment of insulin resistance; HDL-C, high-density lipoprotein-c; TEE, Total energy expenditure; TG, triglyceride; VO_{2peak}, peak volume of oxygen consumption; 1-RM, 1 repetition maximum.

Participants were instructed to perform eight repetitions of each maneuver with each repetition lasting 6 s (3 s concentric, 3 s eccentric). If eight repetitions are completed in controlled fashion, the weight was increased and the exercise repeated. Incremental increases in weight (2.5–5 kg each) was added until more than three but less than eight controlled repetitions could be completed. The 1-RM was calculated from the submaximal resistance measure (weight in the last set) by the Mayhew regression equation[48] as we have previously reported:[28,37] 1-RM = Wt/(0.533+0.419e − 0.055 × reps), where '1-RM' is the calculated one-repetition maximum strength, 'Wt" is the resistance used in the last set, where more than three repetitions but less than eight repetitions were completed, and 'reps' equals the number of repetitions completed in the last set of testing.

Table 5. Target levels for markers of CMS risk

Risk factor	*Criterion (ATP III)*
Abdominal obesity	BMI $\geqslant$ 22 kg m^{-2} for persons with SCI[40,44]
Triglycerides	$\geqslant$ 150 mg dl^{-1}
HDL-cholesterol	$<$ 40 mg dl^{-1}
Hyperglycemia	FPG $\geqslant$ 100 mg dl^{-1}
HOMA-IR	$\geqslant$ 2.3[41,49]

Abbreviations: ATP III, adult treatment panel III; BMI, body mass index; CMS, cardiometabolic syndrome; FPG, fasting plasma glucose; HDL, high-density lipoprotein; HOMA-IR, homeostatic model assessment of insulin resistance; SCI, spinal cord injury.

CASE PARTICIPANTS

Case participants were three males aged 42–56 years with chronic (1.5–29 years) neurologically complete SCI (AIS-A) at the T3-T7 spinal levels, all resulting from motor vehicle accidents. Participant characteristics are summarized in Table 3 and participant subject data in Table 4. Target levels for markers of CMS risk are summarized in Table 5 (and references).[44,49]

Participant 1

At baseline this individual had major risks for obesity (BMI = 28.9 kg m^{-2}) and insulin resistance (HOMA-IR = 3.42). He was a type-2 diabetic (fasting plasma glucose = 138 mg dl^{-1}) by WHO criteria. After 6 months he had lowered his body mass by 6.8 kg (8.3%), his fasting blood glucose from 138 to 123 mg dl^{-1} and insulin resistance by 0.45 using HOMA measures. After 1 year his total mass loss was 7.9 kg (9.7%) lower than measured at the initial assessment and additional lowering of fasting glucose to 114 mg dl^{-1} from the 6-month assessment was then only marginally above normal levels according to WHO guidelines. Overall cardiorespiratory fitness improved from 16 to 22.2 ml kg^{-1} min^{-1} at 6 months and declined to 19.7 ml kg^{-1} min^{-1} at 1 year. Caloric intake was reduced by 553 kcal per day during the initial intervention period and went up (148 kcal per day) by the end of the program. Overall strength increased by 25.5 kg at 6 months and remained 14.8 kg above baseline at the intervention end point.

Participant 2

At baseline this individual had 4 major cardiometabolic risks including morbid obesity (BMI = 44 kg m^{-2}), insulin resistance (HOMA-IR = 6.03), hypertriglyceridemia (TG = 158 mg dl^{-1}) and low HDL (30 mg dl^{-1}). After 6 months he had lowered his body mass by 18.2 kg (7.3%), his fasting blood glucose by 10 mg dl^{-1}, his TG by 97 mg dl^{-1} and insulin resistance by 2.61 using HOMA measures. His HDL-C had increased by 5 mg dl^{-1}. After 1 year his

total mass loss was 20 kg (8.6%) lower than at baseline and his fasting glucose was another 6 mg dl^{-1} below the 6-month assessment, with HDL-C holding steady at 36 mg dl^{-1}. His HOMA-IR continued to be reduced, and after 1 year was within the normal range. Overall cardiorespiratory fitness improved from 11 to 17.2 ml kg^{-1} min^{-1} at 6 months and declined to 15.5 ml kg^{-1} min^{-1} at 1 year. Caloric intake at baseline was increased by 40 kcal per day at 6 months, and another 148 kcal per day at the end of the program. Overall strength increased by 50.25 kg at 6 months and by 36.43 kg at the end point.

