Cecal volvulus in long-distance runners: A proposed mechanism

Participation in marathons and other endurance exercise, including formal sporting events such as triathlons, and the "Ironman" challenge are steadily increasing [1]. Specifically, the popularity of marathon running has increased dramatically: from an estimated 25,000 marathon finishers in 1976, to >500,000 in 2015; this represents a 20-fold increase in the past 4 decades [2].

The benefits of regular physical activity are well-documented; however, participation in endurance exercise is not without risk. Long-distance runners are susceptible to musculoskeletal injuries, electrolyte imbalances, cardiovascular events, dermatologic conditions, genitourinary syndromes and gastrointestinal (GI) side effects including ischemic colitis [3-9].

Exercise-related GI side effects include nausea, abdominal pain, diarrhea, and hematochezia; these are more frequent in runners as compared to participants in other endurance sports, such as cycling and swimming. These GI side effects are likely related to mechanical forces on the body, forces that are 2 times greater in running than in other endurance sports [10].

The general understanding has been that redundant or hypermobilized segments of the colon and colonic mesentery predispose to colonic volvulus [11]. Twisting of the large bowel occurs in the segments of the colon where the mesentery is thin and narrow. Inadequate cecal fixation to the retroperitoneum is thought to predispose to cecal volvulus (CV), which is a twisting of the cecum, ascending colon, and terminal ileum around the ileocolic mesentery. In up to 22% of human cadavers studied, the ascending colon was adequately mobile to allow for a CV [12]. This ascending colonic laxity has been characterized as "mobile cecum syndrome"; it was previously ascribed to a lack of fusion of the right colonic mesentery to the lateral abdominal wall and retroperitoneum [13]. Other proposed causes include a history of prior surgery, colonoscopy, multiple pregnancies, and colonic obstruction [13]. We propose another cause of CV: long-distance running and walking.

We report 6 new cases and 2 previously reported cases [14] of CV in endurance athletes. All patients underwent emergent right hemicolectomy and primary ileocolic anastomosis. Our total of 8 cases add to the evidence supporting the association between CV and long-distance running and walking. We believe that repetitive mechanical stress to the cecum and right colon during running or fast walking leads to stretching and effacement of the colonic mesentery, predisposing to exercise-related CV.

We retrospectively reviewed the records of 6 patients with CV during our 9-year study period from 2009 through 2017. Each patient had a history of endurance running or walking. We describe a mathematical model that may explain the correlation between running and cecal volvulus through biomechanical forces.

Patient 1 and Patient 2 were originally described in 1985 by one coauthor. We describe 6 additional patients with similar clinical characteristics (Table 1). The age range of the patients (4 women, 4 men) was 27 to 73 years. The mean body mass index (BMI) was 22.2. All patients were previously healthy had a history of frequent endurance exercise. One patient was pregnant when she developed CV. Two patients were originally misdiagnosed in the emergency department due to lack of concerning imaging findings and their otherwise good health. For 4 of the patients, preoperative imaging findings were consistent with CV (Fig. 1). Intraoperatively, all patients were noted to have thin, lax, cecal and ascending colonic mesentery (Fig. 2A). We propose that CV in our group of patients was associated with repetitive forces on the colonic mesentery associated with long-distance running and walking.

Exercise offers health benefits to nearly every organ system [3, 10]. Proposed GI health benefits include protection against the following: constipation, diverticular disease, inflammatory bowel disease, cholelithiasis, and colon cancer [10]. Yet exercise is also associated with adverse effects, including exercise-related transient abdominal pain (ETAP or "stitch"), gastroesophageal reflux, esophageal dysmotility, gastritis, abdominal cramping, nausea, vomiting, GI bleeding, iron deficiency "sports anemia", diarrhea and more severe complications such as ischemic colitis [3-5].

