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Analysis of electromyographic changes in gastrocnemius muscle on exposure to 24 h of dry supine immersion

N Manu[1], A Agarwal[2], VK Malhotra[3]

[1]Resident in Aerospace Medicine, Institute of Aerospace Medicine IAF, Bengaluru, India, [2]Aerospace Medicine Specialist, Principal Medical Officer, Central Air Command IAF, Allahabad, India, [3]Physiologist, Institute of Aerospace Medicine IAF, Bengaluru, India.

***Corresponding author:**
Dr N Manu, MBBS,
Resident in Aerospace Medicine, Institute of Aerospace Medicine IAF, Bengaluru - 560017, Karnataka, India.

dr.manu.n@gmail.com

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ABSTRACT

Introduction: Under microgravity, changes are observed in both structure and content of the gravity-dependent muscles. This may result in disuse atrophy and muscle weakening. However, changes have not been described in the short term exposure of 24 h. Examination of changes in electromyographic activity of the gastrocnemius muscle, on exposure to 24 h of simulated microgravity using dry supine immersion (DSI), was the desired objective of the study.

Material and Methods: Ten healthy volunteers were exposed to 24 h of simulated microgravity using DSI. The force generated by maximal voluntary contraction of isometric plantar flexion of ankle was recorded. Electromyography (EMG) of the gastrocnemius corresponding to more than 80% of maximal voluntary isometric contraction (labeled as submaximal contraction) was recorded pre- and post-exposure to 24 h of DSI.

Results: Time domain analysis of the surface EMG of gastrocnemius during submaximal contraction revealed a significant increase in mean integrated EMG (iEMG) amplitude (effect size = 0.73, $P = 0.031$) following 24 h DSI. Power spectral analysis showed a significant decrease in mean frequency (MNF) ($P = 0.043$) and median frequency (MDF) ($P = 0.024$) after 24 h DSI. No significant changes were observed in total power, mean power (MNP), and maximal voluntary contraction. A very strong negative correlation was noted between iEMG, MNF, and MDF for the duration of submaximal voluntary contraction (R = −0.827 and −0.810, $P = 0.003$ and 0.004, respectively); whereas, a very strong positive correlation was noted between iEMG and MNP (R = 0.911, $P = 0.002$).

Conclusion: The findings of the study point toward muscle weakening seen by an early onset of muscle fatigue in anti-gravity muscles as early as 24 h of exposure to microgravity. The same may be borne in mind even during very short duration human space missions.

Keywords: Dry supine immersion, Electromyography, Submaximal contraction, Time domain analysis, Power spectral analysis

INTRODUCTION

Despite six decades of human spaceflight, physiological changes due to microgravity are still not fully understood, especially those happening in a very short time of exposure. Various studies have shown skeletal muscle atrophy and loss of strength as known consequences of space flight along with alterations in bone integrity and calcium homeostasis. The changes in muscle structure may result in loss of muscle power and early fatigue. Usually, muscle fatigue is a result of prolonged or repetitive contractions of the muscle.[1] Detection of early muscle fatigue with submaximal contraction can be used as an indicator of loss of muscle power. Thus, demonstration of early fatigue of muscles after ground-based analogs of microgravity would indicate early changes. Muscle activity and fatigue can be assessed using a number of techniques, namely, acoustic myography, mechano-myography, near-infrared spectroscopy, sono-myography, and ultrasound. The surface electromyography (EMG) is a non-invasive technique for assessing fatigue of a particular muscle. These provide real-time muscle fatigue monitoring during the performance of a defined task.[2]

It is generally believed that discernible bone and muscle loss do not take place on exposure to microgravity for less than a week. We hypothesize that such changes have to develop gradually and the first such instance could be earlier than the heretofore believed 1 week. Understanding this timeline is important, both for a better understanding of the effects of microgravity, and also to institute timely countermeasures. A comparative analysis of electromyographic changes in gastrocnemius muscle following 24 h exposure to simulated microgravity with dry supine immersion (DSI) was used to achieve this objective.

MATERIAL AND METHODS

Subjects

Ten healthy male volunteers with age of 27.1 ± 4.7 years, height of 171.9 ± 7.2 cm, weight of 67.6 ± 11.2 kg, and BMI of 22.84 ± 3.23 kg/m^2 participated in the study conducted at the Department of Space and Environmental Physiology, Institute of Aerospace Medicine, Bengaluru, India.