Participant 3

At baseline this individual had 4 major cardiometabolic risks including obesity (BMI = 29.6 kg m^{-2}) insulin resistance (HOMA-IR = 4.34) hypertriglyceridemia (TG = 205 mg dl^{-1}) and low HDL (35 mg dl^{-1}). After 6 months he had lowered his body mass by 5.7 kg (6.8%), his fasting blood glucose by 10 mg dl^{-1}, TG by 9 mg dl^{-1} and insulin resistance by 0.33 using HOMA measures. His HDL-C had increased by 5 mg dl^{-1} to the lowest end of the normal range. After 1 year his total mass loss was lower by 6 kg (7.1%) and his fasting glucose was another 6 mg dl^{-1} below the 6-month assessment, with HDL declining by 2 mg dl^{-1}. His HOMA-IR was significantly reduced at 6 months but returned to higher than baseline levels despite additional body mass reduction. Overall cardiorespiratory fitness improved from 14.8 to 18.8 ml kg^{-1} min^{-1} at 6 months and declined to 16.9 ml kg^{-1} min^{-1} at 1 year. Caloric intake increased by 250 kcal per day at 6 months and was at the same caloric intake at the end of the program. Overall strength increased by 44.4 kg at 6 months and by 38.5 kg at the end point.

DISCUSSION

The key finding of this case series was the reduction of body mass for all subjects that exceeded the 7% loss target. This target was established by the DPP after trial participants in the lifestyle intervention group reduced their risk of developing diabetes by 58%. The finding in this series is made more noteworthy by the additional loss of body mass during the minimal attention extension phase. We are unaware that any other case-based or trial studies have identified an intervention that was both effective and sustainable once intensive attention to the participants was ended. Interestingly, levels of cardiorespiratory fitness initially improved and then backtracked during the maintainance phase, although not to baseline levels. The same was true for strength benefits, and it is plausible that intermittent periods of more extensive recontact may be necessary to sustain higher levels of fitness reached during intense support. That being conjectured, one of the three participants began the intervention with a fitness level considered by normed data[50] as 'excellent' and two subjects as 'good', while all three ended the MP with scores in the highest tertile ('excellent'). Also, in an earlier study from our center[50] motor level of injury was associated with 22.3% of the variability in peak fitness, but an additional 8.7% was associated with BMI. It is thus plausible that reduced BMI contributed to the increased fitness of the participants.

We believe that the nutritional component of the lifestyle intervention played a significant role in the positive study findings. We are unaware of studies involving persons with SCI in which exercise administered as a monotherapy resulted in clinically significant and sustained losses of both overall and fat mass, and it is generally appreciated that daily exercise cannot counterbalance the energy intake of a hypercaloric diet such as reported in persons with SCI.[9,19–23] Although there has been a recent report where a subset of the study group had caloric intake below their basal energy expenditure,[51] the authors note 'it is possible that the observed reduction in caloric intake compared to BMR and TEE is due to underreporting of caloric intake in the food diaries', a common problem and a well noted study limitation. In addition, several large-scale studies in SCI[9,52,53] report caloric intakes that are more closely aligned with our observations here, suggesting that dietary habits have not changed drastically in recent years. A unique consideration for our participants is that of appropriate protein intake, as there is well noted loss of lean tissue associated with SC,[54–61] although the extent and rate of change of this loss becomes stable in the chronic phase of SCI, reflecting our study participants. In addition, at study onset, the participants were far above the recommended daily allowance for protein intake, whether considering general American dietary guidelines, or recently reviewed recommendations for SCI (0.8–1 g kg^{-1}),[62] and are not at risk for being deficient in this regard. In cross-referencing these values we were able to make appropriate adjustments while adhering to the Mediterranean-style guidelines. In the current series we targeted a daily caloric deficit that would facilitate weekly loss of 0.45–0.91 kg of body mass, which was based upon the DPP intervention strategy. Sample menus were provided as part of the behavior training, although we did not food shop with the participants, direct their food choices or define caloric intake on a daily basis. Only one of the participants met this caloric target without oversight, although we are aware that the composition of the Mediterranean diet during the entire lifestyle intervention was much lower in sugars having a high glycemic index. That noted, baseline caloric intake for our participants was below that reported in the SCI population, and likely significantly lower in saturated fat.[63] We also note that resting energy expenditure was lowered in all subjects, although not at the expense of continued loss of body mass; and similar reduction in resting metabolism following exercise in SCI has recently been reported.[64] As our body mass measurement does not indicate the specific tissue that was lost (that is, fat of fat-free), differentiated studies of body composition would inform the type of tissue that was lost, preferably fat mass. These studies would also be needed to discriminate lean mass changes occurring above and below the level of cord lesion, as people who undertake intense exercise typically have higher, not lower TEE[65] unless extreme levels of mass are lost through caloric restriction. Such, however, was not the case in our participants. We might also consider that nutritional intake was consciously or subconsciously regulated at caloric levels necessary to counterbalance higher levels of exercise expended during intense exercise, or the lowering of TEE.

