EFFECTS OF UNDERNUTRITION

The values given are means ± SEM for UN rats vs C-UN rats.

Undernutrition produced significant reduction in the body weight of the animals (120.6 ± 7.5 vs 238.3 ± 9.6 g, P< 0.001). Similarly, crown-rump length was significantly lower in UN rats (13.0 ± 0.2 vs 15.0 ± 0.3 cm, P< 0.001).

Effects on skeletal muscles:

Effects on soleus:

The following effects were observed in the soleus of UN rats as compared to C-UN rats:

- The muscle weight was significantly lower (71.6 ± 4.0 vs 125.4 ± 6.6 mg, P< 0.001).

- CT was not significantly altered (53.5 ± 2.4 vs 51.9 ± 2.1 ms).

- ½ RT was significantly prolonged (88.8 ± 9.0 vs 66.9 ± 3.5 ms, P< 0.05).

- Twitch force was significantly lower (15.6 ± 1.4 vs 23.3 ± 2.9 g, P< 0.02).

- The tetanic forces at all stimulation frequencies were significantly lower (ANOVA: F(1,248) = 64.223, P< 0.001; Fig.9).
- The maximum tetanic force was significantly lower (92.5 ± 9.3 vs 129.5 ± 11.0 g, P<0.02).

- The force at any particular frequency when expressed for 1 g muscle was not significantly different (Table 2).

- MRR was similar at both 20 and 100 Hz (Table 3).

- ET was similar at both 20 and 100 Hz (Table 3).

- Histologically the number of muscle fibres was not significantly different (2975.9 ± 200.1 vs 2699.6 ± 257.3, Fig.10).

- The average diameter of the muscle fibre was significantly lower (24.3 ± 0.8 vs 33.8 ± 1.1 μm, P<0.001).

Effects on e.d.l.: The following effects were observed in the e.d.l. of UN rats as compared to C-UN rats:

- The muscle weight was significantly lower (73.4 ± 4.5 vs 123.2 ± 6.3 mg, P<0.001).

- CT was similar (27.1 ± 2.5 vs 24.6 ± 1.9 ms).

- ½ RT was similar (26.4 ± 1.2 vs 27.5 ± 1.7 ms).

- Twitch force was significantly lower (18.9 ± 2.2 vs 33.9 ± 4.9 g, P<0.01).
- The tetanic forces at many stimulation frequencies were significantly lower (ANOVA: $F_{(1,216)} = 40.107$, $P < 0.001$; Fig. 11).

- The maximum tetanic force was significantly lower ($80.4 \pm 13.3$ vs $144.4 \pm 20.3$ g, $P < 0.02$).

- The force at any particular frequency expressed for 1 g muscle was not significantly different (Table 2).

- MRR was similar at both 20 and 100 Hz (Table 3).

- ET was similar at both 20 and 100 Hz (Table 3).

- Histologically the number of muscle fibres was not significantly decreased ($2883.5 \pm 230.0$ vs $3534.4 \pm 284.0$, Fig. 12).

- The average diameter of the muscle fibre was significantly lower ($22.4 \pm 0.9$ vs $29.2 \pm 1.6 \mu m$, $P < 0.01$).

**Effects on smooth muscle:**

The following effects were observed in the colon of UN rats as compared to C-UN rats:

- The length of the entire colon was not significantly decreased ($18.2 \pm 0.5$ vs $19.6 \pm 0.7$ cm).
- The weight of entire colon was significantly reduced (899.8 ± 89.4 vs 1269.8 ± 74.7 mg, \( P < 0.02 \)).

- The weight of colonic segment was not significantly different (34.1 ± 4.2 vs 35.2 ± 2.6 mg/cm colon).

- The contraction-pressures at a few stimulation frequencies during electrical field stimulation were significantly lower (ANOVA: \( F_{(1,126)} = 24.822, P < 0.001; \) Figs.13,14).

- The maximum contraction-pressure during electrical field stimulation was not significantly different (11.8 ± 1.3 vs 16.6 ± 2.8 mm Hg/cm colon).

