The forgotten Barcroft/Edholm reflex: potential role in exercise associated collapse

Approximately 80% of the athletes who collapse in marathon and other long distance sporting events do so only after they have crossed the finish line. Although it is usually taught that “dehydration” explains this phenomenon, logic suggests this to be unlikely because any dehydration induced hypovolaemia should cause cardiovascular failure when cardiac stress is highest—that is, during rather than after exercise when cardiovascular function is returning to the resting state.

Instead it is clearly the act of stopping exercise that is the consequence, albeit paradoxical, cause of post-exercise collapse.

We have previously proposed that this form of exercise associated collapse is caused by the persistence into recovery of a state of low peripheral vascular resistance, compounded by removal of the skeletal muscle pump that maintains the right atrial filling pressure during exercise.

According to this theory, the combination of a low peripheral vascular resistance and a sudden reduction in venous return would reduce stroke volume and cardiac output acutely, causing hypotension.

Indeed this mechanism was used to explain the development of postural hypotension due to dehydration exhaustion, in military personnel exposed to eight or more hours of exercise in desert heat without fluid replacement.

Hence they proposed the existence of a potent skeletal muscle vasodilator reflex that is activated when the right atrial pressure either falls below some critical value or begins to fall at a particular rate. This reflex appears atavistic because it compounds rather than corrects the hypotension associated with blood loss that activated the reflex reduction in peripheral vascular resistance.

A tourniquet was applied to the lower limb and inflated before the beginning of the venesection. Hypotension again developed, but after a smaller blood loss of only about 550 ml. Release of the tourniquet immediately corrected the hypotension by reducing forearm blood flow (fig 2). The authors concluded that removal of the tourniquet produced a sudden infusion of blood from the lower limb thereby increasing the right atrial pressure, abolishing the reflex and normalising cardiovascular function.

A second study evaluated the authors’ hypothesis that it was the fall in right atrial pressure induced by blood loss that activated the reflex reduction in peripheral vascular resistance. A tourniquet was applied to the lower limb and inflated before the beginning of the venesection. Hypotension again developed, but after a smaller blood loss of only about 550 ml. Release of the tourniquet immediately corrected the hypotension by reducing forearm blood flow (fig 2). The authors concluded that removal of the tourniquet produced a sudden infusion of blood from the lower limb thereby increasing the right atrial pressure, abolishing the reflex and normalising cardiovascular function.

However, the crucial finding was that fainting occurs as a sudden reduction in peripheral vascular resistance resulting from an increase in forearm blood flow as right atrial pressure falls, the Barcroft/Edholm reflex. Redrawn from data in Barcroft et al.

Thus Adolph’ wrote that “the ultimate failure of the circulation (in dehydration exhaustion) is of a peripheral type... Dilated blood vessels of the skin require additional blood to fill them; correspondingly, the available compensation for vertical posture are diminished, for the blood vessels of the legs compromise between dilating to carry heated blood and constricting to preserve a greater flow to the head” (p 235). He also reported that: “Lying down promptly relieves the circulations and the symptoms” (p 236). Similarly, Lee defined the physiological abnormality causing heat exhaustion as: “A low arterial blood pressure is the critical event, resulting partly from inadequate output by the heart and partly from the widespread vasodilatation.”

He also noted that: “Treatment is simple — recumbency, fluid and salt administration, gentle cooling, and rectification of any predisposing cause” (p 571).

However, these explanations fail to explain why a compensatory tachycardia is not a usual feature of this form of hypotension, or why the onset of symptoms occurs so rapidly and why they are reversed so rapidly when subjects lie supine in the head down position.

An historic study identifying a potentially forgotten reflex and published in The Lancet in 1944 suggests an alternative explanation. Barcroft et al studied the effects of rapid venesection of about 1 litre of blood in 12 minutes. Note that fainting is caused by a sudden reduction in peripheral vascular resistance resulting from an increase in forearm blood flow as right atrial pressure falls, the Barcroft/Edholm reflex. Redrawn from data in Barcroft et al.

A second study evaluated the authors’ hypothesis that it was the fall in right atrial pressure induced by blood loss that activated the reflex reduction in peripheral vascular resistance. A tourniquet was applied to the lower limb and inflated before the beginning of the venesection. Hypotension again developed, but after a smaller blood loss of only about 550 ml. Release of the tourniquet immediately corrected the hypotension by reducing forearm blood flow (fig 2). The authors concluded that removal of the tourniquet produced a sudden infusion of blood from the lower limb thereby increasing the right atrial pressure, abolishing the reflex and normalising cardiovascular function.

