

ORIGINAL RESEARCH

An Assessment of Diarrhea Among Long-Distance Backpackers in the Sierra Nevada



Derek J. Meyer, MD; Amber Costantino, MA; Susanne Spano, MD

From the Department of Emergency Medicine, UCSF Fresno, Fresno, CA (Drs Meyer and Spano); and California State University–Fresno, Fresno, CA (Ms Constantino).

Introduction.—Diarrhea is a common problem among long-distance backpackers, ranging in overall incidence from 11–56% as reported by previous studies on the Appalachian Trail and Long Trail. Differences in age, sex, and regularity of standard backcountry hygiene recommendations and practices have been shown to significantly affect the incidence of diarrhea. No study to date has investigated these trends among long-distance backpackers on the John Muir Trail (JMT) in the Sierra Nevada mountain range of California.

Methods.—Retrospective analysis of online survey data gathered from long-distance backpackers who attempted a JMT trek in 2014. Data were assessed for the significance of variables that might contribute to the incidence and severity of on-trail diarrhea.

Results.—Of 737 valid responders, 16.4% reported experiencing diarrhea (82% with minimal/mild severity; 18% with significant severity). Regular hand sanitizer use was significantly correlated with more severe diarrhea ($P < .05$), but had no effect on incidence. Regular hand sanitizer users followed all other recommended hygiene practices as frequently as or better than those not using hand sanitizer regularly. Of all backpackers, 88% filtered or treated their drinking water regularly, with 18% of those reporting diarrhea of any severity.

Conclusions.—JMT backpackers have a comparatively lower incidence of diarrhea than backpackers on other major long-distance backpacking routes in the United States. Most JMT backpackers follow standard backcountry hygiene recommendations, including regular filtration or treatment of drinking water. No statistical significance was found between the incidence of diarrhea and compliance with standard hygiene recommendations. Regular hand sanitizer use was significantly correlated with more severe diarrhea but was not associated with incidence. There was no significant difference in compliance with standard backcountry hygiene practices between regular and infrequent hand sanitizer users.

Keywords: backpacking, diarrhea, John Muir Trail, Sierra Nevada, hand sanitizer

Introduction

The John Muir Trail (JMT), a world-famous long-distance backpacking trail in the Sierra Nevada mountain range of California, is often compared with other long-distance backpacking trails in the United States, such as the Appalachian Trail (AT), which stretches from Georgia to Maine, and the Long Trail in Vermont. In the past 25 years, several studies have found significant correlation between long-distance backpacker demographics and on-trail hiking behaviors and specific morbidities encountered during such activities. In these previous analyses, diarrhea was consistently regarded as a significant morbidity among long-

distance backpackers, ranging in overall reported incidence from 10.7 to 56%, depending on the year and geographical region surveyed.^{1–6} Furthermore, within previous AT studies, the incidence of diarrhea was found to differ among particular populations of backpackers, with variables including age, sex, and regularity of following standard backcountry recommendations for hand hygiene, dish washing, and water filtration practices.^{4–6} However, no studies to date have attempted to determine the incidence of diarrhea and the potentially implicit variables among long-distance backpackers in the Sierra Nevada or, specifically, on the JMT.

Methods

STUDY DESIGN

This is a retrospective analysis of online survey data gathered from long-distance backpackers who attempted

Corresponding author: Derek J. Meyer, 1350 NE 122nd Ave, Portland, OR 97230; e-mail: meyerdj@ah.org.

Submitted for publication May 2016.

Accepted for publication December 2016.

a JMT trip in 2014. Backpackers were recruited through JMT-related message boards on Yahoo! Groups and Facebook as well as through in-person recruitment on the JMT. Participants completed an online 60-page, 87-question posthike survey after the 2014 hiking season. The online survey and the original data were maintained by a private JMT enthusiast who granted permission for use of the data for this study. Institutional review board approval through the University of California, San Francisco was obtained for retrospective analysis of the survey data.

In the survey, participants were informed that the data may be used for future research and opted into the study by submitting the survey. All data were de-identified by replacing the personal e-mail used to link survey answers with a nonidentifying survey participant identification number. Survey data pertaining to backpacker demographics, on-trail hygiene practices, and diarrhea incidence and severity were analyzed.

