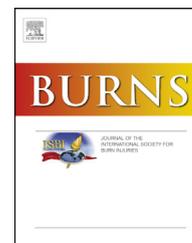


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Relationship between lean body mass and isokinetic peak torque of knee extensors and flexors in severely burned children

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ABSTRACT

Objective: Severe burns cause hypermetabolic responses and prolonged hospitalization, resulting in loss of body mass and muscle strength. This study aimed to determine whether long-term gains in lean body mass (LBM) after structured exercise programs are functionally meaningful and related to greater muscle strength in severely burned children.

Study design: LBM and muscle strength were measured at discharge and at 6, 12, 24, and 36 months after burn in 349 children. Body composition, including LBM, was measured via dual-emission X-ray-absorptiometry. Peak torque was measured using Biodex dynamometer at varying angular velocities (90, 120, 150, 180°/s). Pearson correlation analysis evaluated the association between LBM and peak torque.

Results: LBM progressively increased from discharge (32.5±11.5 kg) to 36 months following injury (40.2±12.3 kg). Peak torque and peak torque/LBM increased from discharge (56.4±34.0 Nm and 1.7±34.0 Nm kg⁻¹) to 36 months after burn (102.3±43.8 Nm and 2.5±0.7 Nm kg⁻¹, $p < 0.01$ for both). LBM and peak torque at all angular velocities showed moderate/strong correlations, with 120°/s being the strongest (all time-points: $R^2 \geq 0.57$).

Conclusion: In severely burned children participating in a rehabilitative exercise program, gains in LBM over time are related to increases in muscle strength, suggesting that gained muscle mass is functional. Measurement of muscle strength at an angular velocity of 120°/s best reflects gains in LBM and should be considered for reliable measure of strength in future studies.

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1. Introduction

Severe burns often result in an extensive hypermetabolic response. The resulting loss of muscle strength is exacerbated by high inactivity associated with prolonged hospitalization and mechanical ventilation [1]. Muscle loss has been shown to begin as early as 48h after immobilization and peaks at 2-3 weeks [2]. This results in decreased quality of life and delayed return to regular social activities [3].

Because changes in body composition, cardiorespiratory fitness, and muscle strength can persist several years after burn injury [4-6], structured programs for rehabilitation are important, especially in severely burned children [7]. Children at our institution are given the opportunity to participate in a 6- or 12-week program for occupational and physical therapy depending on the total body surface area (TBSA) burned (6 weeks: 30%-59% TBSA burned and 12 weeks: >60% TBSA burned). The goal of this program is to increase strength, functionality and cardiorespiratory capacity. The training consisted of resistance and aerobic exercise up to 5 days per week and began immediately after discharge from the intensive care unit [8]. Cardiorespiratory capacity as well as muscle strength and lean body mass (LBM) can be improved after structured exercise programs [7,9,10].

Muscle mass is a major contributor to the body's total LBM. Gains in LBM after exercise programs are thought to be primarily attributable to changes in muscle mass, which in turn lead to changes in strength [9]. We usually measure muscle strength in four angular velocities (90, 120, 150, 180°/s). However, repetitive measures may cause fatigue in the patients with leading to not reflecting the actual strength. Here we measured changes in both LBM and muscle strength in pediatric burn patients to determine whether gains in LBM seen after participating in exercise are related to increases in muscle strength, which may indicate an increase in functionality. We also performed muscle strength measurements at varying angular velocities to determine which best correlated with LBM in severely burned children.

2. Methods

Severely burned children who were admitted to our institution between 2003 and 2017 and who had matching muscle

strength and body mass measurements were included in this study. The study was approved by the Institutional Review Board of the University of Texas Medical Branch, Galveston, Texas (Protocol 04-147). All participating patients or their legal guardians consented and the children assented to the study. The patients participated in a 12-weeks exercise program which consisted of aerobic and resistance training at five days per week. Exercise tests and measurement of body composition were performed at discharge (before starting the exercise program) as well as at follow-up visits at 6, 12, 24, and 36 months after burn.

2.1. Assessment of muscle strength and body composition

Muscle strength was assessed using the Biodex dynamometer (Biodex Medical Systems, Shirley, NY, USA). Tests were performed on the dominant leg and tested at different angular velocities (90, 120, 150, 180°/s) while the patient was seated and stabilized with straps following the manufacturer's instructions. Trained exercise specialists explained the test procedure in detail. Next, the patients were asked to perform a practice set to get familiar with the system, and they then did 10 maximal voluntary muscle contractions at full knee flexion and extension without rest between each repetition. Muscle strength was expressed in peak torque (Nm). The highest peak torque in the 10 repetitions was included in the analyses.