- The contraction-pressure at any particular frequency when expressed for 1 g colon was not significantly different (Table 2).

- The contraction-pressure produced by acetylcholine was not significantly lower (6.8 ± 1.0 vs 9.1 ± 1.6 mm Hg/cm colon).

- Histologically, the muscle layer thickness was similar (105.4 ± 10.0 vs 113.5 ± 3.9 \( \mu \)m, Fig.15).
EFFECTS OF 30 DAYS REHABILITATION

The values given are means ± SEM for 30 R rats vs C-30 R rats.

Rehabilitation for 30 days following the 90 days semistarvation has shown some recovery in the muscle contractile functions. The mean body weight of the animals in 30 R group was not significantly different from that of C-30 R group (217.2 ± 5.5 vs 238.4 ± 9.5 g). The crown-rump length was also similar in both groups (14.5 ± 0.2 vs 15.0 ± 0.2 cm).

Effects on skeletal muscles:

Effects on soleus:

The following effects were observed in the soleus of 30 R rats as compared to C-30 R rats:

- The muscle weight was not significantly different (106.8 ± 5.1 vs 127.4 ± 9.9 mg).

- CT was similar (69.2 ± 2.9 vs 72.5 ± 4.1 ms).

- ¼ RT was not significantly different (76.3 ± 8.4 vs 63.8 ± 3.2 ms).

- The twitch force was similar (22.7 ± 1.6 vs 27.1 ± 2.9 g).

- The tetanic force at any stimulation frequency was not significantly different (Fig.16).
The maximum tetanic force was similar (127.5 ± 12.1 vs 145.3 ± 15.3 g).

The force at any particular frequency when expressed for 1 g muscle was not significantly different (Table 4).

MRR was similar at both 20 and 100 Hz (Table 5).

ET was similar at both 20 and 100 Hz (Table 5).

Effects on e.d.l.:

The following effects were observed in the e.d.l. of 30 R rats as compared to C-30 R rats:

- The muscle weight was not significantly different (97.2 ± 3.6 vs 109.3 ± 5.1 mg).

- CT was similar (33.6 ± 2.3 vs 35.6 ± 4.5 ms).

- ½ RT was similar (27.3 ± 2.4 vs 27.5 ± 2.7 ms).

- The twitch force was not significantly different (35.4 ± 3.7 vs 29.4 ± 2.9 g).

- The tetanic force at any stimulation frequency was not significantly different (Fig.17).

- the maximum tetanic force was not significantly different (156.8 ± 10.5 vs 164.9 ± 17.3 g).
- The force at any particular frequency when expressed for 1 g muscle was similar (Table 4).

- MRR was similar at both 20 and 100 Hz (Table 5).

- ET was similar at both 20 and 100 Hz (Table 5).

Effects on smooth muscle:

The following effects were observed in the colon of 30 R rats as compared to C-30 R rats:

- The length of the entire colon was similar (18.3 ± 0.4 vs 18.2 ± 0.6 cm).

- The weight of the entire colon was not significantly different (1234.9 ± 58.4 vs 1385.8 ± 57.7 mg).

- The weight of the colonic segment used was not significantly different (36.8 ± 2.8 vs 39.8 ± 4.7 mg/cm colon).

- The contraction-pressure at any stimulation frequency during electrical field stimulation was not significantly different (Fig. 18).

- The maximum contraction-pressure during electrical field stimulation was not significantly different (9.2 ± 1.2 vs 11.6 ± 1.5 mm Hg/cm colon).
- The pressure at any particular frequency when expressed for 1 g colon was not significantly different (Table 4).

- The contraction-pressure produced by acetylcholine was not significantly different (5.6 ± 0.8 vs 5.9 ± 0.9 mm Hg/cm colon).

