ORIGINAL ARTICLE

Lower-Limb Muscular Strength, Balance, and Mobility Levels in Adults Following Severe Thermal Burn Injuries

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Severe burn injuries are associated with hypermetabolic response and increased catabolism. These lead to a vast loss of muscle mass and reduced muscle strength and function. Therefore, the aim of this study is to determine the impact of severe burn injuries on lower-limb muscular strength, balance, and mobility level in adults. Forty burned adults with burned TBSA (burned TBSA) ≥40% participated in this study. The peak torque and total work of quadriceps and knee flexors were calculated at 150°/sec using Biodex isokinetic dynamometer. Balance and mobility were tested via the Biodex balance device and the high mobility assessment tool, respectively. Twenty-three matched nonburned healthy adults were evaluated and served as a control group. Severely burned adults exhibited significantly lower peak torque and total work in their quadriceps (27.50 and 22.58%, $P < .05$) and knee flexors (23.72, and 21.65%, $P < .05$) relative to the nonburned adults. Burned adults had a significant decrease in stability index and balance including the dynamic limits of stability ($P < .05$). The high mobility assessment tool scores were significantly lower (42 ± 7.64, $P < .05$) when compared with control subjects (51 ± 1.62). Patients who had severe burns (burned TBSA ≥ 40%) showed muscular weakness, limited balance, and mobility levels between 16 and 24 weeks after discharge from the hospital compared with matched nonburned control subjects. These results can guide therapists in creating rehabilitation programs that focus on the specific difficulties faced by burned patients. (J Burn Care Res 2017;XXX:00–00)

Severe burn injuries are associated with hypermetabolic responses and increased catabolism. These lead to a vast loss of muscle mass, reduced muscle strength and endurance, limited walking ability, and reduced functional mobility.[1–7] These are worsened by deconditioning (eg, prolonged bed rest, immobilization, and inactivity).[5] Previous studies have suggested that sensory neurons impeded in dermal tissue are damaged secondary to burn injuries resulting in impaired perception and postural imbalance.[8–11] These will influence the ability to execute a range of activities and function in both the short and long term.

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Persistence of muscle weakness is well known in both adults[6,12] and children who sustained injury and had more than 30% of burned TBSA (burned TBSA).[13,14] However, there are limited studies on the use of the isokinetic dynamometer to quantify recovery of muscle strength following burn injury.[6,12–19] In addition, the use of the Biodex balance system has not yet been described in the literature, and only a few studies have tested walking and mobility levels following burn injury.[12,16,20–24] Therefore, this study determined the impact of thermal burn injuries on the lower-limb muscular strength, balance, and functional mobility in adults and compared results with norm values of a matched nonburned group.

METHODS

Burned Participants

This is a cross-sectional descriptive study, which was approved by the postgraduate institutional ethical committee at Faculty of Physical Therapy. Burned adults (men and women) were recruited from OM El-Masrien Hospital, Giza, Egypt. The participants with following criteria were enrolled in this study: 1) Aged 18 to 35 years; 2) sustained second to third degrees burns to the dominant or both lower extremities; 3) burned TBSA ≥ 40% as estimated by the rule of nine; 4) completion of skin grafting at least 3 months at the time of assessment. The exclusion criteria were existing leg amputation, psychiatric, neurological, and cognitive disorders. All participants received similar standard medical care and rehabilitation services from the time of emergency admission throughout discharge.

Nonburned Group

Based on the previous study of St-Pierre et al,[6] and Grisbrook et al,[25] the burned participants were matched to nonburned control healthy adults who were voluntarily recruited from the community through personal contact according to sex, age, weight, height, body mass index, and level of physical activity. Participants in both groups were sedentary (not involved in regular physical activity, defined as 1 hour of moderate intensity exercise that performed three times per week) in the past 3 months. They did not engage in any rehabilitation program and/or use medications that may affect muscle strength.