Body composition was measured via dual emission X ray absorptiometry (DEXA). Images were analyzed using QDR 4500A software (Hologic Inc., Waltham, MA, USA). Scans of the whole body were performed with the patient lying in the supine position and following the manufacturer's instructions. This method has been described by our group [10,11]. Bone mineral content, LBM, fat body mass, and total body mass were measured and expressed in kilograms.

2.2. Statistical analysis

Patient demographics, body composition, and muscle strength were expressed as mean (\pm , standard deviation), counts, and percentages as applicable. All data collected at discharge as well as at follow-up visits at 6, 12, 24 and 36 months following burn were analyzed. Parametric data were analyzed using Student's t test, paired t test, or repeated measures ANOVA. Nonparametric data were analyzed using Mann-Whitney U test, and categorical data were analyzed

Table 1 – Patient demographics.

Characteristic ^a	Discharge	6 months	12 months	24 months	36 months
Age at burn (years)	12.2 \pm 4.1	–	–	–	–
Sex, male, n (%)	268 (76.8)	–	–	–	–
%TBSA burned	53.9 \pm 16.3	–	–	–	–
Presence of inhalation injury, n (%)	125 (35.8)	–	–	–	–
Height (cm)	149.6 \pm 19.1	149.9 \pm 18.9	152.1 \pm 18.6	155.1 \pm 15.8	158.3 \pm 14.1
Weight (kg)	46.0 \pm 17.4	49.2 \pm 22.8	52.9 \pm 20.4	56.0 \pm 22.2	57.2 \pm 19.1
BMI (kg/m ²)	19.9 \pm 19.1	22.1 \pm 19.1	21.9 \pm 6.2	22.7 \pm 6.8	22.3 \pm 5.3
Length of stay in ICU (days)	33.0 \pm 25.8	–	–	–	–

^a %TBSA burned, percent total body surface area burned; BMI, body mass index; ICU, intensive care unit.

^a Data expressed as mean \pm standard deviation unless noted otherwise.

using chi square test. To test the hypothesis that a close correlation exists between increases in LBM and strength after severe burn, we plotted changes in LBM and strength over time. Strength was calculated across multiple angular velocities to ensure accuracy. For all strength calculations/trends, an angular velocity of 120°/s (because of its high Pearson correlation across all time points) was used to universalize data. Significance was set at a p value of less than 0.05. Statistical analyses were performed using GraphPad Prism for Windows 7.03 (GraphPad Software, La Jolla, CA, USA).

3. Results

3.1. Patient characteristics

A total of 349 patients (268 males, 81 females) with a mean age at burn of 12.2±4.1 years were included in the study. General demographics are shown in Table 1. The leading mechanism of burn was flame (268/349; 76.8%) followed by electrical, scald, chemical, and contact. TBSA burned was 53.9±16.3% with third-degree burns involving 38.5±23.1% of the TBSA. Patients stayed in the intensive care unit for 33.0±25.8 days.

3.2. Body composition

LBM was calculated at discharge and at 6, 12, 24, and 36 month follow-up visits. At discharge, LBM was 32.5±11.5 kg. LBM gradually increased at each of the follow-ups, reaching 40.2±12.3 kg at 36 months (Fig. 1). Total body weight also progressively increased, starting at 46.0±17.4 kg at discharge and reaching 57.2±19.1 kg at 36 months (Fig. 1). Although body

weight increased, fat percentage remained fairly constant, measuring 26.5±7.6% at discharge and 26.1±8.7% at 36 months (Fig. 1). A paired t-test showed an increase in LBM at 36 months after burn compared to discharge ($p < 0.01$).

3.3. Muscle strength

Like LBM, muscle strength gradually increased with time, and this was seen across all angular velocities (Fig. 2). Peak torque at 120°/s significantly increased from 56.4±34.0 Nm at discharge to 102.3±43.8 Nm at 36 months following burn (Fig. 2A). Muscle strength increased from discharge to all time points for all angular velocities ($p < 0.01$). When normalized to LBM, peak torque at 120°/s increased from 1.7±34.0 Nm kg⁻¹ at discharge to 2.5±0.7 Nm kg⁻¹ at 36 months following burn at all angular velocities and time points ($p < 0.01$, Fig. 2B).

3.4. Correlating between angular velocities and LBM

Peak torque at all angular velocities showed a moderate to strong correlation with LBM at all time points, with R² ranging from 0.53 to 0.78 (Table 2). The strongest correlation between LBM and strength was seen at an angular velocity of 120°/s (Fig. 3). R² was 0.67 at discharge, 0.77 at 6 months, 0.57 at 12 months, 0.78 at 24 months, and 0.75 at 36 months.

