Medico Research Chronicles

ISSN No. 2394-3971

Original Research Article

# EFFECT OF SEASON ON CONTRACTILE PROPERTIES OF IMMOBILIZED GASTROCNEMIUS MUSCLES OF UROMASTIX HARDWICK-II.

**Syed Najamuddin Farooq*[1], Muhammad Abdul Azeem[2], Abdul Halim Serafi[1], Ammad Ahmed[3], Shaikh Muhammad amir Mustafa[1], Muhammad Irfan Safi Rizvi.[1]**

[1]*Department of Physiology, faculty of Medicine, Umm-Al Qura University, Makkah, Kingdom of Saudi Arabia.*

[2]*Department of Physiology United Medical College, Karachi-Pakistan.*

[3]*Department of Immunology, Faculty of Medicine, Umm-Al Qura University Makkah, Kingdom of Saudi Arabia*

Submitted on: February 2015
Accepted on: February 2015
For Correspondence
Email ID:
najamuddin7@hotmail.com

## Abstract

Many workers had reported seasonal changes in the biological activity of various classes of animals including reptile Uromastix hardwickii. However, the effect of season on tension generation ability of immobilized reptilian skeletal muscles is not available in the literature. In this study we observe the response of Imb. Gastrocnemius (Gas) muscle of Uromastix hardwickii to the seasonal changes in terms of its mechanical characteristics and tension generation ability were obtained from control and Immobilized. Gastrocnemius muscles demonstrated significant rise in both twitch and tetanic tensions from winter (Dec) to peak summer (Jun) which then fall significantly till the second winter (Dec). Both control and Immobilized muscles represented a rise in their average values of %P°/mS from winter (Dec) to peak summer (Jun) and a fall again till next winter but statistically this change was found significant only in Immobilized muscles. Whereas, significant reduction in twitch peak duration was demonstrated by both control and Immobilized muscles from winter (Jan) to peak summer (Jun). However, values of twitch peak duration demonstrated a rise again as the season advances towards hot and dry month of October. Statistically this rise was found significant only in control muscles. Our study indicates that, Uromastix is capable of resisting immobilization (IMB) induced effects by the help of seasonal changes in the environmental temperature during summer but during winter it remained under the influence of plaster cast Immobilization as well as season (hibernation) that results in greater reduction in its tension generation ability.

**Keywords**: **Immobilization, Uromastix, Skeletal muscles, Season, isometric tension parameters.**

## Introduction

Effects of season on the different biological activities among various classes of animals have been reported extensively. However, there is scarcity of literature regarding seasonal effects on the physiological and biochemical changes related to skeletal muscle mechanics in general and in particular to the immobilized (Imb) skeletal muscles. Significant changes in the contractile properties of skeletal muscles of Uromastix hardwickii after 20 days of plaster cast Immobilization (IMB) have been reported (1). Anatomical and contractile characteristics of Sartorius (Sar) and Gastrocnemius (Gas) muscles of Uromastix have also been established(2).In another study on Gas muscles of Uromastix (3) a significant rise in the twitch and titanic tensions from winter to summer was observed. Later, the seasonal dependency of skeletal muscles of Uromastix hardwickii has been confirmed(4) when they studied the morphometric and contractile properties of Sar and Gas muscles during winter and spring months of the seasonal cycle. Recently, soomro et al (5) working on the skeletal muscles of reptile Uromastix reported a significant rise in the average values of threshold potential, after potential and in its duration during summer compared to winter. Some studies are also available demonstrating seasonal effects in various activities of Uromastix like, variation in the testes size, changes in the body weight, changes in the plasma and muscle electrolyte concentration and changes in the lipids of adipose tissue (6-9). However, an important aspect, which is not given much consideration, is the effect of season (temperature and environmental changes) or hibernation (dormancy) on the muscle disuse atrophy of skeletal muscles. In this regard of the available literature, majority investigated the mammalian skeletal muscles and ignored the other classes of animals like amphibians and reptiles. Considering these Beth et al., studied the effect of 9 months aestivation on the muscle morphology, fiber morphology and isometric properties of Sar and Ileofibularis muscles of the Frog Cyclorana albaguttata (10). Earlier (11) reported a decline in the metabolic and locomotor activity of the regular hibernators because of season-associated changes in the environmental temperature and available resources. Further it has been proposed by (12, 13) that during hibernation the animal relies for its energy needs primarily on the stored lipids with proteins fulfilling the additional energy demands. As such it has been proposed that the hibernation-associated atrophy of the skeletal muscles is because of catabolism of muscle protein as an energy substrate (14,15,16) and down regulation of protein synthesis during this period (17,18,13). The lizards have a special ecological diversity along with the quality that repeatable measurements of sustained activities alter their various properties within a very negligible range. The reptile Uromastix hardwickii is a winter hibernator that maintains maximum contractile activity of its muscles even above 40C. It also showed hibernation-associated changes in the physiology and biochemistry of its organism. In addition this animal has an specific property of resisting IMB induced morphometric changes in its skeletal muscles as reported by(1). He observed no significant change in the morphometric parameters of any of his experimental muscles after 20 days of plaster cast IMB except stretched and flexed lengths in Gas muscles. As such this animal provides a fascinating model to study the effects of season and temperature changes on the muscle mechanics. However, this lizard is among one of those animals that has been studied scarcely for the season and environmental temperature effects particularly with reference to the contractile behavior of its skeletal muscles during different parts of the seasonal cycle under normal conditions in general and Imb conditions in particular. Present study was therefore designed to investigate the effects of season and environmental temperature changes on contractile properties of the skeletal muscles, that whether the season and temperature associated changes in the physiology and biochemistry of this animal is able to resist the 20 days plaster cast IMB induced changes in the muscle activity or not and also to study the extent of effects produced by the seasonal and environmental temperature changes on the control and Immobilized muscles is same or different.