Materials

DSI tanks

The DSI tanks with a capacity of 1000 L of water were used to simulate weightlessness. The participants floated separated by a thin sheet of plastic [Figure 1a]. The tanks receive preheated water which circulates in a closed loop circulation system to maintain an isothermal water temperature of 34 ± 0.5°C. The water is heated using solar heaters and electric boiler. A tube-type heat exchanger has been integrated to ensure safety and to avoid any electrical interference with collection electromyographic data. The temperature is regulated using a central control unit [Figure 1b]. Figure 2 shows the line diagram of temperature regulation mechanism for the DSI.

Figure 1: (a) Dry supine immersion tanks. (b) Central control unit.

Bionomadix 2Ch wireless EMG amplifier module

Bionomadix 2Ch wireless EMG amplifier module was used for recording EMG. It consists of a matched transmitter and receiver module configured with physiological recording module MP-160. The EMG was recorded at a sampling rate of 2000 Hz band limited from 5 Hz to 500Hz. The software is designed to have a high signal-to-noise ratio. The acquired raw data were analyzed using AcqKnowledge 5.0 software.

Load cell with display

This was used to measure the force generated by maximal voluntary contraction. It is a type of transducer which converts force presented in the form of tension, compression pressure, or torque into electrical signals. Out of the various types of load cells available, we used a S-type load cell along with display.

Experimental protocol

All participants were examined thoroughly and ensured that they were free of any kind of physiological, physical, and psychological pathologies. The protocol was explained to all participants. An informed consent from each participant was taken and Institute Ethics Committee clearance was obtained. Each participant was familiarized with the equipment for their understanding and alleviating apprehensions, if any. A trial exposure to dry floatation for 60 min, and the method to exert maximal voluntary contraction was undertaken for each participant.

The experimentation commenced at 0530 h on the day of study. All participants donned plain cotton clothing and a 5-point harness. EMG electrodes were placed on locations as per Surface Electromyography for Non-Invasive Assessment of Muscles guidelines on the muscle of interest, which was the gastrocnemius muscle in our study. A non-expandable sling was worn around the foot. The S-type load cell was placed between the non-expandable sling and the 5-point harness [Figure 3]. The non-extendable sling ensured maintenance of joint angle while generating force by plantar flexion, thus ensuring maximal voluntary isometric contraction.

Force generated by maximal voluntary contraction was checked before commencement of DSI. A total of three consecutive recordings were made by plantar flexing the foot with a gap of 2 min. The participants were advised to generate maximal force as attempted during the first two attempts and to hold the maximal voluntary contraction.

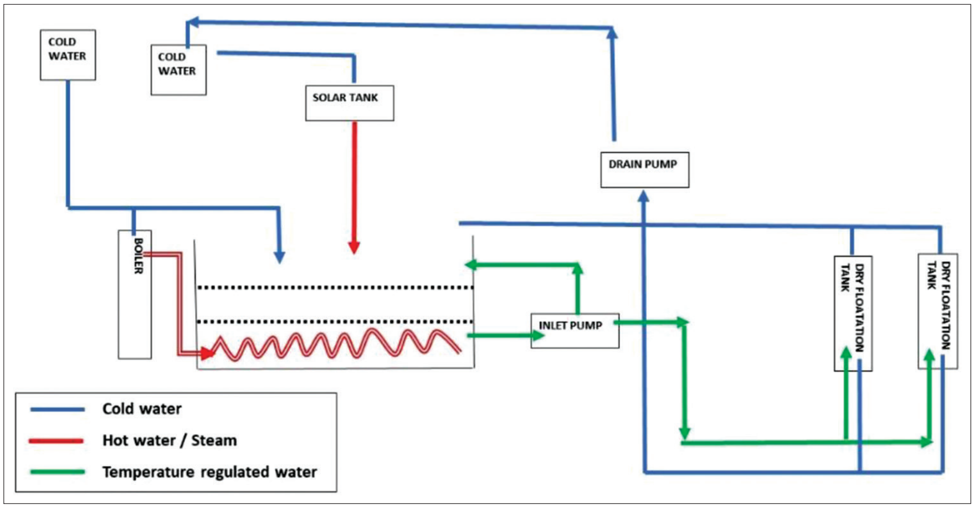

Figure 2: Line diagram of temperature regulation mechanism.