Data Collection Procedures

The assessment procedures and data collection were performed in the Biodex lab at the Faculty of Physical Therapy, Cairo University, Giza, Egypt. Outcomes included muscle strength, balance, and mobility level. These outcomes were measured between 16 and 24 weeks after discharge from the hospital. On the first visit, the therapist provided the participant a brief description of the testing procedures. Demographic data (eg, age, sex, weight, and body mass index) and medical data (eg, extent of burn, location of burns, skin grafting, length of hospital stay, duration since discharge) were collected for all participants. All participants signed an informed consent form before engaging in the study.

Isokinetic Muscle Strength Assessment

A Biodex isokinetic dynamometer (Biodex Medical System, Shiley, NY, linked to IBM PC computer software) was used to measure the muscular strength after calibration according to the manufacturer's instructions. A therapist reported the values of knee flexors and quadriceps muscle strength of dominant leg regardless the location of burns at an angular velocity of 150°/sec.[6,12,14] The details of the protocol and test procedures were described in our previous study.[12,15,16] Values of peak torque (PT) and total work (TW) were calculated using the Biodex software system.

Balance Assessment

A Biodex Balance System (Biodex Medical Systems, Shirley, NY) consists of movable balance platform that provides 20° surface tilt through 360° range of motion. The platform interfaces with computer software that enables the device to serve as an objective assessment of balance. Before the start of each testing session, the Biodex was calibrated according to the manufacturer's manual. The participants were familiarized with testing procedures through free practical sessions to minimize the learning effects that occur during testing. All measurements were performed at level eight of stability (the most suitable level), and the test duration was set at 20 seconds for three successive trials. Each participant was tested for stability index (SI) and limits of stability (LOS). The LOS is defined as the area that the subject safely moves without changing the base of support. The SI represents the patient's ability to control balance and motor control skills at 50% LOS.[26–29]

To test SI, the participants were asked to step on the platform and instructed to grasp the support handles at the beginning and then release them as the test proceeded with open eyes and barefoot. Then, the participants were informed to assume the proper centered position as soon as the platform was released by shifting the foot position on the platform, and the foot position was recorded by using coordinates on the platform's grid.[26–29]

The LOS test prompted participants to move a cursor, viewed on the visual feedback screen by leaning toward a target while standing on the fully unstable platform to keep the cursor at the center of the screen grid. The LOS test measures the time and accuracy with which participants transferred their estimated center of gravity while moving the cursor to intercept each of eight successive targets on the display screen. The targets were positioned at 45° intervals around a central target that represented the participant's center of pressure under static conditions. Each target was randomly highlighted, and the participant reached the target by leaning and returning to the center position before the next target was selected and displayed on the screen. The test was completed when all eight targets had been reached. Target placement was preset by the manufacturer at 50% of the LOS. The system calculated balance indices including the SI and the LOS scores. These were collected and used for further analysis.[26–29]

Mobility Assessment

The high mobility assessment tool (HiMAT) is a valid unidimensional assessment tool developed to examine high-level mobility function in a population with traumatic brain injury.[30–32] The HiMAT can be used for mobility assessment following burn injuries.[23]

The HiMAT includes 13 items that assess a range of high-level activities including walking tasks (eg, walking, walking backwards, walking on toes, and walking over an obstacle), running, skipping, hopping forward, bounding, and going up and down stairs. Each item is scored on a scale 0 to 4, where zero represents the inability to perform an item, and four represents increasing levels of ability (based on the time/distance they receive). All items are summed for a total score of 54. Higher scores show a higher level of performance. Norms for healthy adults aged 18 to 25 are 50 to 54 for men and 44 to 54 for women.[23,30–32] The HiMAT was performed according to published recommendations.[30] The participants were given standardized verbal instructions and one visual demonstration for all items. Then, participants completed one practice trial and one "real" timed trial for each item. The scores for the normal healthy subject were matched with the reported norm scores.