The underlying mechanisms are not entirely clear, but vascular, hormonal, and mechanical factors have all been proposed etiologies of exercise induced abdominal pain [15]. Ischemia is thought to be the result of exercise-induced shunting of blood flow to the skeletal muscle, heart, lungs, and brain—leading to an 80% decrease in splanchnic blood flow [15]. Up to 85% of ultramarathoners test positive for occult GI blood [16]. A variety of mechanical factors resulting from long-distance running and walking have also been proposed, including psoas muscle hypertrophy, the "cecal slap syndrome" (defined as the bruising of the cecum seen in marathon runners due to the repetitive 'slapping' of the posterior cecal wall against the abdominal musculature), and increased friction between the viscera and abdominal wall [17-19]. The mechanical stress during running may be due to repetitive up-and-down movements causing mechanical microtrauma to the abdominal viscera [10, 19, 20]. In animals, strenuous exercise is a reported risk factor for the development of colonic volvulus [21]. In 1985, CV associated with thin mesentery and lax retroperitoneal attachments in 2 long-distance runners was reported by one of our coauthors [14].

The incidence of CV is reported to range from 2.8 to 7.1 per million people per year [22]. In the United States, CV accounts for up to 7% of colonic obstructions; it involves twisting of the bowel around its mesenteric base (Fig. 2B). The sigmoid colon is the most common site, followed by the cecum, which accounts for up to 40% of all cases of colonic volvulus [13, 23]. Sigmoid volvulus is more common in elderly men, while CV tends to occur in younger women [24]. CV often presents with nausea, vomiting, pain, and abdominal distention.

Abdominal radiography detects CV in only about 50% of patients and is not diagnostically sensitive; nonspecific findings can include a dilated cecum with air-fluid levels and proximal small bowel distention. Computed tomography (CT) provides increased diagnostic sensitivity and findings include, a decompressed sigmoid colon with a dilated air-filled cecum, and the appearance of a closed loop obstruction; specific CT findings include the "X-marks-the-spot," whirl, split-wall, and ileocecal twist signs [13, 23, 25]. Despite the increased sensitivity of CT scans, in many occasions, CV is only diagnosed at the time of surgery [26], therefore emergency care providers should be extra vigilant to avoid missing this diagnosis as occurred in our patient series.

Table 1
Characteristics of our patients. All eight presented with cecal volvulus. Wk = week.

Patient #	1	2	3	4	5	6	7	8
Age/Sex	42 M	60 M	39 M	73F	33F	37F	39F	29 M
BMI	19.5	19.9	22.8	20.8	26	23	22.1	23.7
Exercise Habits	10 miles/wk; Ran >10 marathons	60 miles/wk; Ran 138 marathons	Runs >60 miles/wk	Ran >35 marathons	Walks >600 miles/yr	Runs 35 miles/wk; 3 marathons	Runs 40 miles/wk; 2 marathons	Daily elliptical use; 1 marathon

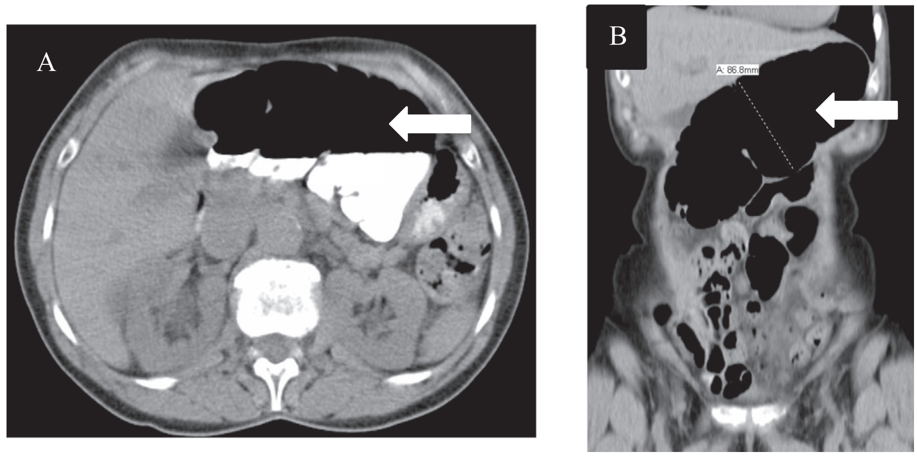


Fig. 1. Computed tomography (CT) scan (Patient 4; A- axial view, B- coronal view) on presentation to the emergency department. The cecum (depicted by white arrow) was notably dilated to 8.6 cm, with some evidence of air distal to the volvulus, suggesting a partial volvulus.