To my knowledge, some contemporary texts of cardiovascular control during exercise do not specifically mention this reflex. For example, Rowell refers to a later 1945 paper in the Journal of Physiogy by Barcroft and Edholm, in which the physiological basis for this skeletal muscle vasodilation was studied. However, the relevance of this specific reflex to the development of syncope is not directly discussed. Rather Rowell presents the findings of...
Barcroft and Edholm as a possible example of neurogenic sympathetic cholinergic vasodilation in skeletal muscle.

It is of interest that we had empirically discovered some years ago that the optimum management of post-exercise collapse is achieved by elevating the feet and pelvis of collapsed athletes above the level of the right atrium. The results of this manoeuvre are usually dramatic, with rapid reversal of hypotension and the symptoms of dizziness. According to the Barcroft/Edholm reflex, the adoption of this head down position would produce this dramatic response by immediately reversing the low atrial pressure that develops on the cessation of exercise in some susceptible athletes. Hence the effect would not result simply by increasing venous return and hence cardiac output, the more usual explanation, but also by reversing the skeletal muscle vasodilation induced by the Barcroft/Edholm reflex.

Finally, I would like to make the obvious point that the Barcroft/Edholm reflex explains why nursing in the head down (Trendelenberg) position would be the more logical treatment for post-exercise collapse than the provision of intravenous fluids. The reason is that nursing in the Trendelenberg position rapidly increases the right atrial pressure whereas any effect of intravenous fluids on right atrial pressure is likely to be smaller and much delayed.

Furthermore the contribution of the Barcroft/Edholm reflex to exercise associated collapse can be very rapidly evaluated by studying the response of the athlete’s blood pressure to changes in posture. Failure of the blood pressure to rise when placed in the head down position must indicate that the Barcroft/Edholm reflex is not active and some other cause for the hypotension, such as myocardial dysfunction or a persistent reduction in peripheral vascular resistance for reasons other than this postulated reflex, must be considered.

Comparative body fat assessment in elite footballers

Much attention is directed to measuring body composition, particularly fat mass, the aim being to estimate the untoward health consequences of excessive amounts of fat or to assess physical fitness. There are two main types of method of measurement: reference and prediction techniques. The former consist of measuring body density or total body water and dual energy x-ray absorptiometry, and the latter include measurement of skinfold thickness and bioelectrical impedance analysis.

The Tanita body fat analyser is a commercially available foot to foot bioelectrical impedance analysis system. It is a novel method because it measures the weight and percentage of body fat simultaneously while the subject stands barefoot, in contrast with traditional impedance devices which comprise a tetrapolar surface electrode system whereby the weight and height of the subjects are manually entered. In this study, we performed comparative body fat analysis of 29 elite football players using a Tanita analyser and skinfold thickness (SFT) measurements and subsequent predictive equations.

Body fat measurements were carried out using a Tanita TBF-350 (Tanita Corp, Tokyo, Japan). Early in the morning after an overnight fast, subjects stood still on the metal sole plates of the machine wearing only light football shorts. SFTs were measured using Holtzhausen calipers (Crymych, UK) at nine sites on the non-dominant side of the body: biceps, triceps, abdomen, subscapula, suprailliac 1 (midaxillary), suprailliac 2 (anterior axillary), thigh, calf, and chest. All measurements were performed by the same examiner. Predicted body density was calculated as described by Durnin and Womersley using biceps, triceps, subscapula, and suprailliac values. The proportion of body fat was calculated from body density using the equation of Siri, and two equations were used to estimate body fat mass, namely those of Siri and Zorba. Weight was measured using a digital scale and height with a wall mounted stadiometer. Statistical analysis was performed using Pearson correlation coefficients.

Table 1 summarises the basic details and SFT values of the subjects. It seems that the subjects accumulated fat mainly in the abdomen and suprailliac regions and least in the chest.