4. Discussion

Here we analyzed changes in body composition and strength in burned children after a 12-week exercise program and in the further course after burn injury. Our data show that LBM,

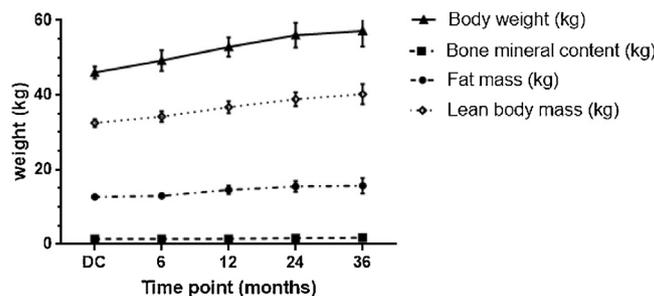


Fig. 1 – Changes in body composition at varying times after burn. DC, discharge.

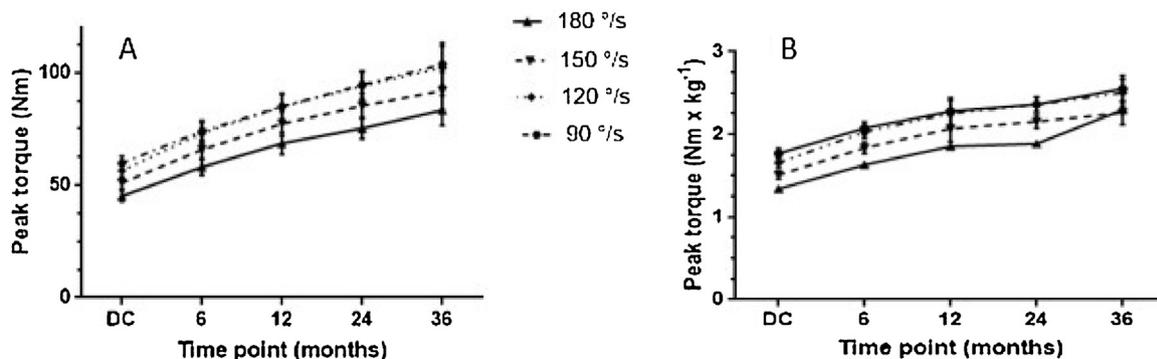
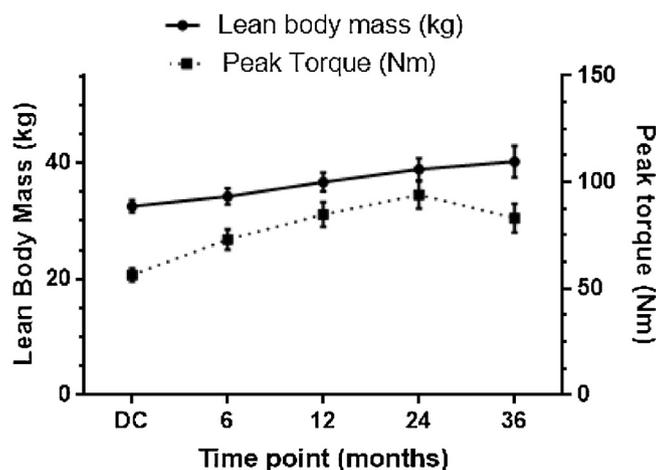


Fig. 2 – Time-dependent changes in peak torque at varying angular velocities. Peak torque is presented (A) as an absolute value and (B) normalized to lean body mass. DC, discharge.

Table 2 – Pearson correlation between lean body mass and muscle strength at varying angular velocities.

Angular velocity	Discharge	6 months	12 months	24 months	36 months
180°/s	$R^2=0.65$	$R^2=0.74$	$R^2=0.44$	$R^2=0.76$	$R^2=0.76$
150°/s	$R^2=0.69$	$R^2=0.77$	$R^2=0.53$	$R^2=0.77$	$R^2=0.75$
120°/s	$R^2=0.67$	$R^2=0.77$	$R^2=0.57$	$R^2=0.78$	$R^2=0.75$
90°/s	$R^2=0.69$	$R^2=0.76$	$R^2=0.54$	$R^2=0.73$	$R^2=0.73$

**Fig. 3 – Comparison of changes in lean body mass and muscle strength at varying times after burn. Muscle strength is expressed as peak torque at an angular velocity of 120°/s. DC, discharge.**

strength, and strength normalized to LBM increase with time. This result is in line with findings by Clayton et al., who showed that LBM and muscle strength improve in pediatric burn patients up to 24 months after injury [9]. Importantly, we saw not only an increase in these two variables, but also a moderate-to-strong correlation between them.

