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**NARRATIVE REVIEW**

# The endurance athlete's "stitch": Etiology and management of exercise-related transient abdominal pain

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## Abstract

*Background:* The endurance athlete's "stitch," or exercise-related transient abdominal pain (ETAP), all too commonly limits the performance of endurance athletes, but its origin, management and possible methods of prevention remain unclear. *Methods:* Published research was reviewed systematically from January 1996 through May 2015.The terms "Athletic Stitch," "Pain in the side" OR "Abdominal pain" were paired with "Exercise/Exercise therapy," "Physical education/Training," OR Fitness/Physical fitness" to identify a total of 66 papers. 35 of these articles relevant to review objectives were supplemented by an additional 50 citations drawn from reference lists and personal files. *Results:* About a fifth of participants in aerobic endurance events are affected by ETAP on any one occasion, and perhaps two thirds of competitors experience ETAP at least once during a year. The risk seems greater in younger, less experienced and female athletes. Postulated causes that include visceral ischaemia, visceral vibration, ischaemia and/or spasm of the respiratory muscles, postural disorders, peritoneal irritation, and psychological factors. Treatment currently remains empirical. Optimizing physical condition, strengthening abdominal and spinal muscles, and avoiding food and hypertonic fluids immediately before an event appear to reduce the risks of ETAP. A slowing of pace, bending, local pressure and an abdominal binder may give immediate relief; the merits of spinal manipulation have yet to be confirmed *Conclusions:* Empirical remedies as yet have limited efficacy, and it remains necessary to develop a clear unifying hypothesis of etiology before evidence-based recommendations for the prevention and treatment of ETAP. Although ETAP may impair performance, it does not have any serious sequelae; the important objective for the practitioner is to distinguish it from other more dangerous causes of abdominal pain. **Health & Fitness Journal of Canada 2015;8(3):23-40.**

*Keywords:* Abdominal symptoms, distance running, endurance performance.

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## Introduction

Previous articles in this series have examined 2 common abdominal problems of the endurance athlete- the "trots", or exercise-induced diarrhoea (Shephard, 2015a) and bloody faeces (Shephard, 2015 b). This review addresses a third important issue, the athlete's "stitch" or exercise-related transient abdominal pain (ETAP) that all-too commonly limits the performance of endurance athletes. Many generations of sports physicians, kinesiologists and competitors have recognized both the problem and the prevalence of the stitch. One group of investigators (Morton & Callister, 2000, 2015) found that 69% of a sample of 439 runners experienced such symptoms during the past year, and that a fifth of competitors were affected in any given event. Likewise, a survey of 230 runners (Koistinen et al., 1991) observed a "stitch" in 32% of 1/4 marathon participants, 21% of 1/2 marathon runners, and 16% of full marathon contestants.

Nevertheless, the precise origins of the stitch and evidence-based methods of prevention have remained unclear. Searches of Ovid/Medline and Google Scholar suggest that ETAP has received relatively little attention in the sports science literature. A systematic review has thus been conducted to collate information on the prevalence and

characteristics of ETAP and its differential diagnosis, to examine hypotheses concerning possible etiologies, and to seek appropriate knowledge for prevention, management and treatment.

## Methods

The human-subject database of Ovid Medline was searched without restrictions of language over the period from January 1996 to September 2015. A combination of the terms "Athletic Stitch," "Pain in the side" OR "Abdominal pain" yielded 18,126 hits. A combination of "Exercise/Exercise therapy" (157,873 hits), "Physical education/Training" (5996 hits), OR Fitness/Physical fitness" (40,844 hits) yielded 188,886 unique entries. Using the AND function to combine the markers of ETAP and physical activity, a total of 99 papers were identified. Review of the abstracts showed 13 papers dealing with the characteristics of stitch, 31 papers relating to differential diagnosis, and 10 papers that discussed dietary and other non-phamacological treatment; 12 of the 54 articles originated from a single laboratory. The quality of these contributions was evaluated, particularly in terms of sample size and questionnaire response rates. The remaining 45 papers covered topics that were not relevant to the present review, and they were thus excluded. Additional citations bearing upon ETAP were found by scanning reference lists and searching the present author's personal files.

## Results

*Early descriptions of ETAP*

There have been repeated claims that the phenomenon of the athlete's "stitch" was described by both Pliny the Elder and Shakespeare [see, for example, (Capps, 1941; Eichner, 2006; Morton, 2003; Morton & Callister, 2015)]. However, such assertions seem incorrect. Pliny referred to a condition where the body was arched violently backwards: "*For the painful cramp, attended with inflexibility, to which people give the name of opisthotony, the urine of a she-goat is injected into the ears*" (Pliny the Elder, Book 28, Chapter 52). Likewise, in "*The Tempest*" (l. 326-328), Shakespeare had Prospero speak of a night-time cramp, apparently unrelated to exercise: *"tonight thou shalt have cramps, side-stitches that shall pen thy breath up, urchins shall, for that vast of night that they may work.*"

The condition of ETAP was briefly mentioned in an early German medical text (Mossler, 1878), and was the subject of vigorous discussion during the 1920s and 1930s. The many rival explanations of physiopathology during this period were summarized by Herxheimer (1927), Kugelmass (1937) and Capps (1941). Hypotheses of causation included a shaking of the suspensory ligaments of the stomach (Herxheimer, 1927), a transient disturbance of the abdominal circulation, a sudden contraction of the spleen, a spasm of the intercostal muscles, and a disorder of breathing (Kugelmass, 1937), with an inadequate pre-exercise warm-up possibly being a contributing factor (Capps, 1941). More recently, interest in ETAP was rekindled by the surveys of Koistinen et al., (1991) in Northern Finland, and by Morton & Callister (2000) in Australia.

*Prevalence of ETAP*

The literature search found 9 articles addressing the overall prevalence of ETAP in athletes, and a further 7 articles that discussed prevalence in single endurance events (Table 1).

**Table 1: Reported prevalence of exercise-related transient abdominal pain.**

| Authors | Activity | Population | Sample | Prevalence | Comment |
|---|---|---|---|---|---|
| **Overall prevalence** | | | | | |
| Halvorsen et al., (1990) | Marathon running | Marathon participants | 279/2800 = 10% | 53/279 = 19% | 3% also had abdominal pain post-race |
| Keeffe et al., (1984) | Marathon running | Marathon participants, 85% men, median age 30-40 | 707/1700 runners (41.6%), median distance 41-50 miles/week | Hard runs 19.3%, runs 13.9%, easy runs 10.9% | Occasionally or frequently vs. rarely or never |
| Morton & Callister (2000) | 6 sports | 54% male, mean age 28.5 yr | 965/1016 (95%) | 589/965 =61% | Experienced within past year, commonly on less than 10% of occasions |
| Peters et al., (1993) | Running<br>Cycling<br>Triathlon | Marathoners<br>Elite cyclists<br>Elite triathloners | 165/177 = 93%<br>160/191 = 84%<br>143/201 = 71% | 71%<br>64%<br>45% (cycle)<br>79% (run) | Lower abdominal symptoms in past year (never vs. sometimes (<50%), often (>50%) or always; stitch not distinguished from other lower abdominal problems |
| Riddoch & Trinick (1988) | Marathon running | Marathon runners, 92% male, average age 34 yr, running 36 miles/wk | 471/1750 participants in Marathon | 146/471 = 31% | Symptoms more common after hard than after easy run, seen during and after run |
| Sullivan, (1981) | Distance running | Recreational & competitive runners | 57 of ? | 14/57 = 25% | |
| Sullivan, (1987) | Triathlon | Triathletes | 110 of ? | 39/110 = 35% | |
| Sullivan & Wong (1992) | Distance running | Running club, men & women | 109 of 134 (81.3%) of members who ran > 3 times/wk | 31/109 = 28% | Often associated with diarrhea |
| Worobetz & Gerrard (1985) | Endurance event (swim/cycle/canoe/ run) | Enduro participants | 70 of 119 (59%) of participants | 29/70 = 35% reported abdominal cramps | |
| **Prevalence in single event** | | | | | |
| Koistinen et al., (1991) | Distance running (10.5, 21 or 42 km) | Joggers to national competitors, | 230 of 426 (55%) participants | Stitch in 32% of 10.5 km, 21% of 21 km, 16% of 42 km | Performance hindered in 19-16% of respondents |
| Morton et al., (2005) | 14 km fun run (76% runners, 24% walkers) | Varied level of experience | 848/893 (95%) of participants | ETAP in 30% of runners, 16% of walkers | Performance hindered in 42% with pain |
| Peters et al., (1993) | 3 h laboratory cycle ergometry & treadmill running | Male triathletes | 32 of 32 | Cycling 3/32 (9%), Running 9/32% 27% | Symptoms in final 90 min, similar for semi-solid, isotonic and placebo fluids |
| Peters et al., (1999) | 4-day walk 40-50 km/day | 79 men, 76 women aged 30-49 yr | 154/480 = 32% | 3/154 = 2% | No time loss vs. delayed walk vs. dropped out; 1 drop-out from abdominal cramps |
| Rehrer et al., (1989) | 25 km race & Marathon | 114 initially untrained subjects | 44/114 = 39% | 25 km 16% Marathon 23% | Same subjects completed marathon at later stage in training |
| Rehrer et al., (1992) | 67 km ultramarathon with 1900 m change of altitude | 158 men, 12 women distance runners | 170/? | 32/170 = 18.8% | |
| ter Steege & Kolkman, (2012); ter Steege et al., (2008) | Recreational running, 10, 21 or 42 km | Recreational runners, 70% male | 1281/2076 = 62% | 17% | Internet response up to 1 month; most had hardly any vs. moderate, severe or very severe complaints |