SETTING AND SUBJECTS

The JMT is a long-distance backpacking trail in the Sierra Nevada mountain range of California, stretching from Yosemite Valley to Mount Whitney, the highest point in the contiguous United States. It passes through some of the crown jewels of America's park system: Yosemite, John Muir and Ansel Adams Wildernesses, Kings Canyon, and Sequoia National Parks. This 338- to 354-kilometers (210 to 220 miles)-long trail (depending on one's starting point) is generally accessible from July through September. For almost all of its length, the trail is in the High Sierra backcountry (above 2438 meters [8000 feet]) and within designated wilderness areas that require permits from either the National Park or Forest Service. Most backpackers attempt to through-hike the entire length of the JMT hike from north to south and complete the trek over the course of several weeks, with several resupply stops along the way. For the majority of its length, backpackers must obtain water from various trailside lakes and streams.

Participants who completed the survey included long-distance backpackers who had attempted some portion of the JMT in 2014. A total of 769 surveys were collected. In an effort to avoid inclusion of data from "day hikers" or "weekend backpackers" in our desired study population, respondents who completed less than 2 days' distance of total backpacking (for which a "day" was considered the average amount of miles hiked per day for all backpackers) were excluded. Seventeen backpackers were eliminated based on this criterion. Additionally, respondents who did not complete sections of the survey needed for data analyses were also excluded,

which removed 15 more backpackers. Following these exclusion criteria, our study comprised a population of 737 valid respondents from the 769 total received surveys.

STUDY DATA

From the 87-question survey, we analyzed response data associated with the following demographic variables: age, sex, prehike body weight, prehike physical activity (hours/week), prehike self-assessed physical condition, previous hiking or backpacking experience (days in previous 10 years), solo or group backpacking itinerary, on-trail average pack weight, on-trail hygiene compliance (water filtration/treatment, hand hygiene, etc), and posthike difficulty assessment (Table 1). Self-reported data on the incidence and severity of diarrhea were also examined, where severity was reported on a scale from 1 (minimal) to 5 (severe).

DATA ANALYSIS

Data analysis was performed by transferring the participants' responses from a Microsoft Office Excel spreadsheet into SPSS statistical software. Statistical significance was set at $P < .05$. Questions regarding compliance rates with suggested backcountry hygiene practices (washing hands with soap and water, use of hand sanitizer, boiling or pretreating water before cooking and cleaning, and management of human waste) were surveyed on a scale of 1 to 5 (1 = never, 2 = occasionally, 3 = regularly, 4 = almost always, 5 = always). Diarrhea severity was also surveyed via a 0 to 5 numerical spectrum (0 = not at all, 1 = minimal, 3 = significant, 5 = severe). There were no descriptive texts in the survey for diarrhea severity scores of 2 or 4.

In running statistical analyses, compliance variables and diarrhea were considered as both continuous and

Table 1. Backpacker demographics from 2014 hiking season (n=737)

<i>Characteristic</i>	<i>Mean ± SD</i>	<i>Mean ± SD</i>
Age (years)	43 ± 14	
Height (cm / in)	175 ± 10	69 ± 4
Starting weight (kg / lbs)	75.9 ± 15.4	167.5 ± 34.1
Ending weight (kg / lbs)	72.5 ± 14.5	159.9 ± 32.0
Pack weight (kg / lbs)	17.6 ± 4.5	38.9 ± 10.1
Total distance hiked (km / mi)	278 ± 125	173 ± 78
Sex	Count (%)	
Male	420 (57)	
Female	281 (38)	
Declined to state	36 (5)	

dichotomous categorical data (compliance recoding to categorical: 0–2 = low compliance, 3–5 = high compliance; diarrhea recoding to categorical: 0 = diarrhea negative, 1–5 = diarrhea positive). When all variables were continuous, linear regressions were used to show contribution to diarrhea severity, and bivariate correlations were used to show any association between one compliance variable and diarrhea. When compliance variables were continuous and diarrhea was categorical, logistic regressions were used to determine whether any of the compliance variables contributed to diarrhea outcome. When all variables were categorical, χ^2 and Fisher exact tests were used to test whether the observed relationships were significant. When compliance variables were categorical and diarrhea was continuous, t tests were used to determine if there was a significant difference in diarrhea severity between those who complied with a single compliance variable and those who did not.

Results

After application of exclusion criteria, our study comprised a population of 737 valid responders. Of this backpacker population, 16.4% (n = 121) reported

experiencing diarrhea at some point on the JMT. Although a majority (82%) of backpackers with diarrhea reported minimal or mild severity, 18% reported having significant diarrhea (rated a 3 or greater), with 5% reporting severe diarrhea (rated a 5). When all hiker demographic variables were combined into a single regression model, there were no significant findings regarding incidence or severity of diarrhea. When each demographic variable was assessed through independent sample t tests, the hiker characteristics of height ($P < .01$), prehike weight ($P < .01$), and posthike weight ($P < .01$) were significantly correlated with diarrhea incidence. Similar results were found when these demographic variables were assessed via bivariate correlation studies against diarrhea severity: the hiker characteristics of height ($P < .01$), prehike weight ($P < .01$), and posthike weight ($P < .01$) were negatively correlated with diarrhea severity (Table 2).