**Materials and Methods**

Fresh animals of both the sexes weighing 250-500 gms were used in all experiments within a week as, change in the season (temperature) is reported to alter their activity(3). In the laboratory, animals were kept at room temperature (25C).Experiments were performed during different parts of the seasonal cycle from Dec. to Dec. According to the standards of International Animal ethics Committee 1ml 2% Xylocaine was injected in the Gluteal muscles prior to the application of plaster cast to the left hind limb(1). In- order to immobilize the Gas muscle in stretched position cast was applied from hip joint till phalanges keeping the knee in stretched and ankle in flexed position. Right hind limb was used as control(1). At the end of 20 days of IMB both the Imb & Cont muscles were isolated and kept in reptilian buffer solution (25C). Isometric twitch and tetanus were then recorded on oscillograph (Harvard apparatus, U.K.) from both Imb & Contr muscles. Later, these records were used for the measurement of isometric tensions, rate of rise of tension in tetanus as percent of maximum tetanic tension (%P°/mS) and twitch peak duration (4).

**Results**

**Isometric Tensions**

Average values of isometric twitch and titanic tensions obtained from the Cont and Imb Gas muscles showed minimum values during the peak winter month of December(Dec) Fig.1 &2. However, as the season advances towards the late winter month of January (Jan), spring month of February (Feb) and early summer month of March (Mar) both the Cont and Imb Gas muscles demonstrated a gradual rise in their average values of twitch and tetanus reaching to the maximum during the peak summer month of June (Jun) Fig.1&2. Statistical comparison of the average values of isometric tension parameters obtained from the Cont and Imb Gas muscles between winter Dec and summer Jun has demonstrated highly significant.

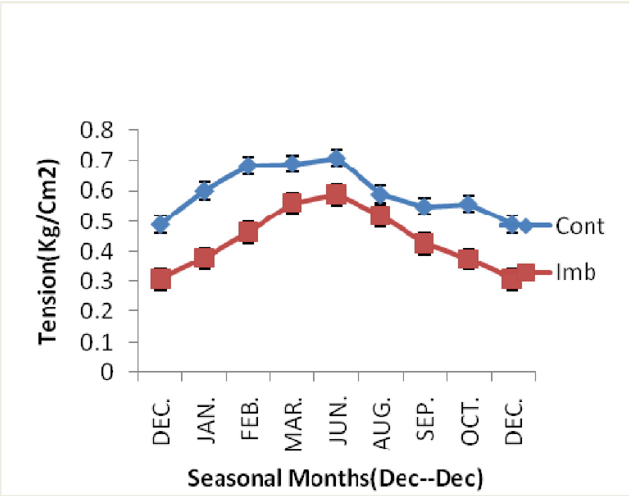


**Figure 1: Effect of season on Isometric twitch Tensions obtained from 20days Immobilized& Control gastrocnemius muscles of Uromastix hardwickii**

(P<0.0005) difference being 31 and 38% for the twitch and 37 and 40% for the tetanus in Cont and Imb muscles respectively Fig.1 & 2. Later with the arrival of late summer August (Aug), hot and humid September (Sept) and hot and dry October (Oct) a gradual and statistically highly significant (P<0.0005) fall was observed in the average values of twitch and tetanus in both the Cont and Imb muscles being 34 (Cont) and 52% (Imb) for twitch and 28 (Cont) and 27% (Imb) for tetanus respectively. Fig. 1 & 2.