Some reports have suggested that as many as a third of participants are affected by ETAP in any given endurance event, and as many as two thirds of athletes experience at least 1 episode over the course of a year (Gil et al., 1998; Riddoch & Trinick, 1988). However, several factors potentially complicate accurate estimates of prevalence. In some studies, ETAP has not been distinguished from other lower abdominal problems such as diarrhoea. Questionnaires have usually been distributed at the end of an athletic event, and in surveys with a response rate as low as 27% (Riddoch & Trinick, 1988), 40% (Keeffe et al., 1984) or 55% (Koistinen et al., 1991), it is possible that the apparent prevalence of ETAP was boosted because there was a greater motivation to respond among those with symptoms than in those who were free of symptoms (Peters et al., 1993 ; Riddoch & Trinick, 1988). One Internet questionnaire achieved a 62% response rate; overall complaints of "side-stitch" (17%) were lower than in most immediate post-race surveys, and most complainants reported "hardly any" rather than "moderate" or "severe" symptoms. However, some of the replies were not received until a month after the event, and this may have affected the recollections of respondents (ter Steege et al., 2008). In studies that have looked at any occurrence of ETAP during the previous year, there has been some confusion as to whether a symptom occurring only "rarely" should be regarded as present or absent (Keeffe et al., 1984; Peters et al., 1999; Riddoch & Trinick, 1988). Further, ETAP is by definition exercise-related and transient, but few investigators have enquired whether those reporting ETAP also had abdominal complaints when they were not exercising (Peters et al., 1999). Finally, the upper abdominal pain typical of ETAP has not always been distinguished clearly from lower abdominal pain; athletes more commonly complain of lower than of upper abdominal symptoms (Moses, 1990).

Despite these methodological issues, the reported prevalence of ETAP during long-distance walking and running events (16-32%) seems relatively consistent across most surveys; the main exception (2%) was a 4-day low intensity (6-7 km) walking event (Peters et al., 1999). Potential modifying factors include age and sex, the type of activity and the intensity of effort of effort relative to the individual's training status.

*Age and sex*

Twelve reports have discussed effects of sex and age upon the prevalence of ETAP (Table 2). Depending in part on the average age and the age-range of the sample, ETAP is more commonly reported by young than by older individuals. Possibly, in events such as a "fun marathon," younger individuals exert themselves to a greater extent than those who are older. An age effect was observed in some studies (Keeffe et al. (1984), Morton & Callister (2000), Morton & Callister (2002), Riddoch & Trinick (1988), Sinclair (1951), ter Steege et al., (2008), Worobetz and Gerard (1985)), but not by other (Halvorsen et al. (1990), Koistinen et al. (1991), Peters et al. (1999), Sullivan & Wong, (1992)). Morton & Callister (2002) found a prevalence of ETAP of 77% in those under the age of 20 years, compared with 40% in those over the age of 40 years; moreover, there was a moderation of the severity of pain in older individuals (Morton et al., 2005).

**Table 2: Age & sex differences in the prevalence of exercise-related transient abdominal pain.**

| Authors | Activity | Population | Sample | Effects of age & sex | Comment |
|---|---|---|---|---|---|
| Halvorsen et al., (1990) | Marathon running | Marathoners | 279/2800 = 10% | Gastro-intestinal problems more frequent in females. No effect of age | Unclear if sex difference is in ETAP. Mean age 39 yr; 52/279 female |
| Keeffe et al., (1984) | Marathon running | Marathoners | 707/1700 runners (41.6%), median distance 41-50 miles/week | Abdominal cramps greater if age <20 yr than if > 40 yr; also twice as frequent in women than in men with all categories of run | Occasionally or frequently vs. rarely or never. Median age 30-40; 85% men |
| Koistinen et al., (1991) | Distance running (10.5, 21 or 42 km) | Joggers to national competitors | 230 of 426 (55%) participants | No effect of age; symptoms more frequent in women | Average age 32 yr (10.5 km), 35 yr (21 km), 38 yr (42 km); 45/230 women |
| Morton & Callister (2002) | 6 different sports | | 965/1016 (95%) | Prevalence and severity of ETAP decreased with age; no effect of sex | Mean age 28.5 yr, 54% male |
| Morton et al., (2005) | 14 km fun run (76% runners, 24% walkers) | Varied level of experience | 848/893 (95%) of participants | ETAP more common in women and younger individuals | Sex differences in pre-event meal. Median age 21-30 yr; Runners 186/627 women. Walkers 132/198 women. |
| Peters et al., (1993) | Running<br>Cycling<br>Triathlon | Marathoners<br>Elite cyclists<br>Elite Triathloners | 165/177 = 93%<br>160/191 = 84%<br>143/201 = 71% | Lower abdominal symptoms more frequent in young, and in women (with exception of triathlon) | (never vs. sometimes (<50%), often (>50%) or always. Narrow age range roughly equal numbers of men and women. |
| Peters et al., (1999) | 4-day walk 40-50 km/day | 79 men, 76 women aged 30-49 yr | 154/480 = 32% | No effect of age (narrow age range). No mention of effect of sex | No time loss vs. delayed walk vs. dropped out. Age 30-49 yr, 243/480 women |
| Rehrer et al., (1992) | 67 km ultramarathon with 1900 m change of altitude | 158 men, 12 women distance runners | 170/? | Side ache more common in women than in men | Mean age 40 yr (men), 35 yr (women) 12/170 women, |
| Riddoch & Trinick (1988) | Marathon running | Marathoners , 92% male, average age 34 yr, running 36 miles/wk | 471/1750 (27%) of participants in Marathon | Abdominal cramps more frequent in women and younger runners (< 34 yr) | Mean age 34 yr; 38/471 women |
| Sullivan & Wong, (1992) | Distance running | Running club, men & women | 109 of 134 (81.3%) of members who ran > 3 times/wk | No significant effect of age; no comment on sex | Mean age 39 yr (men), 34 yr (women) 31/109 women |
| ter Steege & Kolkman, (2012); ter Steege et al., (2008) | Recreational running, 10, 21 or 42 km | Recreational runners, 70% male | 1281/2076 = 62% | Symptoms more prevalent in women and younger runners | Median age ~ 40 yr, 30% women |
| Worobetz & Gerrard (1985) | Endurance event | Enduro participants | 70 of 119 (59%) participants | More common in young than in old, women > men | Unclear if sex difference is in ETAP |

Many studies have included relatively few female athletes. Nevertheless, nine of 12 studies found symptoms more common in women than in men. Two reports appear to refer to lower abdominal symptoms in general rather than ETAP specifically. Further, in many studies, female athletes have had a substantially lower average age than the male participants, and in one study comment was also made on a sex-related difference in pre-event diet (Morton et al., 2005).