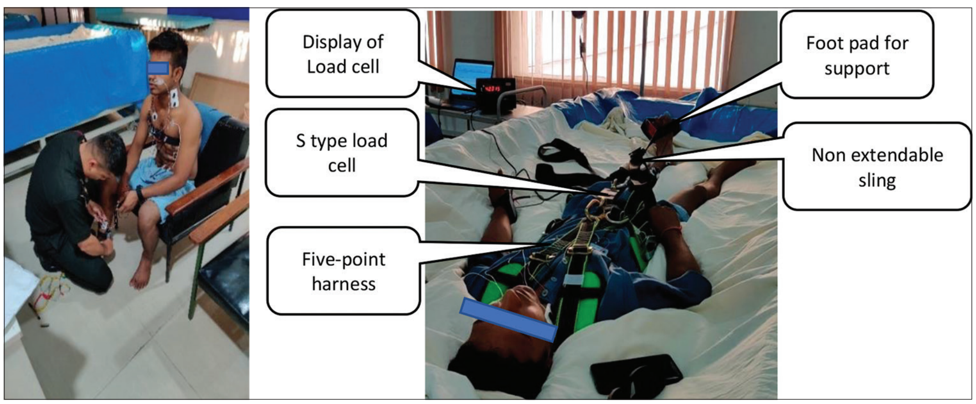

Figure 3: Fixation of electrodes and load cell.

EMG was recorded during the last attempt of maximal voluntary contraction. The whole process was recorded using a video camera. After collection of initial baseline values, the participants were lifted and manually placed in pre-filled DSI tanks. The subjects continued to stay in the tank for 24 h without any break in between [Figure 4]. They were provided with standardized diet plan constituting a total calorie intake of 2378 Cal/day consisting of 76 g of proteins, 79 g of fat, 337 g of carbohydrate, and 42 g of fibers. Hydration was maintained by water based on demands of the participants. A urine pot was provided on the tank for urination. After completion of 24 h, the subjects were taken out the tank, placed on the stretcher and the EMG during generation of maximal voluntary contraction was recorded.

Raw data extraction and analysis

Data pertaining to EMG of the gastrocnemius corresponding to the epoch of more than 80% of maximal voluntary isometric contraction (labeled as submaximal contraction) was extracted and compared. A power spectral analysis was done to deduce the mean frequency (MNF), median frequency (MDF), mean power (MNP), and total power. An integrated EMG (iEMG) for the total epoch duration of submaximal voluntary contraction was calculated. Paired Student's *t*-test was applied with an alpha of <0.05. Correlation between factors was analyzed using the Pearson's correlation technique.

RESULTS

There was no significant difference in the force generated during the MVC following 24 h exposure to DSI as compared to baseline values. The details of important findings are summarized and given in Table 1.

iEMG

Time domain analysis of the surface EMG of gastrocnemius recorded during submaximal contraction of greater than 80% of MVC by integration showed a mean iEMG amplitude of

94.89 ± 32.5 microVolt (µV) before exposure to DSI and 161.01 ± 118.54 µV following 24 h exposure to DSI. This increase in iEMG amplitude was statistically significant with an effect size of 0.73 and the t-stat being lesser than the t-crit with $p = 0.0313$. However, it was observed that the variance of the post-exposure data was higher compared to the pre-test values.

MNF

Power spectral analysis of the surface EMG of gastrocnemius recorded during submaximal contraction of >80% of MVC showed an average MNF of 255.28 ± 33.74 Hz before exposure to DSI and 230.01 ± 42.26 Hz after 24 h exposure. This reduction was statistically significant with an effect size of −0.60 and the t-stat being greater than the t-crit with $p = 0.043$.

MDF

The MDF also showed a reduction from an average value of 145.26 ± 34.524 Hz before exposure to 106.89 ± 38.04 Hz post-24 h DSI exposure during submaximal contraction of gastrocnemius. This reduction was also statistically significant with an effect size of −0.94 and the t-stat being greater than the t-crit with $p = 0.024$.

Total power and MNP

There was no statistically significant difference in these variables between pre and post-exposure to 24 h DSI.

Pearson's correlation was conducted on the percentage change of the variables pre and post-exposure to 24 h DSI which showed the R values as depicted in Table 2. A very strong negative correlation was noted between iEMG and mean frequencies (MNF and MDF) for the duration of submaximal voluntary contraction (R = −0.827 and −0.810, $p = 0.003$ and 0.004). A very strong positive correlation was noted between iEMG and MNP (R = 0.911, $p = 0.002$).

DISCUSSION

The research was undertaken with 10 healthy volunteers who were subjected to 24 h of DSI to simulate microgravity and study electromyographic changes in gastrocnemius muscle. EMG analysis of the duration of submaximal voluntary contraction showed a leftward shift (decrease) of the mean and MDF and an increase in the iEMG values.