### Table 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.62 (3.57)</td>
<td>18–31</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76.12 (8.34)</td>
<td>64.3–105.4</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.81 (0.05)</td>
<td>1.7–1.92</td>
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<tr>
<td>Body mass index (kg/m²)</td>
<td>23.20 (1.79)</td>
<td>20.4–28.6</td>
</tr>
<tr>
<td>Biceps (cm)</td>
<td>4.21 (0.93)</td>
<td>3.2–6.5</td>
</tr>
<tr>
<td>Triceps (cm)</td>
<td>7.44 (2.64)</td>
<td>4–12.7</td>
</tr>
<tr>
<td>Abdomen (cm)</td>
<td>10.67 (4.35)</td>
<td>5.3–21.6</td>
</tr>
<tr>
<td>Subscapula (cm)</td>
<td>9.43 (2.00)</td>
<td>5.3–12.6</td>
</tr>
<tr>
<td>Suprailiac 1 (cm)</td>
<td>7.13 (2.70)</td>
<td>3.4–14.8</td>
</tr>
<tr>
<td>Suprailiac 2 (cm)</td>
<td>10.13 (3.68)</td>
<td>5.3–20.7</td>
</tr>
<tr>
<td>Thigh (cm)</td>
<td>9.05 (3.24)</td>
<td>5.3–15.8</td>
</tr>
<tr>
<td>Calf (cm)</td>
<td>6.96 (2.20)</td>
<td>3.7–12.9</td>
</tr>
<tr>
<td>Chest (cm)</td>
<td>5.43 (2.14)</td>
<td>3.3–13.1</td>
</tr>
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</table>
Table 2  Correlation coefficients between the measurements

<table>
<thead>
<tr>
<th></th>
<th>Body density</th>
<th>Tanita</th>
<th>Zora</th>
<th>Siri</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body density</td>
<td>–</td>
<td>-0.76</td>
<td>0.90</td>
<td>-0.91</td>
</tr>
<tr>
<td>Tanita</td>
<td>-0.76</td>
<td>0.90</td>
<td>0.75</td>
<td>0.98</td>
</tr>
<tr>
<td>Zora</td>
<td>-0.90</td>
<td>0.75</td>
<td>0.74</td>
<td>0.98</td>
</tr>
<tr>
<td>Siri</td>
<td>-0.91</td>
<td>0.74</td>
<td>0.98</td>
<td>-</td>
</tr>
</tbody>
</table>

All p values <0.001.


References

Understanding tendinopathies

We commend Professor Murrell for making a major novel contribution to the understanding, and thus potentially the treatment, of chronic tendinopathies.1 He has shown in patients with supraspinatus tendinopathy that a substantial portion of the cellular compartment of the tendon shows nuclear fragmentation, a key characteristic of apoptosis.2 Does Professor Murrell feel that apoptosis would necessarily be a “harmful” pathological event in tendon or might there be an optimal, basal level of apoptosis? We appreciate that excessive apoptosis—programmed cell death—is a feature of degenerative pathologies such as muscular dystrophy and Alzheimer’s disease.3 In these conditions apoptosis may contribute to deterioration of the diseased tissue. On the other hand, it is a characteristic feature in physiological situations such as scar remodelling, in which coordinated death of myofibroblasts is a desirable outcome.4 A recent study does suggest that proliferation of tenocytes can enhance tendon remodelling, as proliferation of tenocytes after IGF-1 injection was accompanied by improved tendon stiffness and reduced lesion in equine flexor tendinopathy.5 Other studies have shown fibroblast apoptosis from excessive strain6 or, paradoxically, decreased loading7. We would also appreciate Professor Murrell’s opinion on the significance of a third of tendon cells displaying a positive TUNEL assay, months after the onset of symptoms. Could apoptotic cells remain in tissue for months after injury, or might the condition cause continual apoptosis and proliferation concurrently? If the latter were true, would apoptosis be a causal event of tendon degeneration or a secondary effect of scar remodelling? The fact that paratenonitis can directly cause tendinosis and loss of tenocytes suggests a possible causal role of apoptosis.8 Does Professor Murrell see growth factors as playing a role in modulating apoptosis in the tendon, and could the effect of growth factors on tenocyte death and survival be tested in vitro or in model systems? Such investigations would be complicated by the many interacting conditions in the tendon which could promote or prevent apoptosis, including integrin mediated signals, soluble factors, and cellular stresses such as hypoxia and reactive oxygen species. The distinct phenotypes of tenocytes within and among tendons would add yet another layer of complexity to the story.

Again, we commend Professor Murrell for this contribution. We will be very curious to know which caspases are activated in the supraspinatus and in other tendinopathies, and whether there would be an inhibitory effect of caspase inhibitors. By showing for the first time that nuclear fragmentation is a significant feature of tendon degeneration, Professor Murrell has brought us one step closer to a more complete understanding of this condition.