*Type of physical activity*

A survey of 965 regular participants in various sports compared the symptoms of ETAP across 6 different types of physical activity. The occurrence of ETAP over the

past year had a prevalence of 69% in runners, 75% in swimmers, 52% in aerobics participants, 47% in basketball players, and 62% in horse-riders, but only 32% in cyclists (Morton & Callister, 2000). However, the authors of this report later acknowledged that age, sex and training levels differed across the 6 types of activity. In a reanalysis of the data that controlled for differences in age and training status, Morton & Callister (2002) found that relative to cycling, running, horse-riding, swimming and aerobics were still respectively 10.5, 9, 2.5 and 2.5 times more likely to provoke ETAP. Other investigators have also noted a lower prevalence of ETAP in cyclists than in distance runners (Rehrer & Meijer, 1991), and in the cycling and swimming portions of a triathlon relative to the running segment (Peters et al., 1999; Peters et al., 1993; Sullivan & Wong, 1992). Thus, in a survey of 110 triathletes, 68% reported ETAP during running, but only 15% during swimming and 8% during cycling (Sullivan, 1987). Likewise, in laboratory trials where 1 hour of cycling was alternated with 1 h of treadmill running, gastrointestinal symptoms occurred more frequently and lasted longer when running than when cycling. One biomechanical factor differentiating cyclists from runners is a less marked oscillatory movement of the body, a point confirmed by accelerometer measurements made during both running and cycling (Rehrer & Meijer, 1991). In triathlon participants, the cumulative duration of physical activity could also be a factor, since running follows typically the cycling segment of the event (Peters et al., 1993).

Sinclair (1951) maintained that ETAP was particularly likely to develop during downhill running, although in contrast Morton et al. (2005) noted symptoms during flat (42%) and uphill (28%) portions of the Sydney City to Surf community run, as well as when running downhill (30%).

*Intensity and duration of effort*

Although ETAP can occur with the relatively low intensity effort of horse-riding (Morton & Callister, 2000), several reports have suggested that both the incidence and the severity of abdominal symptoms are influenced by the intensity of exercise (Peters et al., 1993; Riddoch & Trinick, 1988; Sinclair, 1951; Sullivan & Wong, 1992). Gastric emptying is delayed, and the risk of rectal bleeding increases with high intensity effort (Peters et al., 1999), but experimental evidence regarding the effects of exercise intensity and duration upon ETAP is quite limited.

Questioning of 848 participants in the 14 km Sydney "City-to-Surf" event found 30% of runners but only 16% of walkers reporting ETAP (Morton et al., 2005); symptoms were not only less frequent, but also less severe among the walkers, suggesting that the intensity of effort may have influenced the incidence of ETAP. However, more women were walkers, the level of training was likely lower for the walkers, and movement characteristics also differ between walking and running. Likewise, although the apparently greater prevalence of ETAP in younger athletes (Table 2) could reflect an effect from a greater intensity of effort, there are other possible explanations, including an age-related dropout among those who have experienced frequent or severe ETAP.

The prevalence of complaints is greater after a "hard" than after an "easy" run (Keeffe et al., 1984; Riddoch & Trinick, 1988; Sullivan & Wong, 1992). Issues of inter-subject differences in

susceptibility are overcome in such comparisons, but responses to the questionnaire descriptor of "hard" could reflect either the intensity or the duration of a run. Multiple regression analysis found that lactate concentrations, a probable correlate of intensity, were correlated with side-ache (Halvorsen et al., 1990).

In terms of exercise duration, "side-ache" was reported by 19% of 170 contestants during a 67 km ultra-marathon that also involved a substantial 1900 m change of altitude (Rehrer et al., 1992). This is similar to what others have reported for marathon events (Table 1). A survey from an event in Northern Finland showed a prevalence of ETAP of 32% in those who ran only 10.5 km, 21% in those running 21 km, and 16% in those completing the full-marathon course (Koistinen et al., 1991). However, the effect of distance was here confounded with differences in training; respective weekly running distances for the 3 groups were 26, 48 and 63 km.

*Training status*

The training status of individual runners has typically been compared in terms of their weekly training distances. or event completion times, although plainly the latter measures can become confounded with the individual's intensity of effort. Capps (1941) found that ETAP disappeared with training in 2 athletes, but in 3 others symptoms continued even though they reached a high level of physical condition. Halvorsen et al. (1990) found no relationship between ETAP and weekly training load. In a 4-day walking event, Peters et al. (1999) noted a significant effect of event experience, but no influence of training status. The prevalence and severity of ETAP was unrelated to completion times in the Sydney City-to-Surf event (Morton et al., 2005), but a multiple regression analysis found that the frequency of occurrence of ETAP was less in those who trained more frequently (Morton & Callister, 2002). Although training may have some beneficial effect, it seems clear that ETAP can still occur in well-trained individuals.

*Diet*

Many athletes blame gastro-intestinal complaints including stitch upon food or drink consumed shortly before or during an event (Morton & Callister, 2000; Morton et al., 2005; Sinclair, 1951), with the ingestion of hypertonic solutions apparently causing the greatest problems (Morton et al., 2004; Plunkett & Hopkins, 1999; Rehrer et al., 1990).

Several authors have reported that fluid ingestion has an adverse effect upon the risk of ETAP (Morton et al., 2004; Pauwels, 2012; Peters et al., 1993; Plunkett & Hopkins, 1999). This might reflect a greater effect of vibration when mechanical forces are acting upon a full stomach. On the other hand, several investigators have also reported that dehydration sufficient to cause a decrease in body mass of > 4% increases the likelihood of abdominal symptoms (de Oliveira & Burini, 2011; Rehrer et al., 1989; Rehrer et al., 1990), and in one report complaints were initiated by drinking after a period of dehydration (Halvorsen & Ritland, 1992). Possibly, the symptoms in some of these studies were from a gastric cramp unrelated to ETAP.

Sinclair (1951) observed ETAP in 30/35 individuals when they ran in the post-prandial state. One precursor of ETAP identified in the questioning of participants in the City-to-Surf event was

the consumption of a large meal in the period 1-2 hours prior to the run (Morton et al., 2005). However, others have found that a gastric cramp was less likely if subjects took fluids and a high fat meal prior to competition (Stuempfle et al., 2013). A large survey of distance runners found no relationship between ETAP and the ingestion of either food or fluids (ter Steege et al., 2008). Likewise, Koistinen et al. (1991) and Rehrer et al. (1992) found no relationship between symptoms and the volume of fluid ingested during an event, Again, the ingestion of a dairy-based meal 90 minutes prior to 80 minutes of exercise at 60% of $\dot{V}O_{2max}$ had no effect upon abdominal symptoms relative to consumption of a non-dairy meal (Haakonssen et al., 2014).

The influence of ingesting differing types of fluid was examined systematically in 40 subjects who reported vulnerability to ETAP (Morton et al., 2004). Each individual performed four 23-minute bouts of treadmill exercise at a self-selected recreational running speed (an average of 10.3 $km \cdot h^{-1}$); 16/40 subjects reported ETAP if no fluid was ingested before or during exercise, 28/40 were affected if they drank flavoured water or Gatorade, and 32/38 were affected if they drank a fruit juice with a high carbohydrate content. Peters et al. (1993) had subjects drink either a fructose, sucrose or a placebo drink during a 3-hour laboratory trial; they, also, found that side-ache was more prevalent with ingestion of the two carbohydrate drinks than with the placebo. Possibly, the hypertonic drink slowed gastric emptying, thus increasing tension on the gastric ligaments. However, the fact that a substantial proportion of the runners in this study experienced symptoms when no fluid was ingested speaks strongly against bloating of the stomach as the sole cause of ETAP.