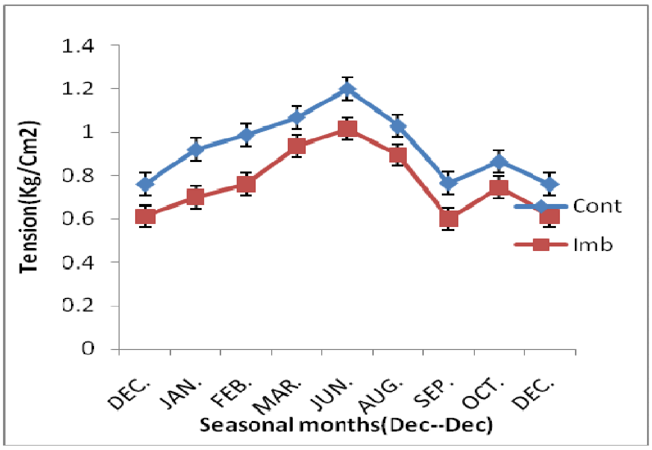


**Figure 2:Effect of season on Isometric tetanic tension obtained from 20days immobilized 7 Control gastrocnemius muscles of uromastix hardwickii**

%P°/mSec.: The average values of %P°/mSec. obtained from the Cont and Imb Gas muscles are presented in the Fig.3. The Cont Gas muscles demonstrated a highly significant (P<0.0005) fall of 22% from winter Dec to the spring month of Feb (Fig.3). However, with arrival of early summer March this parameter showed a rise reaching to its maximum value during peak summer Jun. However, these average values of %P°/mSec. obtained from winter Dec and summer Jun when compared statistically showed a non-significant (P>0.05) difference being 23% higher in the month of Jun (Fig.3).

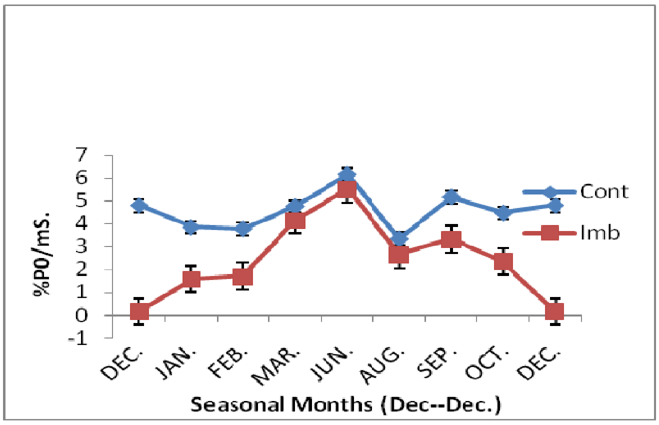


**Figure 3: Effect of season on rate of rise of tension in tetanus as percent of maximum tetanic tension (%P0/mS) obtained from 20days Immobilized & Control Gastrocnemius muscles of Uromastix hardwickii.**

During this part of the seasonal cycle the Imb muscles on the other hand showed a gradual rise of 97% in their average values of %P°/mSec. Which is statistically found to be highly significant (P<0.0005) when compared between winter Dec and summer jun (Fig.3). With further advancement of season towards the hot and dry month of Oct both the Cont and Imb Gas muscles showed a reduction of 28 and 58% respectively in their average values of %P°/mSec. However, statistically this difference in the average values of %P°/mSec. Between summer Jun and hot and dry Oct was found significant (P<0.005) only in the Imb muscles (Fig.3).

**Twitch Peak Duration (TPD)**

The average values of TPD obtained from the Cont and Imb Gas muscles (Fig.4) demonstrated significant (P<0.05) and (P<0.005) rise of 10 and 15% respectively when compared between peak winter Dec and late winter Jan (Fig.4). Later with the arrival of spring and early summer both the Cont and Imb Gas muscles showed a fall in their average values of TPD reaching to their minimum level during peak summer Jun (Fig.4). Statistically this fall in TPD between late winter Jan and summer Jun was found to be highly significant (P<0.0005) being 46 and 42% in the Cont and Imb Gas muscles respectively (Fig.4). With further advancement of season towards the hot and dry period of Oct both Cont and Imb Gas muscles showed a rise of 57 and 11% respectively in their average values of TPD. However, statistically this difference between summer Jun and hot and dry Oct was found highly significant (P<0.0005) only in the Cont Gas muscles (Fig.4).