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Lumbopelvic mechanics

It has annoyed us for a long time when patients present stating that they have been “core conditioning/conjoint tendon/lower back pain”, etc. It is also annoying to find the same terms used in peer reviewed scientific articles with the assumption that they mean something to the readers. Maybe they do to others, and we are missing something! We would like to get some discussion going on this and are happy to open the batting.

We think of lumbopelvic mechanics as three distinct groups:

1 Intrapelvic stability
2 Peripelvic stability
3 Functional stability

Intrapelvic stability

This is dependent on the transversus abdominis contracting with intact posterior sacroiliac joint ligaments. The anatomy of the transversus abdominis is such that it has a major origin off the iliac crest and inguinal ligament/iliopectineal ligament and insert into the PSIS. Therefore it and the pelvic floor are the only muscles that give direct closure across the sacroiliac joint. The long lever arm involved gives it great mechanical advantage, as long as the sacroiliac joint ligaments are intact.

Problems arise from two mechanisms. (1) Loss of the active structures that provide intrinsic pelvic closure (the transversus abdominis and the pelvic floor muscles) because of

• inhibition of the transversus abdominis caused by first onset low back pain;
• pain inhibition through joint inflamma-
tion: “osteitis pubis”, hip joint pathology, and sacroiliac/lumbar spine joint dysfunction;
• a tear of the conjoint tendon/inguinal ligament disrupting the origin of the iliopsoas/psoas major; and
• past abdominal surgery inhibiting con-
traction or affecting the nerve supply to the transversus;
• tearing of the pelvic floor muscles during child birth;
• weakness of the pelvic floor muscles sec-
todary to poor toilet habits.

(2) Loss of passive structures

• pelvic ligamentous laxity due to either body type (hypermobility) or external trauma (either single incident or pro-
longed postural loading), or hormone associated lateral ligamentous laxity (pregnancy);
• laxity of the sacroiliac joint ligaments will cause loss of the closure moment at the sacroiliac joint. A very small loss of ligament strength here can have a profound effect on the closure moment. Is this how Vleeming’s posterior sling exercises work on post partum women?
• Further this is the mode of action of scele-
rotherapy of the sacroiliac joint ligaments?

Peripelvic stability

Once the pelvis is stable and we have a firm foundation, we can look at the pelvis reacting with the rest of the body.

Pelvis on hip joint (pelvifemoral control)

• Does the knee roll inwards as the subject single leg squats?
• Does the pelvis dip as the patient reaches single leg stance?
• Is the lack of pelvic femoral control a strength or timing problem around the hip joint (gluteus medius and gluteus maximus) or is it an inability to appropriately weight transfer on to that side because of hip, knee, or ankle problems, burnt out nerve root pathology, or just disuse of one side because of chronic injury.

Pelvis on lumbar (and thoracic) spine (lumbopelvic control)

• This is concerned with ability of the deep multifidus to contract to control the lumbar segments and the superficial multifidus to orientate the spine on the pelvis.1

Functional stability

Once the muscle strength and activation patterns are in place to allow force transfer through the pelvis, then linking these activities into normal activities and actions and conditioning the lumbopelvic complex can take place. This is really just an “on-field” extension of peripelvic stability. Once the athlete has all the necessary components to hold the pelvis stable on the femur and lumbar spine, can they coordinate that into their particular sporting or every day activity?

This type of stability is more concerned with technique, coaching, and video analysis. Also, as conditioning will no doubt affect the fatigue status of the athlete, high level physi-

•...
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Further details: Gill Bliss, MR Department, Clarendon Wing, Leeds General Infirmary, Great George Street, Leeds LS1 3EX. Tel: +44 (0)113 392 3768; fax: +44 (0)113 392 8241; email: gillian.bliss@leedsth.nhs.uk

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5 October 2003, Glasgow, UK
A study day with Professor Stuart McGill.
Further details: Yvonne Gilbert, BASEMS Secretary, Royal College of Surgeons of Edinburgh, Nicolson Street, Edinburgh EH8 9DW; email: y.gilbert@rcsed.ac.uk; tel: +44 (0)131 527 3409. Organised by BASEM Scotland

The 6th STMS World Congress on Medicine and Science in Tennis in conjunction with the LTA 2004 Sports Science, Sports Medicine and Performance Coaching Conference
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Further details: Dr Michael Turner, The Lawn Tennis Association, The Queen’s Club, London W14 9EG, United Kingdom; email: michael.turner@lta.org.uk

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