*Pain characteristics*

A consideration of pain characteristics is important to differential diagnosis (below). The pain of ETAP first arises after prolonged exercise, and is well-localized in 88% of those who are affected (Morton & Callister, 2000). Most commonly, it is reported in the right (46%) or left (23%) lumbar region (Morton et al., 2005). It is variously described as an aching (25%), sharp (22%), cramping (22%), stabbing (11%) or pulling (11%) sensation (Morton et al., 2005). The severity is sufficient to cause a deterioration of performance in 20% (Halvorsen et al., 1990; Halvorsen & Ritland, 1992) to 42% (Morton et al., 2005) of complainants; Morton et al. (2005) found that 36% of runners slowed their pace, and 6% stopped running entirely, although 64% found complete relief and 31% partial relief if they continued to participate in the event. Abdominal complaints accounted for a total of 23% of drop-outs from a 161-km marathon (Hoffman & Fogard, 2011), although it is unclear what proportion of the affected athletes would be classed as having developed ETAP. Among 155 participants in a 4-day walking event, side-ache was infrequent (4/155); although 2 of the group dropped out of the event because of abdominal symptoms, neither of these attributed this to a side-ache (Peters et al., 1999).

In the survey of 848 Sydney City to Surf participants, ETAP was weakly correlated with reports of nausea, and bore some relationship to shoulder-tip pain, a site of reference for diaphragmatic sensations. However, ETAP was unrelated to other gastro-intestinal symptoms such

as belching and flatulence (Morton et al., 2005). Sinclair (1951) found an association between ETAP and shoulder tip pain in 28/123 athletes. A report based on a small sample of triathlon contestants also noted a relationship between side ache and belching, both of which were correlated with one measure of the intensity of effort, the serum lactate concentration (Peters et al., 1993).

In general, symptoms are relieved soon after stopping exercise, but if ETAP has been severe, some residual soreness may persist after completion of an event (Eichner, 2006).

*Differential diagnosis*

ETAP usually resolves soon after moderating or ceasing physical activity, and can then be treated expectantly. However, it is important for both a runner and health personnel supervising an athletic event to exclude more serious chronic disorders before adopting such an approach. Some authors suggest the need for a detailed physical examination, blood count, measurement of hepatic and pancreatic enzymes and ultrasonography (Dimeo et al., 2004), whereas others consider that a careful history and physical examination usually suffice to exclude more serious diagnoses (Eichner, 2006). Many in a long list of more dangerous causes of abdominal pain (Table 3) are distinguished by a sudden onset in an individual who has previously carried out a similar exercise many times without abdominal pain. Other pointers to a condition other than a functional stitch include pre-exercise complaints, and particularly the persistence or worsening of discomfort after exercise has ceased. Among the many pathologies that can give rise to abdominal pain, we will comment briefly upon mesenteric ischaemia, median arcuate ligament syndrome, and lesions of the abdominal wall.

**Table 3: A partial listing of conditions to be differentiated from an Athlete's Stitch.**

- mesenteric ischaemia (see text)
- median arcuate ligament syndrome (see text)
- lesions of the abdominal muscles (see text)
- myocardial ischaemia
- pulmonary embolus (Ouyang et al., 2010)
- oesophagitis, gastritis, and gastro-oesophageal reflux (Kraus et al, 1990; Moustafellos et al., 2006; Waterman & Kapur, 2012)
- gastro-intestinal motility disorders (Green, 1993)
- gastroduodenal ulcer or malignancy (Waterman & Kapur, 2012)
- colonic spasm (McMahon et al., 1999)
- caecal volvulus (Pruett et al., 1985)
- chronic constipation (Anderson, 1992)
- ovarian cyst (Liu et al., 2008)
- splenic infarction
- diaphragmatic rupture (Yang et al., 2010)
- excessive mobility of the kidney (Leslie, 1983)
- renal colic (Muir, 2009)
- acute renal failure and/or rhabdomyolysis (Haas & Bohnkewr, 1999; Martinez Lopez et al., 2012)
- cholangitis (Dimeo et al., 2004; Touzios et al, 2005)
- pancreatitis (Touzios et al., 2005)
- stress fracture of the ribs
- chronic inflammatory bowel disease
- intra-abdominal and gall-bladder adhesions (Dimeo et al., 2004; Lauder & Moses, 1995)
- various infections including appendicitis (Egloff et al., 2009; Eichner, 2006)

*Mesenteric ischaemia*

Mesenteric ischaemia is a normal component of the physiological response to very vigorous and prolonged exercise (Shephard, 1982), and it may be one factor contributing to ETAP in a healthy adult. Mensink and colleagues (2006) found that 48% of 107 patients with chronic mesenteric ischaemia developed symptoms during exercise. Symptoms of mesenteric ischaemia can develop in the elderly with a more modest bout of exercise, reflecting atherosclerotic narrowing of the coeliac vessels.

Demetriou et al., (2010) described an elderly man who experienced severe epigastric pain after walking only a short distance. Angiography demonstrated a marked narrowing of the coeliac artery. Performing an angioplasty on the affected vessel relieved the patient's symptoms.

Severe mesenteric ischaemia is often accompanied by a bloody diarrhoea (Moses, 2005). This plainly is a warning to stop exercising and undergo a thorough evaluation. Sometimes, a blood transfusion may be required, and on occasion it can be life-threatening. Chronic mesenteric vascular insufficiency can often be diagnosed in the laboratory, based upon the development of a large partial pressure gradient of $CO_2$ between gastric and arterial blood during exercise (Otte et al., 2005).

*Median arcuate ligament syndrome*

Severe, exercise-related abdominal pain and diarrhoea can arise if the median arcuate ligament compresses the coeliac artery. Again, there is visceral ischaemia, but there is usually a history of weight loss and post-prandial pain while sitting at rest, and sometimes an epigastric bruit can be detected. Symptoms are relieved by surgical division of the constricting ligament (Desmond & Roberts, 2004).

*Lesions of the abdominal muscles*

A strain of the rectus abdominis or oblique muscles, or a rectal sheath haematoma can give rise to abdominal pain. Although sometimes precipitated by a specific bout of vigorous exercise, each of these conditions are usually one-time events, and they become worse rather than better once the bout of activity has ceased. Creatine kinase levels typically are elevated, and the rectal sheath haematoma is usually accompanied by scrotal swelling and pain (Auten et al., 2010; Choi & Lee, 2009; Costello & Wright, 2005; Jansen et al., 2008; Johnson, 2006; Jones et al., 2010; Oh et al., 2010). The gastro-intestinal tract can also be compressed by a hypertrophied psoas muscle, but this seems more likely to cause diarrhoea than ETAP (Dawson, 1985).

*Etiology of ETAP*

Many potential etiologies of ETAP have been suggested, but a consensus on causation has yet to be reached. Disagreements reflect in part the use of univariate rather than multivariate analyses (Peters et al., 1993). Potential hypotheses may be grouped under the headings of visceral ischaemia, visceral vibration, ischaemia and/or spasm of the respiratory muscles, postural disorders, peritoneal irritation, and psychological factors.

*Visceral ischaemia*

Visceral ischaemia is one of the older explanations of ETAP (Gil et al., 1998; Moses, 2005; Mossler, 1878) It is widely agreed that prolonged and vigorous exercise causes a major decrease in visceral blood flow, as discussed above. Moreover, as already noted], mesenteric ischaemia can be extremely painful, and in extreme cases it can lead to penetration of the gut wall by endotoxins, with fatal consequences (Jeukendrup, Vet-Joop, & Sturk, 2000; Moses, 2005). However, an argument against this hypothesis is that the timing of ETAP is poorly correlated with the gradual decrease of visceral blood flow that is seen in young athletes over the course of an endurance event (Plunkett & Hopkins, 1999).