EFFECTS OF 60 DAYS REHABILITATION

The values given are means ± SEM for 60 R rats vs C-60 R rats

Rehabilitation for 60 days following the 90 days semi-starvation has shown more or less complete recovery in the muscle contractile functions. The body weight of the animal in 60 R group was not significantly different from C-60 R (262.5 ± 6.6 vs 289.9 ± 11.4 g). The crown-rump length was also similar in both groups (15.5 ± 0.2 vs 15.8 ± 0.2 cm).

Effects on skeletal muscles:

Effects on soleus:

The following effects were observed in the soleus of 60 R rats as compared to C-60 R rats:

- The muscle weight was not significantly different (134.7 ± 7.2 vs 153.9 ± 7.8 mg).
- CT was similar (62.8 ± 6.6 vs 56.7 ± 5.0 ms).

- ½ RT was similar (73.9 ± 7.9 vs 76.7 ± 7.5 ms).

- The twitch force was similar (34.9 ± 1.1 vs 31.3 ± 4.2 g).

- The tetanic force at any stimulation frequency was not significantly different (Fig. 19).

- The maximum tetanic force was similar (169.1 ± 23.0 vs 172.9 ± 24.6 g).

- The force at any particular frequency when expressed for 1 g muscle was similar (Table 6).

- MRR was similar at both 20 and 100 Hz (Table 7).

- ET was similar at both 20 and 100 Hz (Table 7).

Effects on e.d.l.:

The following effects were observed in the e.d.l. of 60 R rats as compared to C-60 R rats:

- The muscle weight was not significantly different (119.3 ± 6.1 vs 130.7 ± 5.5 mg).

- CT was similar (25.8 ± 1.5 vs 30.0 ± 2.0 ms).

- ½ RT was similar (30.7 ± 5.2 vs 31.0 ± 2.9 ms).
- The twitch force was similar (38.3 ± 6.4 vs 34.1 ± 2.3 g).

- The tetanic force at any stimulation frequency was not significantly different (Fig.20).

- The maximum tetanic force was not significantly different (146.3 ± 24.8 vs 174.7 ± 15.6 g).

- The tetanic force at any particular frequency expressed for 1 g muscle was not significantly different (Table 6).

- MRR was similar at both 20 and 100 Hz (Table 7).

- ET was similar at both 20 and 100 Hz (Table 7).

Effects on smooth muscle:

The following effects were observed in the colon of 60 R rats as compared to C-60 R rats:

- The length of the entire colon was similar (20.7 ± 0.6 vs 20.4 ± 0.3 cm).

- The weight of the colon was not significantly different (1587.3 ± 148.2 vs 1634.3 ± 130.1 mg).

- The weight of the colonic segment used was not significantly different (37.7 ± 3.9 vs 46.9 ± 4.8 mg/cm colon).
- The contraction-pressure at any stimulation frequency during electrical field stimulation was not significantly different (Fig. 21).

- The maximum contraction-pressure during electrical field stimulation was similar (10.9 ± 1.5 vs 10.0 ± 2.1 mm Hg/cm colon).

- The contraction-pressure at any particular frequency, when expressed for 1 g colon was not significantly different (Table 6).

- The contraction-pressure produced by acetylcholine was not significantly different (7.7 ± 1.5 vs 5.8 ± 1.2 mm Hg/cm colon).

**EFFECTS OF UNDERNUTRITION PLUS SWIMMING-I**

The values given are means ± SEM for UNS rats vs C-UN rats

The combination of undernutrition and swimming has produced different effects in the muscle contractile functions. The body weight of the animal in UNS group was reduced significantly (123.9 ± 9.4 vs 238.3 ± 9.6 g, $P < 0.001$). The crown-rump length was significantly decreased (13.0 ± 0.3 vs 15.0 ± 0.3 cm, $P < 0.001$).
Effects on skeletal muscles:

Effects on soleus:

The following effects were observed in the soleus of UNS rats as compared to C-UN rats:

- The muscle weight was significantly lower (70.3 ± 6.9 vs 125.4 ± 6.6 g, P < 0.001).

- CT was prolonged (67.5 ± 4.9 vs 51.9 ± 2.1 ms, P < 0.01).