The iEMG increased significantly with an average increase of the amplitude by 21.12 µV during submaximal voluntary contraction. An increase in iEMG in fatigue situations has been noted by by Edwards and Lippold (1956), Lippold *et al.* (1960), Currier (1969), De Vries (1968), Kuroda *et al.* (1970), and Rau and Vredenbregt (1970).[3-8] On the other hand, in this case, there is no exertion other than the submaximal contraction at the end of the experiment. There is thus no reason for fatigue to have occurred. The only possible explanation for this observation is that the muscle power had reduced and that it got fatigued in trying to maintain submaximal contraction. In their endeavor to maintain contraction, the individual's active fibers exert less force progressively. To compensate for this, new motor units are recruited and the active motor units fire with an increased amplitude. Hence, the increase in iEMG amplitude of gastrocnemius, a major antigravity muscle, is considered an important finding indicating possibility of early onset fatigue that could happen even in short duration microgravity exposure.

Figure 4: Complete experimental setup.

Table 1: t-test results of iEMG, MNF, MDF, total power, and MNP following 24 h exposure to DSI.

Variable	Pre-24 h DSI	Post-24 h DSI	t-stat	t-critical	*p*-value
iEMG	94.89± 32.53	161.01± 118.54	−2.122	1.833	0.031*
MNF	255.27± 33.74	230.01± 42.26	1.925	1.833	0.043*
MDF	145.26± 34.52	106.89± 38.04	2.287	1.833	0.023*
Total power	3.73E-05± 2.61E-05	1.69E-04± 3.26E-04	−1.331	1.833	0.107
MNP	9.57E-09± 6.01E-09	7.93E-08± 1.61E-07	−1.398	1.833	0.097

iEMG: Integrated electromyography, MNF: Mean frequency, MDF: Median frequency, MNP: Mean power, DSI: Dry supine immersion, *: $p < 0.05$

Table 2: Pearson's correlation study.

	MVC	iEMG-G	MNF-G	MDF-G	MNP-G
MVC	1	−0.595	0.545	0.364	−0.601
iEMG-G		1	−0.827	−0.810	0.911
MNF-G			1	0.563	−0.770
MDF-G				1	−0.704
MNP-G					1

iEMG: Integrated electromyography, MNF: Mean frequency, MDF: Median frequency, MNP: Mean power, DSI: Dry supine immersion

A frequency power spectral analysis performed to deduce the MNF, MDF, total power, and MNP, showed a reduction in MNF and MDF by an average value of 25 Hz and 38.37 Hz, respectively, and these changes were found to be statistically significant. In the assessment of surface EMG, MNF and MDF have been taken as important indicators of muscle fatigue which result in a downward shift of the frequency spectrum of the EMG signal.[9] During the process of fatigue of muscle, several changes have been reported in various studies such as decrease in signal power at high frequency, increase in signal power at low frequency, an increase in spectrum slope at high frequency, and a decrease in spectrum slope at low frequency.[2,10,11] These changes in the EMG signal may be due to the modulation of recruitment firing rate, the grouping and slowing of synchronization of the signal.[11-13] In static contraction, the EMG signals may be assumed to be stationary during short time intervals (0.5–2 s), therefore, the changes in MNF and MDF are considered important findings to detect muscle fatigue in static contractions.[14]

Conjecturally, the above effects may be due to muscle atrophy due to microgravity. Atrophy is expected to be greater in postural muscles, as compared to the non-postural muscles. Studies have shown that astronauts lose 10–20% of their muscle mass on short missions.[15] However, the present study exposed the subjects to only 24 h of simulated microgravity conditions wherein, atrophy has, so far, not been described. Hence, the results of the study carry substantial practical relevance and point toward changes in anti-gravity muscles with as little as 24 h exposure to microgravity.

CONCLUSION

Several conclusions can be drawn from the study: (a) Exposure to even 24 h duration microgravity conditions can result in demonstrable changes in anti-gravity muscles. (b) The electromyographic changes indicative of fatigue can only be explained by muscle weakening, consequent to DSI. (c) In the extensive literature review conducted, this was the first study showing a definitive indication of muscle changes in as little as 24 h of exposure to DSI. (d) These effects of gravity off-loading and possible muscle atrophy in major anti-gravity muscles may be borne in mind even in very short duration human space missions.

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Declaration of patient consent

The authors certify that they have obtained all appropriate consent from the participants.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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