On the basis of limited evidence, some early investigators linked ETAP to other

vascular changes in the viscera, including a congestion or contraction of the spleen and/or the liver. Thus Benjamin (1923) maintained that faulty vasomotor regulation led to a swelling of the liver and spleen during exercise; however, he relied on the highly fallacious technique of abdominal percussion to determine the extent of liver enlargement. Other early investigators argued for a painful contraction of the spleen (Barcroft, 1926; Rautmann, 1927), or splenic tension (Mosse, 1927). There is indeed some evidence that the human splenic capsule contains contractile muscle fibres, and that splenic volume decreases during vigorous exercise (Laub et al., 1993; Otto et al., 1995; Stewart & McKenzie, 2002), but there is no compelling evidence that this is the cause of ETAP.

*Visceral vibration*

Because the pain of ETAP is typically sub-costal in location, and is seen more commonly during running than in cycling, many have espoused the hypothesis that visceral vibration places a mechanical stress on the visceral ligaments at their site of attachment to the diaphragm (Herxheimer, 1927; Plunkett & Hopkins, 1999; Schmidt, 1931; Sinclair, 1951). This tension could be exacerbated by a slowing of gastric emptying and thus distension of the stomach (Morton & Callister, 2000; Plunkett & Hopkins, 1999). In support of the vibration hypothesis, symptoms are greater during running than during cycling, and eased by abdominal exercises, breathing out through pursed lips, and wearing an abdominal belt (Eichner, 2006). On the other hand, there is a high prevalence of ETAP in swimmers, where one would anticipate much less vibration of the viscera than during running. Moreover, the symptoms normally experienced during running are not exacerbated by running on a hard surface or by relaxing the abdomen, both of which would be expected to increase visceral vibration (Eichner, 2006), and fluoroscopy shows no change in diaphragmatic movement when a person is running after ingesting a large meal (Sinclair, 1951).

Nevertheless, mechanical trauma has been suggested as causing a caecal slap syndrome (Porter, 1982), and excessive movement of the kidneys (Leslie, 1983), with evidence of visceral irritation that includes a release of prostaglandins (Beubler & Juan, 1978) and/or vasoactive intestinal polypeptide (MacLaren et al., 1995; Opstad, 1987).

*Respiratory muscle ischaemia or spasm*

Another early explanation of ETAP was an ischaemia and/or spasm of the diaphragm (Capps, 1941; Eichner, 2006; Morton & Callister, 2000; Shephard, 1982) or intercostal muscles (Kugelmass, 1937). The idea of respiratory muscle involvement was sparked by the frequent periumbilical/subdiaphragmatic localization of the pain, and referral of symptoms to the shoulder tip; although the latter phenomenon is seen in only about a quarter of cases of ETAP, it is suggestive of phrenic nerve irritation (Morton & Callister, 2002). Nevertheless, there are several pointers against respiratory muscle ischaemia: subjects can carry out sustained hyperventilation when they are already engaged in near maximal effort (Shephard, 1967), blood flow does not seem to be shunted away from the respiratory muscles during vigorous effort (Roussos & Macklem, 1982), spirometric measurements are unaffected by the development of ETAP (Morton & Callister, 2006), and symptoms

of ETAP are common in horse riders (where mechanical vibration of the viscera is considerable, but levels of ventilation are relatively low) (Eichner, 2006).

A cramping of the respiratory muscles also seems an unlikely explanation, since EMG recordings have shown no change in their electrical activity coincident with the development of ETAP (Morton & Callister, 2008).

*Postural disorders*

The hypothesis that ETAP is due to a postural disorder has quite a long history. Herxheimer (1927) and Kugelmass (1937) both suggested that symptoms were reduced by adopting a better posture, with associated improvements of breathing. Capps (1941) also noted that kyphosis was a predisposing factor, and Nassau (1935) postulated that there was a perversion of respiration, with shallow breathing and a relaxation of the abdomen during inspiration; in Nassau's opinion, this led to a stagnation of blood in the viscera, with congestion and distension of the abdominal organs. More recently, Morton & Callister (2010) again suggested that spinal problems had a role in the causation of ETAP. In support of this idea, they noted that symptoms could be reproduced in many athletes by palpating the thoracic facets T8 to T12, and relief was obtained by body inversion (Morton, 2004).

*Peritoneal Irritation*

Irritation of the parietal peritoneum can give rise to a sharp and localized pain (Capps & Coleman, 1922); it was thus suggested that exercise could generate pain through friction between the parietal and visceral layers of the peritoneum, with symptoms possibly exacerbated by changes in the properties of the peritoneal fluid caused by ingesting hypertonic liquids.

*Psychological factors*

Finally, ETAP is most frequently seen in young and inexperienced athletes, and some manifestations are apparently aggravated by anxiety and competitive stress, suggesting that psychological factors may play a role in exacerbating if not in causing symptoms (Morton & Callister, 2002; Priebe & Priebe, 1988; Riddoch & Trinick, 1988; Sullivan & Wong, 1992).

*Conclusions*

Points can be cited in favour of and against each of the current hypotheses concerning the etiology of ETAP, and much further research is required before a definitive cause can be ascribed.

*Prevention and management of ETAP*

Given that the etiology of ETAP is still far from clear, most of the proposed methods of prevention and treatment are empirical, based upon clinical impressions rather than a solid evidence-base. In terms of prevention, some competitors find benefit from dietary modification. In one survey, 26 of 131 respondents recommended avoiding food for 2-5 hours before an event (Keeffe et al., 1984). Likewise, 35% of a sample of distance runners from Northern Ireland thought that the best remedy was to run in the fasted state (Riddoch & Trinick, 1988). The consumption of fluid and drink should certainly be limited in the 2 hours preceding an event, and in particular drinks with a high carbohydrate content should be avoided (Morton et al., 2004).

Symptoms tend to be less frequent in those who are well-trained (Waterman & Kapur, 2012), and thus physical preparation for an event should be optimized. Some investigators have found benefit in a specific strengthening the diaphragm, postural, and abdominal muscles. One study of 50 runners found that symptoms were less common in individuals with strong trunk muscles and a large transversus abdominis (Mole et al., 2014); these muscles are important to spinal stability (Hodges, 1999). It may also be helpful to breath with a full exhalation, coordinating breathing with foot strikes, and minimizing torso movement (Eichner, 2006).

Finally, the recreational athlete may find it helpful to replace endurance running by some other pursuit where ETAPO is less prevalent.

If what appears to be ETAP develops during or following an event, it is important first to exclude more serious causes of abdominal pain, as discussed above. Classical sources of relief have been to bend over, to apply local pressure or an abdominal binder, to breathe through pursed lips, to tighten the abdominal muscles, and to slow the pace until symptoms disappear (Herxheimer, 1927). As a longer-term measure, mobilization and/or manipulation of the thoracic spine has been advocated by some chiropractors, apparently with success relative to placebo treatments (DeFranca & Levine, 1995; Morton & Aune, 2004; Muir, 2009; Schiller, 2001), Other empirical recommendations have included a stretching of the psoas and quadratus lumborum muscles (Muir, 2009). Finally, where symptoms appear to have a major psychological component, athletes should be advised that there are no major sequelae to ETAP, and if more dangerous diagnoses have been excluded, it is not imperative to abandon an event.

## Discussion and Conclusions

ETAP is a frequent occurrence in many classes of endurance activity. About a fifth of participants are likely to be affected in any given endurance event, with younger, less experienced and female athletes being the predominant victims. Many causes of ETAP have been postulated, including visceral ischaemia, visceral vibration, ischaemia and/or spasm of the respiratory muscles, postural disorders, peritoneal irritation, and psychological factors. Although ETAP appears to be a single condition, it has yet be established that there are not several similar syndromes. Given the prevalence of ETAP and its negative effects upon athletes, further research is urgently needed to evaluate current hypotheses and to replace empirical measures of doubtful efficacy by evidence-based tactics for prevention and treatment. A first step to any major investigation would be to establish a clear consensus on those symptoms that would give an unequivocal diagnosis of ETAP. Possibly, the contribution of visceral ischaemia to ETAP could also be examined by the provision of oxygen to those attending emergency tents at athletic events.