- 4 RT was prolonged (88.8 ± 11.6 vs 66.9 ± 3.5 ms, P < 0.05).

- The twitch force was similar (20.0 ± 2.8 vs 23.3 ± 2.9 g).

- The tetanic force at any stimulation frequency was not significantly different (Fig.22).

- The maximum tetanic force was not significantly different (105.2 ± 13.9 vs 129.5 ± 11.0 g).

- The force expressed for 1 g muscle was significantly more at all frequencies (Table 8).

- MRR was similar at both 20 and 100 Hz (Table 9).

- ET was similar at both 20 and 100 Hz (Table 9).
- Histologically, the number of muscle fibres was similar
  \((2483.0 \pm 211.8 \text{ vs } 2699.6 \pm 257.3)\).

- The average diameter of the muscle fibre was similar
  \((38.9 \pm 4.6 \text{ vs } 33.8 \pm 1.1 \mu m)\).

Effects on e.d.l.:

The following effects were observed in the e.d.l. of UNS rats as compared to C-UN rats:

- The muscle weight was significantly lower \((59.4 \pm 4.9 \text{ vs } 123.2 \pm 6.3 \text{ g, } P < 0.001)\).

- CT was prolonged \((35.0 \pm 3.9 \text{ vs } 24.6 \pm 1.9 \text{ ms, } P < 0.02)\).

- \(1/2\) RT was prolonged \((34.3 \pm 3.0 \text{ vs } 27.5 \pm 1.7 \text{ ms, } P < 0.05)\).

- The twitch force was not significantly different \((20.6 \pm 3.9 \text{ vs } 33.9 \pm 4.9 \text{ g})\).

- The tetanic force at any stimulation frequency was not
  significantly different (Fig.23).

- The maximum tetanic force was not significantly different
  \((91.2 \pm 12.9 \text{ vs } 144.4 \pm 20.3 \text{ g})\).

- The force at any particular frequency expressed for 1 g
  muscle was not significantly different (Table 8).
- MRR was similar at both 20 and 100 Hz (Table 9).

- ET was similar at both 20 and 100 Hz (Table 9).

- Histologically, the number of muscle fibres was not significantly different \((2631.3 \pm 379.1 \text{ vs } 3534.4 \pm 284.0)\).

- The average diameter of the muscle fibre was similar \((27.6 \pm 1.1 \text{ vs } 29.2 \pm 1.6 \, \mu m)\).

Effects on smooth muscle:

The following effects were observed in the colon of UNS rats as compared to C-UN rats:

- The length of the entire colon was significantly lower \((16.9 \pm 0.3 \text{ vs } 19.6 \pm 0.7 \, \text{cm}, \, P<0.01)\).

- The weight of the entire colon was significantly lower \((908.1 \pm 65.9 \text{ vs } 1269.8 \pm 74.7 \, \text{mg}, \, P<0.01)\).

- The weight of the colonic segment was similar \((29.4 \pm 1.3 \text{ vs } 35.2 \pm 2.6 \, \text{mg/cm colon})\).

- The contraction-pressure at any stimulation frequency during electrical field stimulation was not significantly different (Fig.24).

- The maximum contraction-pressure during electrical field stimulation was similar \((12.0 \pm 1.3 \text{ vs } 16.6 \pm 2.8 \, \text{mm Hg/cm colon})\).
- The contraction Pressures at various stimulation frequencies when expressed for 1 g colon were similar (Table 8).

- The contraction-pressure produced by acetylcholine was similar (9.8 ± 1.0 vs 9.1 ± 1.6 mm Hg/cm colon).

- Histologically, the muscle layer thickness was significantly more (188.1 ± 11.1 vs 113.5 ± 3.9 µm, P < 0.001).

**EFFECTS OF UNDERNUTRITION PLUS SWIMMING - II**

A comparison of UNS values with C-UNS

The values given are means ± SEM for UNS rats vs C-UNS rats.