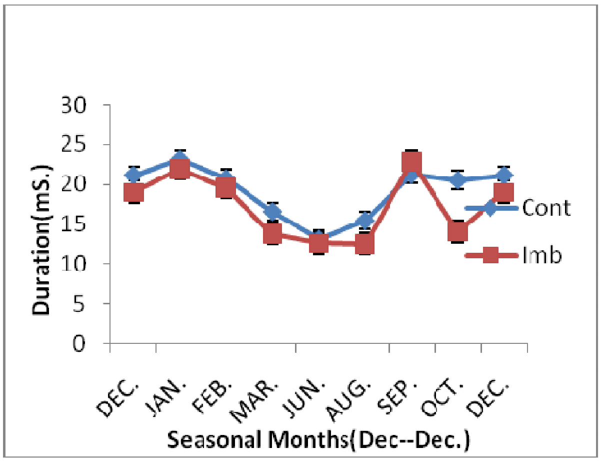


**Figure 4: Effect of season on Twitch Peak Duration obtained from 20days Immobilized & Control Gastrocnemius muscles of Uromastix hardwickii.**

**Discussion**

The reptile Uromastix hardwickii is a winter hibernator that shows maximum activity during summer and becomes slow and sluggish during winter(19). The body temperature, metabolic and neuroendocrine activity of this animal have been reported to be at their maximum during summer(20). Uromastix also represent variations in the contractile properties of their skeletal muscles with the change of season as reported by(3). They observed a significant rise in the twitch and tetanic tensions obtained from Gas muscles from winter to summer. In present study our Cont and Imb. Gas muscles also showed minimum values of twitch and tetanic tensions during

winter(Dec.)and maximum values during summer (June) Fig.1 &2.
However, the purpose of this study was not only to investigate the season associated changes in the contractile properties of Cont. and Imb. muscles but also to highlight and confirm that, this animal is capable of resisting plastercast IMB induced effects on the contractile properties of its skeletal muscles with the help of season associated changes in the physiology and biochemistry of its organism. As such we analyzed the effects of IMB as percent(%) of control for all parameters and present them in table 1 and Fig.5,7,8.

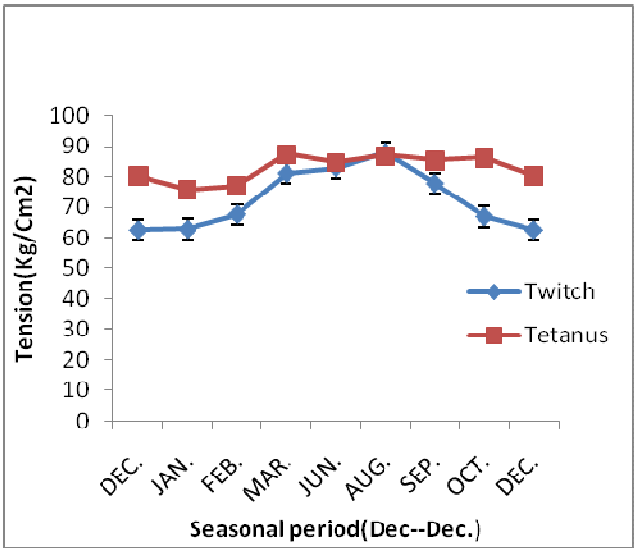


**Figure 5: Isometric Twitch & tetanic tensions Immobilized % control obtained from Gastrocnemius muscles (Imb.) of Uromastix hardwickii**

The effects of IMB as % of Cont. for isometric twitch and tetanic tensions presented in Fig. 5 showed stronger effect of season on tension generation ability of our Imb. muscles during winter period of Dec., Jan., Feb. and hot and dry month of Oct. compared to the summer month of Mar., Jun. and Aug. with particular reference to twitch tension (Fig.1).
In our opinion this reduction in the tension generation ability of Immobilized muscles during winter is the result of reinforcement to the IMB induced changes by the depressed metabolic activity (19), depressed ionic contents and their fluxes (4), decreased enzymatic activity (22) and decreased environmental temperature that is found during this part of the seasonal cycle. However, an increase in the metabolic and enzymatic activity(23,24) with the arrival of summer helps the animal to resist the IMB induced effects on its muscles and as such the difference in the tension generation ability of Cont. & Imb. muscles get reduced compared to winter (Fig.1-2). However, greater reduction in the tension generation ability of Imb muscles during hot and dry period of Oct. can be explained on the basis of decreased utilization of energy by the Uromastix during this period because according to (25) during this part of the seasonal cycle Uromastix prepare itself for the hibernation by building energy reserves in terms of increased fat deposition. Also

during this period Uromastix reduces its overall activity in general and of its skeletal muscles in particular by restricting locomotion.