From the viewpoint of sports physicians, sports scientists and organizers of athletic events, perhaps the most vital task is to distinguish ETAP from a long list of other more dangerous conditions. A careful history and physical examination will often reveal that the athlete has suffered similar symptoms on many previous occasions. Typically, there will be no symptom or sign other than abdominal pain, induced only after prolonged exercise, and quickly relieved

by a slowing or stopping of activity. ETAP may impair competitive performance, but it does not have any serious sequelae. Once the diagnosis has been clearly established, symptomatic treatment can thus be offered, and athletes can be encouraged to return to physical activity.

The risks of developing ETAP during an event appear to be reduced by optimizing the athlete's physical condition, strengthening abdominal and spinal muscles, and avoiding food and hypertonic fluids immediately before competition. A slowing of pace, bending, local pressure and application of an abdominal binder may give some immediate relief of symptoms. The merits of more long-term treatment by spinal manipulation have yet to be confirmed.

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## References

Anderson, C.R. (1992). A runner's recurrent abdominal pain. *Physician & Sportsmedicine, 20(3)*, 81-83.

Auten, J.D., Schofer, J.M., Banks, S.L., & Rooney, T.B. (2010). Exercise-induced bilateral rectus sheath hematomas presenting as acute abdominal pain with scrotal swelling and pressure: case report and review. *Journal of Emergency Medicine, 38(3) e9-e12*. doi:10.1016/j.jemermed.2007.06.027.

Barcroft, J. (1926). Die stellung der milz im Kreislaufsystem. Ergebnisse der Physiologie. [The position of the spleen in the circulation. Physiological results]. *Ergebnisse der Physiologie, 25,* 818-861.

Benjamin, K. (1923). Zur Pathogenese der Wachstumsblässe. [Pathogenesis of growth pallor]. *Jahrbuch für Kinderheilkunde, 102,* 203.

Beubler, E., & Juan, H. (1978). PGE release, blood flow and transmucosal water movement after mechanical stimulation of the rat jejunal mucosa. *Naunyn Schmiedebergs Archiv für Pharmacologie, 305,* 91-95. doi: 10.1007/BF00497010.

Capps, J.A., & Coleman, G.H. (1922). Experimental observations on the localization of the pain sense in the parietal and diaphragmatic peritoneum. *Annals of Internal Medicine, 30,* 778-789. doi:10.1001/archinte.1922.00110120097004.

Capps, R.B. (1941). Causes of the so-called side-ache in normal persons. *Archives of Internal Medicine, 68,* 94-101. doi:10.1001/archinte.1941.00200070104006.

Choi, Y., & Lee, D. (2009). A case of rectus sheath hematoma caused by yoga exercise. *American Journal of Emergency Medicine, 27,* 899.e891-899.e892. doi: 10.1016/j.ajem.2008.11.003.

Costello, J., & Wright, J. (2005). Rectus sheath haematoma: 'a diagnostic dilemma'? *Emergency Medicine Journal, 22*, 523-524. doi:10.1136/emj.2004.015834.

Dawson, M. (1985). Psoas muscle hypertrophy: mechanical cause for jogger's trots. *British Medical Journal, 291,* 787-788. doi: http://dx.doi.org/10.1136/bmj.291.6498.787.

de Oliveira, E.P., & Burini, R.C. (2011). Food-dependent exercise-induced gastrointestinal distress. *Journal of the International Society of Sports Nutrition, 8:12*. doi: 10.1186/1550-2783-8-12.

DeFranca, G.G., & Levine, L.J. (1995). The T4 syndrome. *Journal of Manipulative and Physiological Therapeutics, 18(1),* 34-37. PMID: 7706958.

Demetriou, V., Liong, W.C., & Warakaulle, D. Exercise-induced abdominal pain: an unusual presentation of mesenteric ischaemia. *Journal of the Royal Society of Medicine, 103*, 455-457. doi: 10.1258/jrsm.2010.100210.

Desmond, C.P., & Roberts, S.K. (2004). Exercise-related abdominal pain as a manifestation of the median arcuate ligament syndrome.

*Scandinavian Journal of Gastroenterology, 19,* 1310-1313. doi: 10.1080 /00365520410008150.

Dimeo, F.C., Peters, J., & Guderian, H. (2004). Abdominal pain in long distance runners: case report and analysis of the literature. *British Journal of Sports Medicine, 38(5), e24*. doi:10.1136/bjsm.2003.007237.

Egloff, B.P., Dombrowsky, J., McKinnon, H., & O'Connor, F.G. (2009). Abdominal pain in a marathon runner. *Current Sports Medicine Reports, 8(2),* 49-51. doi: 10.1249/JSR.0b013e31819d6a07.

Eichner, E.R. (2006). Stitch in the side: causes, workup, and solutions. *Current Sports Medicine Reports, 5*, 289-292. doi: 10.1097/01.CSMR.0000306432.46908.b3.

Gil, S.M., Yazaki, E., & Evans, D.F. (1998). Aetiology of running-related gastrointestinal dysfunction. *Sports Medicine, 26,* 365-378. PMID: 9885094.

Green, G.A. (1993). Exercise-induced gastro-intestinal symptoms. A case-oriented approach. *Physician & Sportsmedicine, 21(10)*, 60-70.

Haakonssen, E.C., Ross, M.L., Cato, L.E., Nana, A., Knight, E.J., Jenkins, D.G., Martin, D.T. & Burke, L.M. (2014). Dairy-based preexercise meal does not affect gut comfort or time-trial performance in female cyclists. *International Journal of Sport Nutrition & Exercise Metabolism, 24(5),* 553-558. doi: 10.1123/ijsnem.2014-0069.

Haas, D.C., & Bohnker, B.K. (1999). Abdominal crunch-induced rhabdomyolysis presenting as right upper quadrant pain. *Military Medicine, 163(2),* 160-161. PMID: 10050578.

Halvorsen, F. A., Lyng, J., Glomsaker, T., & Ritland, S. (1990). Gastrointestinal disturbances in marathon runners. *British Journal of Sports Medicine, 24,* 266-268. PMID: 2097027.

Halvorsen, F.A., & Ritland, S. (1992). Gastrointestinal problems related to endurance event training. *Sports Medicine, 14(3),* 157-163. doi: 10.1007/s40279-014-0153-2.

Herxheimer, H. (1927). Ueber das "Seitenstechen." [On side-stitch]. *Deutsche Medizinische Wochenschrift, 53,* 1130-1131.

Hodges, P. (1999). Is there a role for transversus abdominis in lumbo-pelvic stability? *Manipulative Therapy, 4(2),* 74-86. PMID: 10509061.

Hoffman, M.D., & Fogard, K. (2011). Factors related to successful completion of a 161-km ultramarathon. *International Journal of Sports Physiology & Performance, 6,* 25-37. PMID: 21487147.

Jansen, J.A., Mens, J.M., Backx, F.J., Kolfschoten, N., & Stam, H.J. (2008). Treatment of longstanding groin pain in athletes: a systematic review. *Scandinavian Journal of Medicine & Science in Sports, 18(3),* 263-274. doi: 10.1111/j.1600-0838.2008.00790.x.

Jeukendrup, A.E., Vet-Joop, K., Sturk, A., Stegen, J.H., Senden, J. Saris, W.H., & Wagenmakers, A.J. (2000). Relationship between gastrointestinal complaints and endotoxaemia, cytokine release and the acute phase reaction during and after a long-distance triathlon in highly trained men. *Clinical Science, 98*, 47-55. PMID: 10600658.

Johnson, R. (2006). Abdominal wall injuries: rectus abdominis strains, oblique strains, rectus sheath haematoma. *Current Sports Medicine Reports, 5*, 99-103. PMID: 16529681.

Jones, E., Ho, G., & Howard, T. (2010). Abdominal pain in a female runner. *Current Sports Medicine Reports, 9(2),* 99-102. doi: 10.1249/JSR.0b013e3181d401dc.