Regularity of compliance with standard backpacking hygiene recommendations and practices was also analyzed against diarrhea incidence and severity. The only significant positive correlation involved regularity of hand sanitizer use and severity of diarrhea. Those who used hand sanitizer more regularly (rated a 3 or greater)

Table 2. Independent sample t tests of diarrhea incidence and bivariate correlations of diarrhea severity with both hiker demographics and hygiene compliance

Hiker demographics	Diarrhea incidence		Diarrhea severity		N
	t value	P value	Pearson's r	P value	
Age	0.46	.64	−0.04	.31	701
Prehike physical condition	0.56	.58	−0.03	.49	698
Prehike physical activity	0.68	.50	−0.01	.77	701
Days hiked in past 10 years	0.88	.38	−0.07	.09	701
Pack weight	−0.77	.44	0.02	.57	700
Height	2.72	<.01 ^a	−0.10	<.01 ^a	700
Prehike weight	3.26	<.01 ^a	−0.11	<.01 ^a	697
Posthike weight	3.57	<.01 ^a	−0.13	<.01 ^a	692
Hygiene	χ^2	P value	Pearson's r	P value	N
Overall hygiene compliance	<0.01	.97	−0.07	.07	700
Buried waste	0.81	.37	−0.02	.58	693
Packed toilet paper	0.05	.82	0.01	.90	634
Washed hands with soap	0.11	.74	−0.01	.72	674
Washed hands with water	1.19	.28	−0.02	.68	674
Used hand sanitizer	2.78	.10	0.08	.03 ^b	675
Filtered drinking water	1.77	.18	0.06	.12	696
Filtered cleaning water	0.55	.46	0.01	.86	630

Incidence assessed as categorical (positive/negative) with hygiene variables recoded as categorical (0–2 low compliance, 3–5 high compliance). Severity assessed as continuous (1–5) with hygiene variables left as continuous.

^a $P < .01$

^b $P < .05$

had significantly more severe diarrhea than those who did not use hand sanitizer regularly ($P < .05$, in both 2- and 1-tailed bivariate correlations). No other statistical test examining relationships between hygiene practices and diarrhea severity or incidence reached significance (Table 2).

Further analyses revealed that regular hand sanitizer use overall was not correlated with having a significantly higher incidence of diarrhea when assessed categorically. Additionally, among all backpackers, regular hand sanitizer users were more likely to bury their waste, pack toilet paper, and filter water for cleaning purposes than those who did not use hand sanitizer regularly ($P < .05$). Among only backpackers reporting diarrhea, regular hand sanitizer users were more likely to pack toilet paper ($P < .05$). All other standard backpacking hygiene recommendations and practices were followed at least as frequently among both regular and infrequent hand sanitizer backpacker groups.

Drinking water filtration or treatment regularity and incidence of diarrhea were also examined. Most backpackers on the JMT filtered or treated their drinking water at least regularly (88%; $n=655$), with 18% of that group reporting diarrhea of any severity. Backpackers who practiced infrequent filtration or treatment of drinking water (12%; $n=82$) reported a diarrhea incidence of 10%. There was no statistical significance between regularity of water filtration or treatment and diarrhea incidence or severity (Table 2).

Discussion

Our study suggests that diarrhea affects a small percentage (16.4%) of JMT long-distance backpackers, with only 5% of those hikers reporting severe diarrhea. This is in contrast to the higher incidence rate of 56% reported

on the AT (Table 3).^{5,6} Regarding demographics, our study found no significant difference in JMT backpacker age, sex, or prior hiking experience as related to the incidence of diarrhea. The average age of JMT backpackers was 43 years. Comparatively, AT backpackers who did not experience diarrhea were significantly older than those hikers who did experience diarrhea (39.1 vs 31.4 years).⁶ Additionally, AT backpackers over the age of 30 years were found to have a reduced occurrence of diarrhea and better mean hygiene scores for handwashing after urination or defecation.⁶ Although our JMT study population was on average older than that examined on the AT, we found no significant difference in hiker demographics associated with hygiene practice regularity. Interestingly, backpacker height, prehike weight, and posthike weight were significantly correlated with increased diarrhea incidence and severity, although a combined regression model of all demographics failed to reach significance. The finding that shorter, lighter backpackers were more likely to have diarrhea and to report more severe diarrhea than taller, heavier backpackers is certainly unusual and may be reflective of sampling error (type 1 error) when these demographics were analyzed independently.