The combination of undernutrition and swimming has produced different effects in the muscle contractile functions. The body weight of the animal in the UNS group was reduced to about 50% (123.9 ± 9.4 vs 216.3 ± 13.9 g, P < 0.001). The crown-rump length was significantly different (13.0 ± 0.3 vs 14.8 ± 0.3 cm, P < 0.001).

**Effects on skeletal muscles:**

**Effects on soleus:**

The following effects were observed in the soleus of UNS rats as compared to C-UNS rats:
- The muscle weight was significantly lower (70.3 ± 6.9 vs 108.2 ± 7.9 mg, $P < 0.01$).

- CT was similar (67.5 ± 4.9 vs 64.0 ± 6.2 ms).

- RT was not significantly different (88.8 ± 11.6 vs 66.0 ± 5.4 ms).

- The twitch force was not significantly different 20.0 ± 2.8 vs 26.6 ± 2.8 g).

- The tetanic forces at a few stimulation frequencies were significantly lower (ANOVA: $F_{(1,112)} = 29.304$, $P < 0.001$; Fig.25).

- The maximum tetanic force was not significantly different (105.2 ± 13.9 vs 147.6 ± 14.6 g).

- The force expressed for 1 g muscle was significantly more at 10 Hz (1004.9 ± 74.2 vs 729.9 ± 64.0 g, $P < 0.02$) and at other frequencies it was similar (Table 10).

- MRR was similar at both 20 and 100 Hz (Table 11).

- ET was similar at 20 Hz (Table 11) and significantly more at 100 Hz (33.8 ± 3.3 vs 23.4 ± 3.0 s, $P < 0.05$).
Effects on e.d.l.:

The following effects were observed in the e.d.l. of UNS rats as compared to C-UNS rats:

- The muscle weight was significantly lower (59.4 ± 4.9 vs 90.9 ± 7.6 mg, P < 0.01).

- CT was similar (35.0 ± 3.9 vs 30.0 ± 2.5 ms).

- ½ RT was significantly prolonged (34.3 ± 3.0 vs 26.0 ± 1.3 ms, P < 0.02).

- The twitch force was not significantly different (20.6 ± 3.9 vs 32.5 ± 4.3 g).

- The tetanic forces at a few stimulation frequencies were significantly lower (ANOVA: F(1,120) = 32.050, P < 0.001; Fig.26).

- The maximum tetanic force was not significantly different (91.2 ± 12.9 vs 139.9 ± 17.8 g).

- The force at any particular frequency expressed for 1g muscle was not significantly different (Table 10).

- MRR was similar at both 20 and 100 Hz (Table 11).

- ET was similar at both 20 and 100 Hz (Table 11).
Effects on smooth muscle:

The following effects were observed in the colon of UNS rats as compared to C-UNS rats:

- The length of the entire colon was significantly lower
  \(16.9 \pm 0.3 \text{ vs } 18.9 \pm 0.7 \text{ cm, } P < 0.05\).

- The weight of the entire colon was significantly lower
  \(908.1 \pm 65.9 \text{ vs } 1307.1 \pm 70.7 \text{ mg, } P < 0.01\).

- The weight of the colonic segment was significantly lower
  \(29.4 \pm 1.3 \text{ vs } 34.0 \pm 1.1 \text{ mg/cm colon, } P < 0.05\).

- The contraction-pressures at many stimulation frequencies
during electrical field stimulation were significantly more
  \(\text{ANOVA: } F(1,117) = 33.836, P < 0.001 ; \text{ Fig.27})\).

- The maximum contraction-pressure during electrical field
stimulation was significantly more
  \(12.0 \pm 1.3 \text{ vs } 7.6 \pm 1.4 \text{ mm Hg/cm colon, } P < 0.05\).

- The contraction-pressures at various stimulation frequencies
when expressed for 1 g colon were significantly more
  (Table 10).

- The contraction-pressure produced by acetylcholine was
  significantly more
  \(9.8 \pm 1.0 \text{ vs } 6.0 \pm 1.0 \text{ mm Hg/cm colon, } P < 0.02\).