**Table 1**

Average and Immobilization percent control values of Isometric twitch and tetanic tensions, %P°/mS and Twitch Peak Duration obtained from control and 20 days immobilized Gastrocnemius muscles during different periods of seasonal cycle. Values are given as Mean ± S.E.M. Figures in parentheses represent the number of muscles used.

| Seas. period | Twitch Tensions | | | Tetanic Tensions | | | %P°/mS | | | Twitch Peak Duration | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | Immob | Imb.% Cont. | Control | Immob | Imb. %Control | Control | Immb. | Imb.% Cont. | Control | Immob. | Imb.% Cont. |
| December | 0.49± 0.024 (11) | 0.307± 0.022 (11) | 62.653 | 0.761± 0.042 (11) | 0.612± 0.044 (11) | 80.42 | 4.792± 0.24 (11) | 0.157± 0.070 (11) | 3.276 | 21.183± 0.81 (8) | 19.073± 0.74 (8) | 3.276 |
| January | 0.601± 0.033 (12) | 0.378± 0.022 (12) | 62.895 | 0.92± 0.052 (12) | 0.698± 0.032 (12) | 75.87 | 3.846± 0.12 (12) | 1.583± 0.164 (12) | 41.16 | 23.19± 0.74 (7) | 21.974± 0.46 (7) | 41.16 |
| Feberuary | 0.685± 0.021 (11) | 0.464± 0.021 (11) | 67.737 | 0.987± 0.033 (11) | 0.762± 0.036 (11) | 77.204 | 3.78± 0.12 (12) | 1.706± 0.215 (12) | 45.132 | 20.756± 0.52 (11) | 19.593± 0.93 (9) | 45.132 |
| March | 0.691± 0.022 (10) | 0.56± 0.029 (10) | 81.041 | 1.069± 0.045 (10) | 0.935± 0.079 (10) | 87.465 | 4.751± 0.36 (10) | 4.155± 0.87 (10) | 87.455 | 16.62± 0.73 (10) | 13.8± 1.06 (8) | 87.455 |
| June | 0.71± 0.033 (13) | 0.588± 0.029 (13) | 82.816 | 1.2± 0.070 (13) | 1.017± 0.057 (13) | 84.75 | 6.15± 0.89 (13) | 5.519± 0.88 (13) | 89.74 | 13.116± 0.62 (11) | 12.606± 0.61 (13) | 89.74 |
| August | 0.589± 0.034 (7) | 0.518± 0.057 (7) | 87.945 | 1.028± 0.057 (7) | 0.895± 0.105 (7) | 87.062 | 3.336± 0.74 (5) | 2.657± 0.57 (6) | 79.646 | 15.48± 1.00 (5) | 12.51± 0.72 (4) | 79.646 |
| September | 0.549± 0.043 (4) | 0.427± 0.056 (4) | 77.777 | 0.766± 0.077 (4) | 0.599± 0.081 (4) | 85.426 | 5.164± 0.58 (4) | 3.32±1.05 (4) | 64.291 | 21.287± 3.33 (3) | 22.927± 1.67 (3) | 64.291 |
| October | 0.558± 0.048 (8) | 0.374± 0.035 (8) | 67.025 | 0.864± 0.060 (8) | 0.745± 0.054 (8) | 86.227 | 4.466± 0.162 (8) | 2.349± 0.35 (8) | 52.597 | 20.558± 1.49 (8) | 14.073± 1.73 (8) | 52.597 |
| December | 0.49± 0.024 (11) | 0.307± 0.022 (11) | 62.653 | 0.761± 0.042 (11) | 0.612± 0.044 (11) | 80.42 | 4.792± 0.24 (11) | 0.157± 0.070 (11) | 3.276 | 21.183± 0.81 (8) | 19.073± 0.74 (8) | 3.276 |

Another possibility that helps this animal to resist the effect of IMB on its muscles during summer is its way of movement during different parts of the seasonal cycle. According to Azeem (4) this animal moves by crawling during winter and walking during summer. He also proposed that, Gas is not actively involved in crawling but is included in more active muscles during summer, helping the animal to raise the body above the hot desert sand while standing and moving above the ground.

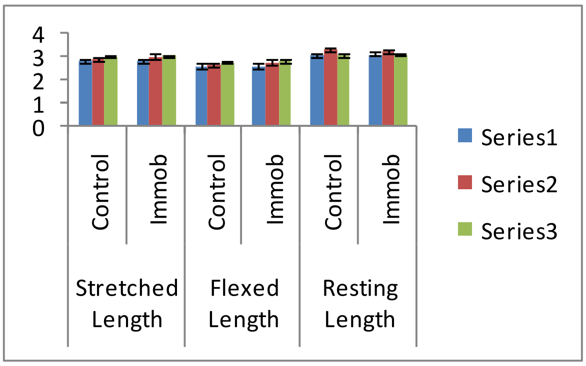


**Figure 6**

As such this muscle is able to attain the required resting length to generate maximum force during summer while fails to attain it during winter. This possibility is also supported by our results of stretched, flexed and resting lengths (Fig.6,tab.2).that shows significantly higher values of these parameters during summer Jun. compared to winter month of Jan. Further it is to be noted that, our Gas muscles inspite of significantly higher values of muscle weight during winter(tab.2) develops lesser isometric tensions compared to summer. This suggests that, for Gas muscle instead of muscle weight, muscle length played a dominant role for tension generation.