CV requires emergent surgical exploration and possible bowel resection. Colonic perforation occurs in 25% of patients; gangrene, in 50%. Those 2 findings increase patient mortality by 3-fold [13, 23]. Currently, the procedure of choice is a right hemicolectomy with a primary ileocolonic anastomosis [23]. Surgical reduction and cecopexy has also been reported, as has endoscopic reduction, but these alternative procedures are generally not recommended due to their association with a high risk of recurrence [13, 23]. A recent study at our multi-

A B

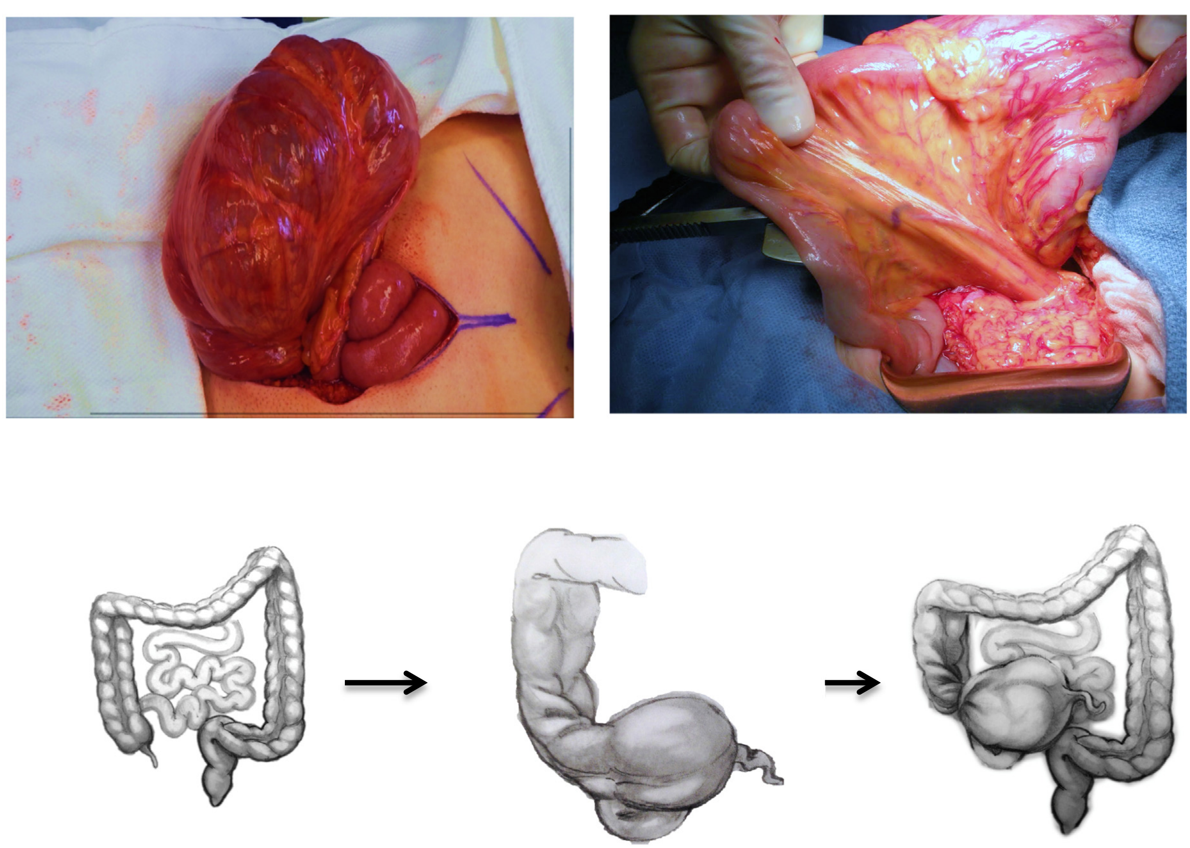
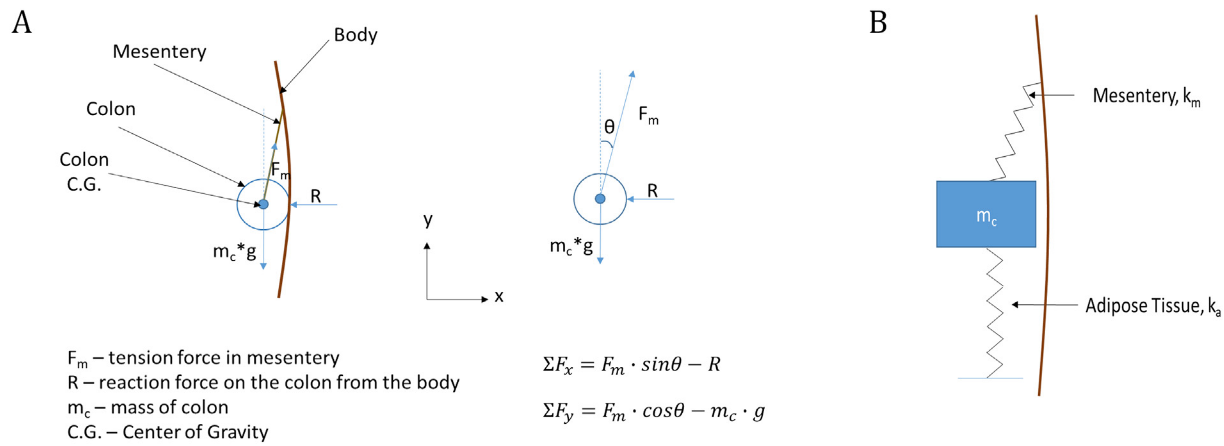