Keeffe, E.B., Lowe, D.K., Goss, R., & Wayne, R. (1984). Gastrointestinal symptoms of marathon runners. *Western Journal of Medicine, 141(4),* 481-484. PMC1021858.

Koistinen, P.O., Jauhonen, P., Lehtola, J., Takala, T., & Salokannel, J. (1991). Gastrointestinal symptoms during endurance running. *Scandinavian Journal of Medicine & Science in Sports, 1*, 232-234. doi: 10.1111/j.1600-0838.1991.tb00302.x.

Kraus, B.B., Sinclair, J.W., & Castell, D.O. (1990). Gastroesophageal reflux in runners: characteristics and treatment. *Annals of Internal Medicine, 112,* 429-433. PMID: 2178535.

Kugelmass, I.N. (1937). The respiratory basis of periodic subcostal pain in children. *American Journal of Medical Science, 194,* 376-381. doi: 10.1097/00000441-193709000-00012.

Laub, M., Hvid-Jacobsen, K., Hovind, P., Kanstrup, I.L., Christensen, N.J., & Nielsen, S.L. (1993). Spleen emptying and venous hematocrit in

humans during exercise. *Journal of Applied Physiology, 74,* 1024-1026. PMID: 8387068.

Lauder, T.D., & Moses, F.M. (1995). Recurrent abdominal pain from abdominal adhesions in an endurance athlete. *Medicine & Science in Sports & Exercise, 27,* 623-625. PMID: 7674863.

Leslie, B.R. (1983). Exercise-induced abdominal pain. *Journal of the American Medical Association, 250,* 3283 (letter).

Liu, Y-P., Shih, S-L., & Yang, F-S. (2008). Sudden onset of right lower quadrant pain after heavy exercise. *American Family Physician, 78(3),* 379-384. PMID: 18711954.

MacLaren, D.P., Raine, N.M.,O'Connor, A.M., & Buchanan, K.D. (1995). Human gastrin and vasoactive intestinal polypeptide responses to endurance running in relation to training status and fluid ingested. *Clinical Science (London), 89*, 137-143. PMID: 7554754.

Martinez Lopez, A.B., Hidalgo Cebrián, R., & Rivas Garcia, A. (2012). Otras causas de dolor abdominal: rabdomiólisis aguda en relación con el ejercicio físico [Other causes of abdominal pain: acute rhabdomyolysis associated with physical exercise]. *Anales de Pediatria (Barcelona), 77(6)*, 352-353. doi: 10.1016/j.anpedi.2012.04.005.

McMahon, J.M., Underwood, E.S., & Kirby, W.E. (1999). Colonic spasm and pseudo-obstruction in an elongated colon secondary to exertion: Diagnosis by stress barium enema. *American Journal of Gastroenterology, 94(11)*, 3362-3364. doi:10.1111/j.1572-0241.1999.01554.x.

Mensink, P.B., van Petersen, A.S., Geelkerken, R.H., Otte, J.A., Huisman, A.B., & Kolkman, J.J. (2006). Clinical significance of splanchnic artery stenosis. *British Journal of Surgery, 93,* 1377-1382. doi: 10.1002/bjs.5481.

Mole, J L., Bird, M-L., & Fell, J.W. (2014). The effect of transversus abdominis activation on exercise-related transient abdominal pain. *Journal of Science & Medicine in Sport, 17,* 261-265. doi: 10.1016/j.jsams.2013.05.018.

Morton, D.P. (2003). Exercise related transient abdominal pain. *British Journal of Sports Medicine, 37,* 287-288. doi: 10.1007/s40279-014-0245-z.

Morton, D.P., Aragón-Vargas, L.F., & Callister, R. (2004). Effect of ingested fluid composition on exercise-related transient abdominal pain. *International Journal of Sport Nutrition & Exercise Metabolism, 14,* 197-208. PMID: 15118193.

Morton, D.P., & Aune, T. (2004). Runner's stitch and the thoracic spine. *British Journal of Sports Medicine, 38(2),* 240. PMC1724783.

Morton, D.P., & Callister, R. (2000). Characteristics and aetiology of exercise-related transient abdominal pain. *Medicine & Science in Sports & Exercise, 32(2),* 432-438. PMID: 10694128.

Morton, D.P., & Callister, R. (2002). Factors influencing exercise-related transient abdominal pain. *Medicine & Science in Sports & Exercise, 34,* 745-749. PMID: 11984289.

Morton, D.P., & Callister, R. (2006). Spirometry measurements during an episode of exercise-related transient abdominal pain. *International Journal of Sports & Physiological Performance, 1*, 336-346. PMID: 19124891.

Morton, D.P., & Callister, R. (2008). EMG activity is not elevated during exercise-related transient abdominal pain. *Journal of Science & Medicine in Sport, 11,* 569-574. PMID: 17703996.

Morton, D.P., & Callister, R. (2010). Influence of posture and body type on the experience of exercise-related transient abdominal pain. *Journal of Science & Medicine in Sport, 13*, 485-488. doi: http://dx.doi.org/10.1016/j.jsams.2009.10.487

Morton, D.P., & Callister, R. (2015). Exercise-related transient abdominal pain (ETAP). *Sports Medicine, 45,* 23-35. doi: 10.1007/s40279-014-0245-z.

Morton, D.P., Richards, D., & Callister, R. (2005). Epidemiology of exercise-related transient abdominal pain at the the Sydney City to Surf community run. *Journal of Science & Medicine in Sport, 8(2),* 152-162. doi:10.1016/S1440-2440(05)80006-4.

Moses, F.M. (1990). The effect of exercise on the gastro-inbtestinal tract. *Sports Medicine, 9*, 159-172. PMID: 2180030.

Moses, F.M. (2005). Exercise-associated intestinal ischemia. *Current Sports Medicine Reports, 4*, 91-95. doi: 10.1097/01.CSMR.0000306079.74945.ea.

Mosse, M. (1927). *Medizin Welt, 1*, 17. (cited by Kugelmass, 1937).

Mossler, F. (1878). *Ziemssen's Handbuch der speziellen Pathologie und Therapie, Vol. 8*. Leipzig, Germany F.C.W. Vogel.

Moustafellos, P., Hadjianstasiou, V., & Gray, D. (2006). Postural epigastric pain as a sign of CMV gastritis. *Transplantation Proceedings, 38,* 1357-1358. PMID: 16797302.

Muir, B. (2009). Exercise related transient abdominal pain: a case report and review of the literature. *Journal of the Canadian Chiropractic Association, 53(4)*, 251-260. PMC2796944.

Nassau, E. (1935). Uber das sogenannten ‘‘Seitenstechen’’ der Kinder [On the so-called side-stitch of children]. *Klinische Wochenschrift, 14,* 1252-1254.

Oh, J.H., Kim, T.H., Cha, S.J., & Kim, S.H. (2010). Rectus sheath hematoma caused by non-contact exercise mimicking acute appendicitis. *Journal of Emergency Medicine, 39(3), 39* e117-e119. doi: 10.1016/j.jemermed.2007.10.088.

Opstad, P.K. (1987). The plasma vasoactive intestinal peptide (VIP) response to exercise is increased after prolonged strain, sleep and energy deficiency and extinguished by glucose infusion. *Peptides, 8,* 175-178. doi:10.1016/0196-9781(87)90183-5.

Otte, J.A., Geelkerken, R.H., Oostveen, E., Mensink, P.B.F., Huisman, A.B., & Kolkman, J.J. (2005). Clinical impact of gastric exercise tonometry on diagnosis and management of chronic gastrointestinal ischemia. *Clinical Gastroenterology & Hepatology, 3,* 660-666. PMID: 16206498.

Otto, A.C., Rona du Toit, D.J., Pretorius, P.H., Lötter, M.G., & van Aswegen, A. (1995). The effect of exercise on normal splenic volume measured with SPECT. *Clinical Nuclear Medicine, 20(10),* 884-887. PMID: 8616992.