Data Analysis

Data were analyzed with Statistical Package of Social Science version 22.0 (Chicago, IL). Normal distributed data (Kolmogorov–Smirnov test, $P > .05$) were described as the mean and SD. Otherwise, the data were represented as frequency, median, and range; they were then nonparametrically analyzed. Baseline characteristics, muscular strength, balance indices, and mobility level between groups were compared with an independent sample *t*-test and the Mann–Whitney *U* test. The differences in PT and TW were calculated from the following equation based on work of St-Pierre et al,[6] as following: "100 − burn value/control value × 100) at 150°/sec", where "burn values" are obtained from burn patients, whereas "control values" are the measurements obtained from the control healthy subjects.

Using norm values from the nonburned group, results were converted to a *Z* score to report individual performance. Then, the mean of normalized scores was calculated at the group level.[19] Pearson correlation coefficients were calculated between the outcome variables (muscular strength, balance, and mobility) and burn characteristic variables (eg, burned TBSA and length of time since discharge). Variables that showed significant correlations were included in a logistic regression analysis. Statistical significance was set at $P < .05$.

RESULTS

Participant Characteristics

Table 1 summarizes the demographic characteristics of both groups. Forty burned adults (26 males and 14 females) and 22 matched, nonburned healthy adults (13 males and 10 females) were involved in this study. No significant differences were observed between groups with regard to age ($P = .75$), weight ($P = .11$), height ($P = .91$), BMI ($P = .17$), and distribution of sex ($P = .33$). The mean extent of the burned TBSA was 45.02% (range 40 to 55%). The extent of full-thickness burned TBSA was 18.50% (range 15 to 25%). The average extent of burns to lower limb burned TBSA was 18% (range 15 to 27%). All the burned participants had burns to their lower limbs. Eighteen of the participants also had bilateral upper limb burns; five also had injuries to the face. Forty participants had skin grafting surgery during hospitalization, partial thickness skin grafts (n = 10), and full-thickness skin grafts (n = 5) in their dominant lower limb. None of the subjects had surgeries for at least 3 months before assessments. The mean length of stay was 76.75 ± 16.21 days (range 42 to 98 days), and 52.50% (21 participants) were discharged within 11 weeks of the burn.

Muscle Strength

Table 2 reports the mean values of PT and TW for the participants' quadriceps and knee flexors. The PTs for quadriceps and knee flexors significantly differed ($P = .03$) in the burned participants (62.89 ± 7.38 and 57.17 ± 5.87 Nm), relative to the nonburned

Table 1. Participants characteristics and demographic data

Variables	Burned Group (n = 40)	Control Group (n = 23)
Sex, males/females, N (%)	26/14	13/10
Age (yr)	26.32 ± 4.02	24.60 ± 3.49
Weight (kg)	73.57 ± 15.65	76.31 ± 16.60
Height (cm)	170.30 ± 7.09	169.40 ± 11.3
BMI (kg/cm^2)	25.36 ± 5.26	26.59 ± 4.59
Burned TBSA (%)	45.02 ± 3.58 (40–55)	NA
Full-thickness burn (%)	18.50 ± 6.82 (15–25)	NA
Average % TBSA of LL	18 ± 3.85 (15–27)	NA
Average % TBSA of UL	13 ± 3.58 (10–20)	NA
Length of hospital stay (d)	76.75 ± 16.21 (42–98)	NA
Duration since discharge (wk)	20 ± 3.31(16–24)	NA

Data presented as mean ± SD, or number, and range as in bracket, no significant ($P > .05$) differences between groups.
BMI, body mass index; *LL,* lower limb; *N/A,* nonavailable; *UL,* upper limb.

Table 2. Mean values of peak torque (Nm) and total work (J) for quadriceps and hamstrings of dominant leg in both burned and matched control groups.