In addition to lowering of BMI, the lifestyle intervention resulted in beneficial and sustained effects on various CMS constituent risks. While the five risks factors within the CMS determination are equally weighted by the guideline of the American Heart Association,[66,67] excessive fat mass and insulin resistance are considered more serious risks than others.[68] Aside from benefits already presented on the reduction of body mass, participant #1 had a lowering of fasting blood glucose—the preferred glucose-based diagnostic test recommended by the ADA—from levels that are diagnostic of type-2 diabetes to levels only nominally above normal. In two participants (#1 and 2) there was lowering of insulin resistance proxy values for HOMA-IR from scores that denote insulin resistance and CMS[69]—$>$1.8 and $>$1.4, respectively—to scores within the normal range, as outlined by the AHA. For participant #3 the HOMA-IR was lowered at the end of the 6-month intense intervention but increased at the 1 year end point, even though his body mass did not increase at the same sampling time point. When considering dyslipidemia as an additional CMS risk, several reports have indicated the distinct threat posed by elevated plasma TG and depressed plasma HDL-C in SCI.[10–13,15,16] These reports are consistent with evidence, including meta-analysis that TG and HDL-C are important independent risk factors for CVD in the general population.[70–74] In our participants, TG levels were lowered for all three participants, in two participants which reduced the hazard

category from high to moderate risk (participant #3) and moderate to normal (participant #2). In the two subjects having low HDL-C at baseline (participants #2 and 3), these were improved to levels within several points of the cut-scores for the acceptable range. We have reported similar benefits of CRT on HDL-C scores in persons with chronic paraplegia. In addition, a meta-analysis of 50 studies reporting on 534,906 individuals undergoing the Mediterranean diet found credible evidence for the same HDL-C elevation, TG lowering and CMS risk reduction.[75]

The development of cardiometabolic risks after SCI is complex, having various contributing factors, with energy balance understood as a central factor in weight management. Deleterious changes in body composition, typified by rapid and long-term declines in metabolically active muscle-mass[54–61] and bone,[76–82] and stark increases in central adiposity,[6–9] contribute to the maladaptive metabolic profile in SCI. With SCI, measured RMR is shown to be 14–27% lower than in non-disabled controls,[83–88] caused in part by varying degrees of loss in fat-free mass and altered sympathetic nervous system activity, particularly with a higher neurologic injury. Importantly, data comparing TEE and energy (caloric) intake indicates a surplus of approxmately 300–500 kcal per day in SCI,[19–22] which if maintained, leads to weight gain and co-morbid CMS risk. It is known that physical deconditioning plays a part in this process, as persons with SCI are known to exist near the lowest end of the human fitness continuum. When considering caloric intake, a multi-center study[89] warned of the dietary hazard that existed among persons with SCI. In particular, fat intake accounted for 37.9% of calories, typical of the American diet, with the ratio of polyunsaturated to saturated fat ~1/2 the recommended levels. A follow-up to this study[9] determined that the 'obesogenic' diet of persons with SCI has not changed over a 15-year timeframe, and was still excessive in total dietary and saturated fat.

Recent evidence supports that the suggested macronutrient composition of a Mediterranean-style diet may be optimal for weight loss and reduction of disease risk.[40–42,90,91] When compared to low-fat diets, Mediterranean-style diets studied for durations ranging from 3 months to 4 years result in significantly greater improvements in body weight,[41,42,90] insulin sensitivity[40,42,91,92] cardiovascular disease risk,[42,90,91] endothelial function[90] and vascular inflammation[90] in overweight/obese subjects at risk for, or newly diagnosed with Type II Diabetes Mellitus. This nutritional strategy was incorporated in the DPP and identified a lifestyle intervention program that could be maintained in persons at risk for Type II Diabetes Mellitus as long as 10 years after initiation, and modified for both clinical and community settings hosting persons of different racial backgrounds and socioeconomic risk strata. Thus, in combination with the caloric restriction, the amount and types of fats recommended in the Mediterranean-style diet is well suited to offset CMS risk and long-term compliance.

CONCLUSION

In a three-person case series of persons with chronic paraplegia, a therapeutic lifestyle intervention involving circuit resistance training, a calorie-restrictive Mediterranean-style diet, and behavioral support, results in substantial weight loss of $\geqslant 7\%$, matching DPP findings, and report effectively reduced component risks for CMS. These results appear to be maintained following an additional 6 months of minimal contact. A larger sample population is necessary to confirm these findings and determine the extent to which the lifestyle intervention would be optimal for persons with SCI. Future analysis will include additional measures of body composition, dynamic glucose metabolism and postprandial lipemia. These results are, however, promising in substantiating the effectiveness of this population-specific lifestyle intervention program, and in addressing the growing secondary health complications associated with SCI throughout the lifespan.

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COMPETING INTERESTS

The authors declare no conflict of interest.

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