**Table 2**

Average values of muscle weight,stretched,flexed and resting length obtained from control and 20days immobilized Gastrocnemius muscle during winter month of January, summer month of june and hot and dry month of October.Values are given as Mean ± S.E.M. Figures in parentheses represent the number of muscles used.

| Seas.Period | muscle weight | | Stretched Length | | Flexed Length | | Resting Length | |
|---|---|---|---|---|---|---|---|---|
| | Control | Immob | Control | Immob | Control | Immob | Control | Immob |
| January | 1023.88±41.22 (11) | 1000.16±44.46 (11) | 2.83±0.05 (11) | 2.84±0.05 (11) | 2.61±0.05 (11) | 2.61±0.05 (11) | 3.08±0.05 (11) | 3.17±0.05 (11) |
| June | 848.74±47.49 (16) | 827.07±47.12 (16) | 2.90±0.04 (16) | 3.02±0.04 (16) | 2.67±0.04 (16) | 2.78±0.03 (16) | 3.30±0.04 (16) | 3.25±0.04 (16) |
| October | 1074.25±0.58 (8) | 996.80±25.63 (8) | 3.01±0.04 (8) | 3.05±0.03 (8) | 2.79±0.05 (8) | 2.83±0.03 (8) | 3.071±0.03 (8) | 3.10±0.06 (8) |

However, our results of effect of IMB as percent of control for tetanic tension demonstrated more or less same difference during winter and summer seasons representing a weaker effect of season as compared to twitch tensions. This difference may be because of the activation of greater number of muscle fibers as a result of tetanic stimulation even in the Imb state thus leading to greater generation of tetanic tension. Earlier this kind of recruitment at lower temperatures has been demonstrated by (26) in frog muscles. Faulkner et al (27) also reported motor unit recruitment in mammalian skeletal muscles during winter as a compensatory mechanism to increase muscle force. It is to be noted that, during winter our experimental muscles are under the influence of two types of IMB an experimental plaster cast and the other season (hibernation) induced IMB. It is therefore possible that during winter single twitch stimulation may get failed to activate the contractile component effectively against the non-contractile component leading to lesser rise in tension while recruitment of the muscle fibers during tetanic stimulation produces an effective action against the non-contractile component thus leading to higher generation of tension.

It is interesting to note that, our experimental muscles demonstrated significantly lesser tensions during winter in spite of significantly higher values of TPD (Fig.4). This suggests that during this part of the seasonal cycle the ionic fluxes through sarcolemma and enzymes involved for cross bridge interaction were decreased to such an extent in our experimental muscles that even higher values of TPD were unable to increase the significantly reduced tensions (4). Decreased tension generation by our experimental muscles in presence of higher values of TPD during winter may also be the result of slow rate of cross bridge cycling for interaction between actin and myosin filaments in these muscles. Further this slow rate of cross bridge cycling may be the result of decreased myosin ATPase activity in these muscles during winter.

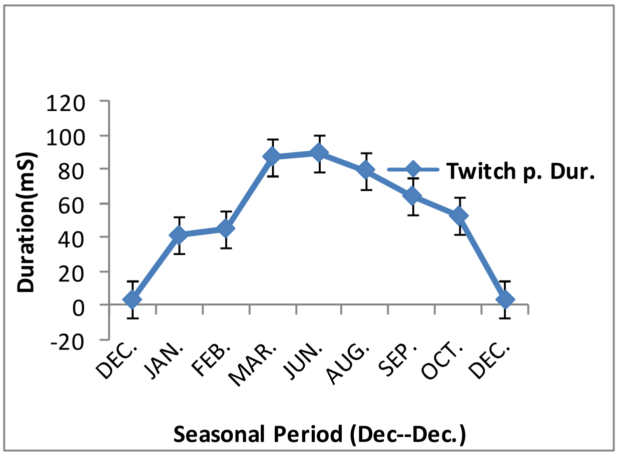


**Figure 7: Immobilized % Control values of Twitch Peak Duration obtained from Gastrocnemius muscles (Imb.) of Uromastix hardwickii**

Takekura et al. (28) demonstrated an increase in myosin ATPase activity on administration of testosterone and Uromastix are found to have decreased plasma testosterone level during winter as reported by Aliya (29).We are of the opinion that, reduced plasma testosterone level during winter in our experimental animal may also be responsible for reduced myosin ATPase activity leading to slow rate of cross bridge cycling, long TPD but reduced tension generation by our experimental muscles. This slow cross bridge cycling for actin myosin interaction during winter also leads to reduced values of %P°/mS. As shown by our experimental muscles during winter.