	Groups	
	Burned Group (n = 40)	Control Group (n = 23)
Isokinetic Test (150°/sec)	Mean ± SD	Mean ± SD
Quadriceps		
Peak torque (Nm)	62.89 ± 7.38*	86.75 ± 8.50
Total work (J)	57.37 ± 5.62*	73.63 ± 10.37
Hamstrings		
Peak torque (Nm)	57.17 ± 5.87*	74.94 ± 8.50
Total work (J)	49.05 ± 5.28*	62.61 ± 5.56

*Significant ($P < .05$) decrease compared with control group.

group (86.75 ± 8.50 and 74.94 ± 8.50 Nm). The TW performed for quadriceps and knee flexors were significantly (P = .03) decreased in burned participants (57.37 ± 5.62 and 49.05 ± 5.28 J) vs the nonburned group (73.63 ± 10.37 and 62.61 ± 5.56 J). The burned participants exhibited significantly (P = .02) lower PT in the quadriceps (27.50%) and knee flexors (23.72%) and produced less (P = .02) TW in the quadriceps (22.58%) and knee flexors (21.65%) compared with the nonburned group. In general, the individual mean Z score for PT and TW for both quadriceps and knee flexors was significantly lower ($P < .05$) in all burned participants vs the nonburned group.

Balance Assessment

Table 3 reports the mean values of the SI and dynamic LOS. There was a significant difference (P = .02) in SI between the burned participants (4.42 ± 0.35) and the nonburned group (1.92 ± 0.50). The dynamic LOS showed significant differences (P = .03) between the burned participants (15.50 ± 2.30) when compared with the nonburned group (21.22 ± 3.62).

Table 3. Mean values of SI and total dynamic LOS in both burned and matched control groups.

	Groups	
	Burned Group (n = 40)	Control Group (n = 23)
	Mean ± SD	Mean ± SD
Balance		
SI	4.42 ± 0.35*	1.92 ± 0.50
LOS	15.50 ± 2.30*	21.22 ± 3.62

*Significant ($P < .05$) decrease compared with control group.
LOS, dynamic limit of stability; *SI,* stability index.

These differences demonstrated lower balance ability in patients with severe burn injuries. In total, all burned participants had significantly lower Z scores. There was also a significant deviation from the norm in the group mean for SI and LOS.

High Mobility Assessment Tool

The total HiMAT score and all subscores for the burned and nonburned groups are presented in Table 4. The mean total HiMAT score in the burned adults was 42 ± 7.64 compared with 51 ± 1.62 in the nonburned group (P = .01). Eight of the 13 mobility task scores differed significantly from the nonburned group: "walking backwards," "running," "hop forward," "bound affected leg," and "four-stair activities." Five males had a normal average total HiMAT score, whereas 35 participants scored lower than normal (14 females and 21 males) in the burned group. The HiMAT scores were lower in females than males in the burned (39.19 ± 5.7 and 46.00 ± 7.84, P = .03) and nonburned (52.07 ± 1.49 and 49.70 ± 1.05, P = .01) groups. The Mann–Whitney U test showed a significant (P = .03) difference between sex distributions in total HiMAT scores between the two groups.

Source of Variation in the Strength Measures

For the burned group, significant correlations were observed between burned TBSA with muscular strength (r = .40, P = .01) and mobility level on HiMAT (r = .30, P = .03). Moreover, there was a

Table 4. Total HiMAT score and item scores in the burned group compared with matched control group.