Ouyang, D.L., Chow, A.Y., Daly, T.K., Garza, D., & Matheson, G.O. (2010). Bilateral pulmonary emboli in a competitive gymnast. *Clinical Journal of Sports Medicine, 20,* 64-65. doi: 10.1097/JSM.0b013e3181c96806.

Pauwels, N. (2012). Bet 1. Is exercise-related abdominal pain (stitch) while running preventable? *Emergency Medicine Journal, 29,* 930-931. doi:10.1136/emermed-2012-201952.2.

Peters, A.M., Bos, M., Seebregts, L. Akkermans, L.M., van Berge Henegouwen, G.P., Bol, E., Mosterd, W.D. & de Vries, W.R. (1999). Gastrointestinal symptoms in long-distance runners, cyclists, and triathletes: prevalence, medication and etiology. *American Journal of Gastroenterology, 94,* 1570-1581. doi:10.1111/j.1572-0241.1999.01147.x.

Peters, A.M., Zweers, A.M., Backx, F.J., Bol, E., Hendricks, R.H.A., Mosterd, W.L., & De Vries, W.R. (1999). Gastrointestinal symptoms during long-distance walking. *Medicine & Science in Sports & Exercise, 31(6),* 767-773. PMID: 10378901.

Peters, H.P., Van Schelven, F.W., Verstappen, P.A., de Boer, R.W., Bol, E., Erich, W.B., van der Togt, C.R. & de Vries, W.R. (1993). Gastrointestinal problems as a function of carbohydrate supplements and mode of exercise. *Medicine & Science in Sports & Exercise, 25(11),* 1211-1224. PMID: 8289607.

Plunkett, B.T., & Hopkins, W.G. (1999). Investigation of the side pain "stitch" induced by running after fluid ingestion. *Medicine & Science in Sports & Exercise, 31(8)*, 1169-1175. PMID: 10449020.

Porter, A.M.W. (1982). Marathon running and the caecal slap syndrome. *British Journal of Sports Medicine, 16(3)*, 178. PMC1858957.

Priebe, W., & Priebe, J. (1988). Runner's diarrhoea- prevalence and clinical symptomatology. *American Journal of Gastroenterology, 79,* 827-828.

Pruett, T.L., Wilkins, M.E., & Gamble, W.G. (1985). Cecal volvulus: a different twist for the serious runner. *New England Journal of Medicine, 312,* 1262-1263. PMID: 3990725.

Rautmann, H.L. (1927). Ertrinkungstod und Wiederbelebung [Drowning and resuscitation]. *Medizin Welt, 1*, 1047.

Rehrer, N.J., Beckers, E.J., Brouns, F., & Ten Hoor, F. (1990). Effects of dehydration on gastric emptying and gastrointestinal distress while running. *Medicine & Science in Sports & Exercise, 22(6),* 790-795. PMID: 2287256.

Rehrer, N.J., Brouns, F., Beckers, E.J., Frey, W.O., Villiger, B., Riddoch, C.J., Menheere, P.P.C.A. & Saris, W.H.M. (1992). Physiological changes and gastro-intestinal symptoms as a result of ultra-endurance running. *European Journal of Applied Physiology, 64,* 1-8. PMID: 1735404.

Rehrer, N.J., Janssen, G.M.E., Brouns, F., & Saris, W.H.M. (1989). Fluid intake and gastrointestinal problems in runners

competing in a 25-km race and marathon. *International Journal of Sports Medicine, 10(Suppl. 1),* S22-S25. PMID: 2744925 .

Rehrer, N.J., & Meijer, C.A. (1991). Biomechanical vibration of of the abdominal region during running and bicycling. *Journal of Sports Medicine & Physical Fitness, 31*, 231-234. PMID: 1753730.

Rehrer, N.J., van Komenado, M.C., Meesler, T.A., Saris, W.H.M., & Brouns, F. (1990). Nutrition in relation to GI complaints among triathletes. *Medicine & Science in Sports & Exercise, 22(2 Suppl)*, S107. (abstract).

Riddoch, C., & Trinick, T. (1988). Gastrointestinal disturbances in marathon runners. *British Journal of Sports Medicine, 22*, 71-74. PMID: 3167507.

Roussos, C., & Macklem, P.T. (1982). The respiratory muscles. *New England Journal of Medicine, 307(13),* 786-797. PMID: 7050712.

Schiller, L. (2001). Effectiveness of spinal manipulative therapy in the treatment of mechanical thoracic spine pain: a pilot randomized clinical trial. *Journal of Manipulative and Physiological Therapy, 24(6),* 394-401. doi:10.1067/mmt.2001.116420.

Schmidt, F.A. (1931). *Unser Körper*. *[Our body].* Leipzig, Germany, Voigtländer.

Shephard, R.J. (1967). The maximum sustained voluntary ventilation in exercise. *Clinical Science, 32*, 167-176. PMID: 6022812.

Shephard, R.J. (1982). *Physiology & Biochemistry of Exercise*. New York, NY, Praeger Publications.

Shephard, R.J. (2015 a). Hiow fast must you trot? Vigorous exercise and diarrhoea. *Health & Fitness Journal of Canada*: In press.

Shephard, R.J. (2015 b). Occult bleeding, haematochezia and the endurance athlete: what are the risks? *Health & Fitness Journal of Canada*: In press.

Sinclair, J. D. (1951). Stitch: the side pain of athletes. *New Zealand Medical Journal, 50(280),* 607-612. PMID: 14891018.

Stewart, I.B., & McKenzie, D.C. (2002). The human spleen during physiological stress. *Sports Medicine, 32(6),* 361-369. PMID: 11980500

Stuempfle, K.J., Hoffman, M.D., & Hew-Butler, T. (2013). Association of gastrointestinal distress in ultramarathoners with race diet. *International Journal of Sport Nutrition & Exercise Metabolism, 23(2),* 103-109. PMID: 23006626.

Sullivan, S.N. (1981). The gastrointestinal symptoms of running. *New England Journal of Medicine, 304(15)*, 915. doi: 10.1056/NEJM198104093041522.

Sullivan, S.N. (1987). Exercise associated symptoms in triathletes. *Physician & Sportsmedicine, 15(9)*, 105-110.

Sullivan, S.N., & Wong, C. (1992). Runners' diarrhea. Different patterns and associated factors. *Journal of Clinical Gastroenterology, 14,* 101-104. PMID: 1556421.

ter Steege, R.W., & Kolkman, J.J. (2012). Review article: the pathophysiology and management of gastrointestinal symptoms during physical exercise, and the role of splanchnic blood flow. *Alimentary Pharmacology & Therapeutics, 35,* 516-528. doi:10.1111/j.1365-2036.2011.04980.x

ter Steege, R.W., Van der Palen, J., & Kolkman, J.J. (2008). Prevalence of gastrointestinal complaints in runners competing in a long distance run: an internet-based observational study in 1281 subjects. *Scandinavian Journal of Gastroenterology, 43(12),* 1477-1482. doi: 10.1080/00365520802321170.

Touzios, J.G., Krzywda, B., Nakeeb, A., & Pitt, H.A. (2005). Exercise-induced cholangitis and pancreatitis. *HPB (Oxford), 7(2)*, 124-128. doi: 10.1080/13651820510028882.

Waterman, J.J., & Kapur, R. (2012). Upper gastrointestinal issues in athletes. *Current Sports Medicine Reports, 11(2),* 99-104. doi: 10.1249/JSR.0b013e318249c311.

Worobetz, L.J., & Gerrard, D.F. (1985). Gastrointestinal symptoms during exercise in enduro athletes: prevalence and speculation on the aetiology. *New Zealand Medical Journal, 98(784)*, 644-646. PMID: 3861978.

Yang, Y.M., Yang, H.B., Park, J.S., Lee, S.W., & Kim, J.H. (2010). Spontaneous diaphragmatic rupture complicated by perforation of the stomach during Pilates. *American Journal of Emergency Medicine, 28*, 259.e251-259e.253. doi: 10.1016/j.ajem.2009.06.012.