Fig. 2. A. Delivery of cecal volvulus through a laparoscopic hand-assist surgical incision prior to performing a right hemicolectomy. B. Intraoperative photographs of open surgery demonstrating the mobile cecal syndrome C. Illustrations demonstrating the sequence of events leading to cecal volvulus.



C

$$\Delta F_m = k_m \cdot \Delta s = k_m \cdot \left(\frac{m_c \cdot g}{k_m} + \sqrt{\frac{m_c^2 \cdot g^2}{k_m^2} + \frac{2 \cdot m_c \cdot g \cdot y_{max}}{k_m}} - \frac{m_c \cdot g}{cos\theta} \right)$$

Fig. 3. A. Diagram representing the forces on the colon hanging from a mesentery, while the body is at rest. B. The opposing effect of adipose tissue on the mesenteric force (Ka = stiffness coefficient of adipose tissue, Km = stiffness coefficient of the mesentery, mc = mass of the colon). D. Mathematical equation describing colonic forces during exercise. (ΔF_m = load on mesentery, k_m = mesenteric elasticity constant, g = force of gravity, m_c = mass of the colon, $\cdot y_{max}$ = maximum colonic vertical displacement, Δs = change in position of the colon).

institutional, health care system found a total of 53 cases that presented over a 6 year period, i.e., approximately, 10 patients per year [27], however, an exercise history is not routinely obtained from these patients. The six patients that we report in this study, were sequential patients that presented to a single surgeon who collected histories of endurance training.

We propose that exercise-related CV is the result of gradual stretching of the ascending colonic mesentery caused by repetitive vertical displacement (Fig. 3A, B, C). Our proposed mathematical model is based on physics of a spring [28]; during aggressive walking or running, intraabdominal forces vertically displace the colon, altering the length and shape of the mesentery [29]. We propose that the cecal mobilization is proportional to the frequency of the forces resulting from vertical displacement, and that cecal hypermobilization is inversely proportional to the patient's BMI and stride length. When these forces exceed the elastic recoil limit, mesenteric laxity results, and a propensity for CV develops.