	Burned Group (n = 40)	Control Group (n = 23)
	Mean ± SD	Mean ± SD
Walk	4 ± 0.60	4 ± 0.30
Walk backwards	3 ± 0.51*	4 ± 0.20
Walk on toes	3 ± 0.70	3 ± 0.31
Walk over obstacle	3 ± 0.70	3 ± 0.20
Run	2 ± 1.20*	3 ± 0.70
Skip	3 ± 1.81	3 ± 0.61
Hop forward	3 ± 1.31*	4 ± 0.51
Bound (affected)	3 ± 1.21*	4 ± 0.60
Bound (less affected)	3 ± 1.20*	4 ± 0.60
Up stair dependent	4 ± 0.80*	5 ± 0.31
Up stair independent	3 ± 0.70*	4 ± 0.21
Down stair dependent	4 ± 0.61	5 ± 0.30
Down stair independent	3 ± 0.81*	4 ± 0.20
Total score of HiMAT	42 ± 7.64	51 ± 1.62

*Significant ($P < .05$) decrease compared with control group.
HiMAT, high mobility assessment tool.

trend indicating an effect of the extent of burn on muscular strength and mobility level. There was no significant relationship between length of time since discharge and muscular strength, mobility level, and balance indices.

DISCUSSION

The current study indicates a significant decrease in the amount of PT and TW generated by quadriceps and knee flexors in our burn patients. Furthermore, a significant loss of balance and high-level mobility problems were presented in adults with burned TBSA ≥ 40% relative to the nonburned group.

Regarding muscle strength, our findings agreed with our earlier study.[12,15] The PT of the knee extensors and flexors in the burned group were significantly lower (28 and 24%, respectively) when compared with the nonburned adult.[12] Moreover, the PT of knee extensor demonstrated a 30% decrease in the burned group vs the nonburned group.[15] Recent study by Ebid and Elsden[16] concluded that the PTs of eccentric, concentric, and isometric muscles contraction increased by 24.50, 32.48, and 52.38% in nonburned subjects when compared with burned adults at 12 weeks post burn. Moreover, the findings of the current study are consistent with previous results that demonstrated persistence muscular weakness in burned adult (TBSA > 35%)[6,17] and children (TBAS; 18–42%).[13,14,33] In contrast to our findings, Grisbrook et al[25] and Disseldrop et al[19] failed to show a significant difference in muscle strength between burned and nonburned subjects.

This inconsistency across the literatures might be related to the variability in the population (adults vs children), evaluation time post burn injury (range 4–40 months), discrepancies in average percentage of TBSA (18–42%), and sample size. Finally, muscle strength was tested using isokinetic at different angular velocities (60 and 150°/sec), different instruments (isokinetic vs hand-held dynamometer), and different muscles groups (knee extensors and flexors, elbow flexors and extensors, back muscles and handgrip strength).

The decrease in muscle strength might be attributed to deconditioning after burn injury and insufficient rehabilitation.[5,34] In addition, severe burns can lead to a change in metabolism that might persist up to 24 months after the initial injury. These cause significant muscle wasting and deconditioning.[1–3] Recent studies suggested that burn has a direct impact on the mitochondrial function and gene expression of skeletal muscles in a nonburned limb. However, a complete understanding of these processes is still lacking.[35,36]

In this study, we used isokinetic testing to assess muscle function. Isokinetic testing also allows measurement of dynamic muscular parameters under a predetermined rate. The rate chosen for this experiment was 150°/sec, which approximates the motion of walking activities.[6,12,14] For practicality, we chose this value because rehabilitation programs should focus on helping the patient to resume normal walking and daily living activities or goal-oriented tasks—these are dynamic muscular functions.[16,17]

To the best of our knowledge, the current study is the first to use Biodex balance in burned participants, and the results should encourage further development of using balance assessment. Our findings of reduced balance indices in adult participants with severe burns are consistent with existing literature. However, previous studies used other outcome measures for balance assessment such as the Berg Balance Scale, single leg stance, time-up-and-go test, and tandem walk test.[20,21] These results agreed with findings of Schneider et al,[20] who reported lower scores (26-medium risk of fall) on Berg Balance Scales in the burned group on admission.