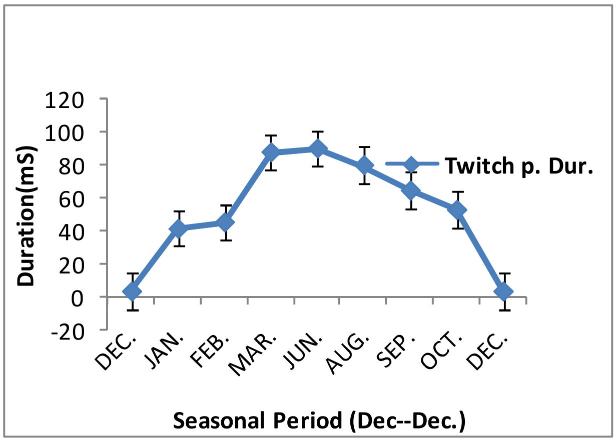


**Figure 8: Immobilized % Control values of Twitch Peak Duration obtained from Gastrocnemius muscles (Imb.) of Uromastix hardwickii**

Another possible factor responsible to produce greater reduction in the values of %P°/mS. During winter is a probable reduction in the level of organic and inorganic phosphates in our experimental muscles during winter and organic and inorganic phosphates play very important role in energy transfer in enzyme system(30).

Witzmann et. al., (31) attributed decreased values of rate of rise of tension in Imb. Soleus muscles of rat to be associated with IMB induced depressed functional capacity of sarcoplasmic reticular vesicles. We are also of the opinion that, in our experimental muscles low environmental temperature during this part of the seasonal cycle also depresses the sarcoplasmic reticular activity leading to a reduction in the rate of rise in tension. Our opinion is also supported by the significantly higher values of TPD shown by our experimental muscles during this part of the seasonal cycle indicating slow release and slow uptake of calcium by the depressed sarcoplasmic reticular vesicles.

In view of our experimental results we are of the opinion that, during winter our experimental muscles remained influenced by two different types of IMB, an experimental through plaster casting and superimposed on it was the seasonal (hibernation) induced IMB with an overall depression of the metabolic and neuroendocrine activities of the animal leading to greater reduction in all parameters during winter. However, with advancement of season towards summer an increase in the environmental temperature takes the overall activity of animal to its maximum that helps it to resist the IMB induced effects and as such we observe lesser reduction in the activity of our experimental muscles during this part of the seasonal cycle. In the end we can conclude that, our experimental muscles are affected by both plaster cast as well as season induced (hibernation) IMB and seasonal changes playing a dominant role. It is also observed that, the season affects the kinetics of different parameter while plaster casting produces qualitative changes in our experimental muscles.

**References**


1. farooq sn, azeem ma, rakkah n, mustufa s. effect of cast immobilization on contractile characteristics of skeletal muscles of uromastix. pak j physiol. 2007.
2. Azeem MA, Shaikh HA. A correlation between anatomical and mechanical characteristics of the gastrocnemius and sartorius muscles of Uromastix hardwickii. A. B., Crac.29, 105-114 (1987).
3. Azeem MA, Shaikh HA. Seasonal variations in the contractile behaviour of gastrocnemius muscles of Uromastix hardwickii. Acta Physiol Hung. 1991 Dec 31;77(2):159–68.
4. Azeem MA. Seasonal and temperature variations in the mechanical contraction, strength duration and length tension properties of skeletal muscles of Uromastix. Ph. D. thesis Dept of Physiology University of Karachi, Pakistan. 1992.
5. Soomro MS, Azeem MA, Kaneez FS. Effects of season (summer & winter) on electrical characteristics of skeletal muscle membranes of the spiny-tailed lizard, Uromastix hardwickii. Indian J Physiol …. 2013.
6. Soomro MS, Azeem MA, Soomro MN. Seasonal effects on water and osmotically-active ionic contents (Na+, K+ & Cl–) of skeletal muscles of the spiny-tailed lizard, Uromastix hardwickii. Journal of Molecular …. 2012.
7. Lal R, Nirmal BK, Saxena AK. Interactive seasonal changes in the testis and thymus of the lizard Calotes versicolor Daudin. srbceorg
8. KHALIL F, ABDEL-MESSEIH G. Tissue constituents of reptiles in relation to their mode of life. II. Lipid