Our equation describes the forces acting upon the colonic mesentery during exercise. It demonstrates that higher the vertical displacement (Δy_{max}) of the body's center of gravity, or the heavier the volume of stool (m_c), the higher the increased load (ΔF_m) in the mesentery will be during walking or running. Therefore, if the body's center of gravity is displaced more during running or fast walking than during normal walking, the mesentery will be subjected to higher loads. The magnitude of the mesenteric load, the velocity, and the kinetic and potential energies all depend on the position of the colon as it falls from its maximum vertical displacement to its maximum downward displacement during running.

We propose that cyclic mechanical forces of sufficient magnitude cause permanent elongation in biologic tissue [30, 31]. Our mathematical model may thereby explain why these forces lead to mesenteric laxity, resulting in chronic stretching and thereby increasing the prevalence of GI symptoms in runners. Anatomic differences in mesenteric laxity may also explain why some runners have a greater risk for CV. For example, visceral adipose tissue may 'cushion' the mesentery and protect against deformation (Fig. 3B). Visceral adiposity may therefore prevent and diminish the mesenteric elongation required for exercise associated CV according to our proposed mechanism; we note, none of our patients were obese, with an average BMI of 22.2.

Exercise-related volvuli may be more prone to occur in the cecum rather than the sigmoid colon, as the cecum is larger in dimension and can hold more liquid stool mass, thus making it heavier and, according to our equation, more prone to develop mesenteric laxity and volvulus. Small frequent stresses may not cause the mesentery to elongate, however, cumulative stresses over time may predispose to permanent mesenteric deformation and CV. As a living tissue and organ, the mesentery is expected to undergo remodeling as it is subjected to repeated loads. Mesenteric remodeling may therefore alter the stiffness (k_m), on the yield point, the load over which permanent deformation occurs, and on the ultimate strength, the load at which tissue will tear [32].

To our knowledge, in addition to the two cases reported earlier [14], no other study has evaluated the proposed association between long distance running and CV. We acknowledge the limitations of our study; the retrospective nature of this study, rarity of presentation and limited sampling of cases precludes our ability to determine causality. Additionally, 75% of the cases reported here, presented to a single provider who collected histories of long distance running, thus contributing to some selection bias. Clinical factors such as histories of chronic constipation, consumption of high-fiber diets, and late pregnancy, which have all previously been described as factors important in the development of CV may have confounded our results [24, 33, 34]. Our mathematical model attempts to explain the pathophysiological basis of CV development in athletes and may not directly explain other associated GI symptoms such as nausea, vomiting, abdominal pain and dysmotility. These symptoms may have a multifactorial, physiology origin and may be explained by the aforementioned vascular, mechanical and neurohormonal mechanisms. More studies using animal models and prospectively collected clinical data on exercise habits are essential to further validate our hypotheses.

5. Conclusion

Given the increasing number of long-distance runners and walkers, exercise-related CV should be a part of the differential diagnosis in those with abdominal pain. Our case series demonstrates a potential association between CV and long-distance running and walking in otherwise healthy patients. We propose that the repetitive vertical displacement of the colon during long-distance running and walking may be an independent risk factor for exercise-related CV, and emergency care providers need to be cognizant of eliciting a history of extreme endurance activities in patients presenting with clinical symptoms of colonic obstruction. Given the heterogeneity in clinical presentation, and the non-specificity of imaging studies, providers may fail to attain an accurate diagnosis, and in these circumstances discerning exercise habits may be particularly valuable.

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Brent D. Bauman
Jennifer E. Witt
Victor Vakayil*
Shumaila Anwer
Eric D. Irwin
Mary R. Kwaan
Timothy L. Pruett
James V. Harmon
Department of Surgery, University of Minnesota, MMC 450, 420 Delaware St SE, Minneapolis, MN 55455, United States of America
*Corresponding author.
E-mail addresses: bauma292@umn.edu (B. Bauman), witt0399@umn.edu (J.E. Witt), vvakayil@umn.edu (V. Vakayil), anwe0002@umn.edu (S. Anwerl), mkwaan@umn.edu (M.R. Kwaan), tlpruett@umn.edu (T.L. Pruett), harm0031@umn.edu (J.V. Harmon).

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