The defect in balance following burn injuries might contribute to multiple factors such as loss of tactile sensation, proprioception, and muscle strength, as well as limited joint mobility and cognition. All are potentially affected in severe burn injury.[20] Balance can further worsen due to burn complications including prolonged hospitalization, poor nutrition, pain, and neuropathies. In addition, Nedelec et al[8] and Malenfant et al[37] reported that burn injury affects dermal tissue that contains sensory neurons. These neurons send conscious and automatic feedback, which controls balance and coordination.

The current study used the HiMAT to assess mobility level. Our findings of mobility problems in adults with severe burns are consistent with the literature.[12,15,23] In our study, the burn-injured participant displayed decreased mobility activities (42/54) relative to the nonburned group (51/54). Some tasks did not reach full functional capacity such as hopping, skipping, and running, walking on toes, walking backwards, and walking over an obstacle. These results agreed with findings of Grisbrook et al,[23] where the authors showed a significant decrease in the total HiMAT score in burned injury subjects vs a nonburned group.

Recently, Ebid and Elsden[16] found that ambulation speed differed markedly between burned subjects (mean = 2.80 seconds) compared with age-matched healthy subjects (mean = 4.30 seconds). Data from our previous study showed a significant decrease in walking speed on the treadmill in burn-injured participants (72.60 m/min) 6 m/min compared with age-matched health subjects (99.70 m/min) 7 m/min after 6-month post burn in the adult with TBSA ≥ 40%.[12,16] Despite these similarities between our results and the existing literature, the previous studies used other outcome measures for mobility assessment, such as walking speed and distance,[12,15] and three-dimensional motion analysis.[23] Only female participants (n = 9) were tested with variation in assessment time from 1 to 12 weeks following burn injury in the study conducted by Grisbrook et al.[25]

There was a lack of information in the literature regarding assessment of muscle function by an objective and reliable method. Furthermore, there were only a few trials that described mobility level following burn injuries, and no study described the effect of burn on balance. We thought our study results would share in documenting data in this field. Moreover, it has potential clinical importance in the field of burn rehabilitation because this information can evaluate and compare muscle function, balance, and mobility of burned patients to nonburned individuals. Moreover, it can help in planning a rehabilitation protocol.

Furthermore, we used two different strategies to control for possible confounding factors in this study: matching and logistic regression analysis. Controls were matched on age, sex, BMI, and physical activity. Thus, these variables should not be confounding factors. Furthermore, age ranged from 18 to 35 years in all groups. This is a relatively narrow range, and age-related differences regarding muscular strength, balance, and mobility outcome within this range are unlikely. This further suggests that age is unlikely to be a confounding factor. Sex distribution was matched between burned and nonburned subjects. However, sex distribution differed within the burned group (26 M/14 F). This may have influenced the comparison on the raw scores and total mean scores because the normative values are sex specific.

The current study had several limitations including the small sample size and local burn site recruitment. These limit generalization. Therefore, large sample size associate with multiple sites recruitments are recommended. Location of burn (eg, traversing the joint, near to joint or away from joint) may affect the results in a disproportionate manner. Therefore, additional studies are required to investigate all these factors. Normalizing data by lean body mass can facilitate data interpretation. However, in our study, mean values of PT were not corrected by lean body mass. Therefore, further study should use lean body mass of leg muscles as a correction factor for the observed values of PT and TW. However, the effects of lean body mass may be secondary to changes in neuromuscular efficiency, fiber recruitment, or intrinsic contractile characteristics of muscle. Normative values of undefined population were used as reference standards to compare our findings. However, these studies were from different countries, and involved participants of different ages, sex, and ethnicities. Discrepancies in assessment and follow-up times were reported between studies.[13,14,17–19,23,25,33]

CONCLUSION

Muscular strength, balance, and mobility are determinately affected by severe burn injuries. Because functional outcomes are the prime focus in burn rehabilitation, the current study used objective measures that provide a more detailed assessment of muscle strength, balance, and mobility in a severely burned adult population. Therefore, these results can guide therapists in creating rehabilitation programs that focus on the specific difficulties faced by each patient.

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