content. Comp Biochem Physiol. 1962 Jun;6:171–4.
9. Zain-ul-Abedin M, Katorski B. Certain blood constituents of a lizard during hibernation and activity. Can J Physiol Pharmacol. 1966 Dec 31;45(1):115–9.
10. Symonds BL, James RS, Franklin CE. Getting the jump on skeletal muscle disuse atrophy: preservation of contractile performance in aestivating Cyclorana alboguttata (Gunther 1867). J Exp Biol. 2007 Mar;210(Pt 5):825–35.
11. Guppy M, Withers P. Metabolic depression in animals: physiological perspectives and biochemical generalizations. Biol Rev Camb Philos Soc. 1999 Jan 31;74(1):1–40.
12. Harlow HJ, Lohuis T, Beck TD, Iaizzo PA. Muscle strength in overwintering bears. Nature. 2001 Feb 21;409(6823):997–7.
13. Pakay JL, Withers PC, Hobbs AA, Guppy M. In vivo downregulation of protein synthesis in the snail Helix apersa during estivation. Am J Physiol Regul Integr Comp Physiol. 2002 Jul;283(1):R197–204.
14. Steffen JM, Koebel D, Musacchia XJ, Milsom WK. Morphometric and metabolic indices of disuse in muscles of hibernating ground squirrels. Comp Biochem Physiol B. 1990 Dec 31;99(4):815–9.
15. Wickler SJ, Hoyt DF, van Breukelen F. Disuse atrophy in the hibernating golden-mantled ground squirrel, Spermophilus lateralis. Am J Physiol. 1991.
16. Wickler SJ, Hoyt DF, van Breukelen F. Disuse atrophy in the hibernating golden-mantled ground squirrel, Spermophilus lateralis. Am J Physiol. 1991 Nov;261(5 Pt 2):R1214–7.
17. Frerichs KU, Smith CB, Brenner M, DeGracia DJ, Krause GS, Marrone L, et al. Suppression of protein synthesis in brain during hibernation involves inhibition of protein initiation and elongation. Proc Natl Acad Sci USA. 1998 Nov;95(24):14511–6.
18. Fuery CJ, Withers PC, Hobbs AA, Guppy M. The role of protein synthesis during metabolic depression in the Australian desert frog Neobatrachus centralis. Comp Biochem Physiol A Mol Integr Physiol. 1998 Feb;119(2):469–76.
19. Zain AM and Zain BK. biochemistry of Uromastix hardwickii. Pub. Bureau. Trans. Compil. University of Karachi, Pakistan. 1977.
20. Arsalan M, samina J and Mahmood HQ. Seasonal variations in the testes of the spiny tailed lizard, Uromastix hardwickii. Gray. Biologia Lahore.1972 18(1):18-28.
21. Azeem MA, Shaikh HA. Effect of season on length-tension relation of gastrocnemius muscle of Uromastix hardwickii. Pak J Physiol. 2006.
22. Sinha AK, Choubey BJ. Seasonal changes in the thyroid gland of Indian spiny tailed, sand lizard, Uromastix hardwickii (Gray) male. Z Mikrosk Anat Forsch. 1980 Dec 31;95(1):72–80.
23. ZIMNY ML, GREGORY R. High energy phosphates during hibernation and arousal in the ground squirrel. Am J Physiol. 1958 Sep 30;195(1):233–6.
24. Zari TA. The influence of body mass and temperature on the standard metabolic rate of the herbivorous desert lizard,Uromastyx microlepis. J Therm Biol. 1990 Dec 31;16(3):129–33.
25. Afroz H, Ishaq M, Ali SS. Seasonal changes in t lipids of adipose tissue in a hibernating lizard (Uromastix hardwickii). Experimental Biology and Medicine. 1971. 136 (3); 894-898

26. Rome LC. Influence of temperature on muscle recruitment and muscle function in vivo. Am J Physiol. 1990 Aug;259(2 Pt 2):R210–22.
27. Faulkner JA, Zerba E, Brooks SV. Muscle temperature of mammals: cooling impairs most functional properties. Am J Physiol. 1990 Aug;259(2 Pt):R259–65.
28. Takekura H, Kasuga N, Yoshioka T. Effects of Testosterone on The Contractile Profiles of Denervated Rat Skeletal Muscle. Jap. J. Phys. Fitness sports med. 1991 40 (1): 41-47.
29. Aliya S. Seasonal changes and effect of temperature on pitutary and testicular functions, in a lacertilian species, Uromastix hardwickii. Ph. D. thesis Dept of biological sciences Quaid e Azam university Islamabad, Pakistan. 1994.
30. Carets RL, Denniston KJ, Topping JJ. Principles and Applications of Organic & Biological Chemistry. WCB/McGraw-Hill; 1997. 1 p.
31. Witzmann FA, Kim DH and Fitts RH, Effect of hind limb immobilization on the fatigue ability of skeletal muscle. J. Appl. Physiol. Respirat. Environ. Exercise physiol. 1983 54 (5): 1242-1248