The physiologic response to burns is characterized by hypermetabolism that persists throughout recovery and in some cases up to a year after burn [2,12]. This response is marked by high levels of catecholamines, glucocorticoids, and proinflammatory cytokines [13]. These are the major culprits associated with muscle protein breakdown leading to loss of LBM [14]. This loss of muscle mass and strength can be counteracted by exercise programs, which help attenuate the response and expedite the recovery process [8].

In this study, DEXA was used to measure LBM and determine changes in muscle mass. DEXA scans continue to prove useful as a tool to measure body composition in pediatric burn patients. Rapid results and ease of use make it an ideal means of measurement in this population [15,16]. In studies at our institution, the DEXA scan has been efficient and effective.

In the pediatric population, increased strength as response to exercise is largely related to the intensity and volume of loading as a result of increased neural activation, rather than hypertrophy [17]. This supposedly accounts for gains in LBM following an exercise program. As in previous studies [9], our patients were able to successfully gain both weight and LBM following burns. Overall, LBM among patients increased by 19.2% in 36 months. While LBM and body weight increased over time, total fat percentage remained relatively constant (i.e., $26.5 \pm 7.6\%$ at discharge and $26.1 \pm 8.7\%$ at 36 months). This

further supports the notion that exercise training leads to a predominant gain of LBM rather than fat. However, in the pediatric population LBM and peak torque undergo a normal increase with age [18,19] and the changes showed in this study are not only related to the exercise program, but also to the physiological development. In a three year exercise program with six to nine year old children, Detter et al. showed that exercise can be beneficial for a greater gain in both LBM and peak torque [20].

Muscles enable the body to perform physical work, and their hypertrophy should result in an increase in strength. Our results confirmed this, showing a continuous increase in peak torque (determinant of muscle strength) across all angular velocities from discharge to 36 months after burn. Evidence suggests that more than once weekly exercise is needed to maintain this increase in strength, so having patients participate in a program that involves exercise more than once a week is important [21]. This continued increase in strength, in turn, will lead to greater power and ability to do work. These changes help children to return to normal daily living activities and should increase both emotional and physical independence as well as self-confidence [8]. They can also be beneficial for bone growth, prevention of obesity, and cardiovascular health [22].

In this study, we also compared various angular velocities to LBM to see which correlated most closely. These multiple measures of strength helped ensure accuracy. However, a downfall to this method may be the extensive amount of exercise involved. Because each angular velocity required multiple repetitions, this approach may have led to physical exhaustion amongst subjects, skewing the results. Here we

found that 120°/s correlated most closely to LBM. Perhaps only one trial at 120°/s is necessary to evaluate muscle strength following pediatric burn injuries. This may be useful in short-term clinical work and follow-up assessments as well as in future studies, since multiple trials of strength at varying angular velocity may tire patients. Eliminating unnecessary trials may prevent patients from losing energy, thus removing unreliable data.

4.1. Limitations

The muscle strength measurements performed at discharge may have been affected by general weakness and pain. However, muscle strength and body composition measurements were similarly correlated at discharge and the other follow-up time points. As previously stated, multiple trials of strength at each angular velocity may have produced a lower strength measurement as time progressed. Hypertrophic burn scars may have decreased range of motion and affected strength values at later follow-up time points as well. Another limitation is related to total LBM, which is composed of skin, organs, bones, and water in the body. In the pediatric population, organs, skin and bones may still grow, and this may slightly elevate prediction of gains in muscle mass. In addition, we did not include a non-burned control group that participated in the exercise program and gains in muscle mass and strength can also be related to the normal recovery of the patients. However, we have previously shown that exercise programs are beneficial in terms of gaining LBM and strength compared to no exercise. Moreover, this study aimed to evaluate correlations between muscle strength and body composition in burn patients.

5. Conclusion

Following burns in the pediatric population, the body experiences a hypermetabolic response resulting in significant reductions of total body weight, LBM and strength. Our study showed that an exercise program can be beneficial for the management and treatment strategy of the known loss. Increases in strength and LBM can be seen as a result of an exercise program following burns. In severely burned children participating in a structured exercise program, gains in LBM are related to increases in muscle strength up to 36 months after burn. Measurement of muscle strength at 120°/s best correlates with gained muscle mass and could be performed alone in place of multiple measurements at different angular velocities, which may lead to fatigue and skew muscle strength results. Thus, it could help ensure more reliable data in both clinical and research settings.

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Declarations of interest

None.

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Author's contributions

Study conception and design: CT, DNH, LKB, JOL, OES; acquisition of the data: CT, AA, DP; statistical analysis: CT, OES; analysis and interpretation of the data: CT, AA, OES; drafting of the manuscript: CT, AA, DP, LKB, JOL, OES; critical revision: DNH, LKB, JOL, OES. All authors approved the final version of the manuscript.

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