Standard wilderness hygiene practices are an important aspect of backpacking preventative medicine. Backpackers on the JMT reported following hygiene recommendations, on average, “almost always,” although they reported washing their hands without soap more often than with soap. Interestingly, our study shows no significant difference in incidence or severity of diarrhea regardless of regular compliance with such hand washing practices. This contrasts with previous studies on the AT, where practicing “good hygiene”—defined as routine cleaning of cooking utensils with soap and warm water and cleaning hands after urinating or

Table 3. Comparison of diarrhea incidence between JMT (2014) and AT (1997)^{5,6}

<i>Variable</i>	<i>JMT (2014)</i>	<i>AT (1997)</i>
Diarrhea		
Incidence	16%	56%
Severe or incapacitating	5%	12%
Hand hygiene		
Consistent hand washing with soap	36%	14%
Diarrhea with consistent hand washing with soap	16%	36%
Diarrhea without consistent hand washing with soap	17%	59%
Water treatment		
Consistent water treatment	88%	55%
Diarrhea with consistent water treatment	18%	45%
Diarrhea without consistent water treatment	10%	69%

JMT, John Muir Trail; AT, Appalachian Trail.

bowel movements—was associated with a significantly decreased risk of developing diarrhea.⁶ In the Sierra Nevada, use of soap in the backcountry's pristine streams and lakes has been shown to prompt conditions that lead to increased survival or growth of coliform bacteria, and recommendations against such practices have been made.⁷ The “pack it in, pack it out” practice for all soiled toilet paper is the current gold standard for long-distance backpackers in the Sierra Nevada. Unfortunately, this practice may not be consistently applied by all JMT backpackers or day hikers, possibly leading to contamination of pristine water sources.

Fecal contamination of watersheds used as sources of water for long-distance backpackers poses a great threat for the potential development of pathogen-associated diarrhea. Pathogens such as *Escherichia coli*, *Salmonella*, *Campylobacter*, *Aeromonas*, and protozoa such as *Giardia* all have animal reservoirs in addition to human hosts. With specific attention to waterborne pathogens with potential for causing diarrhea in long-distance backpackers in the Sierra Nevada, Derlet et al found that water sources frequented by cattle or pack animals had the greatest degree of fecal contamination and coliform bacteria; very few backpacker-only sites had coliform bacteria present in water sources.⁸ Recommendations from that study included maximal water disinfection techniques in areas used by cattle or pack animals.⁸ Additionally, in wilderness areas of the Sierra Nevada, water from alpine side streams that was found to be free of domesticated animal activity had a very low risk of harboring pathogenic organisms and thus posed minimal risk of illness if drunk untreated.⁸ In a subsequent study by Ursem et al, water sources along the central portion of the JMT were specifically analyzed and found to demonstrate the same trend, in that there was a higher prevalence of coliform bacteria in water sources near stock and pack animal use as compared with backpacker-only sites.⁹ In contrast, a majority of water access points near AT backpacker shelters in Great Smoky Mountains National Park harbored coliform bacteria and/or *E coli*, thus requiring water treatment.¹⁰ The difference in pathogen burden between these 2 trail systems is likely a major contributing factor to the increased incidence of diarrhea observed on the AT as compared with the JMT.

Backpackers are encouraged to filter and treat all water obtained from wilderness sources for drinking and cleaning purposes. Backpackers on the JMT reported filtering or treating drinking water on average “almost always” to “always,” with 88% filtering drinking water at least regularly. Our study did not find a significant correlation between water filtration or treatment

regularity and diarrhea incidence or severity. This is in contrast to similar studies from the AT where the incidence of diarrhea was significantly greater among those who frequently drank untreated water from streams or ponds.^{5,6} Among backpackers on the AT who practiced regular treatment of drinking or dishwashing water with filtration or iodine methods, 45% still experienced diarrhea.^{6,7} This is in contrast to the 18% of JMT backpackers in our study who reported similar compliance with water filtration or treatment but still had diarrhea. This variability in the incidence of diarrhea between JMT and AT backpackers who regularly complied with water filtration or treatment standards may be due to a variety of factors, including substantially different trail distances and total time spent backpacking, geographical differences related to watershed patterns, snow melt in the Sierra, stock usage and proximity to water sources, previously described higher density of coliform bacteria and *E coli* in AT water sources, or possibly better compliance in filtering or treating water by JMT backpackers. Further research is needed to compare these hypotheses.

Hand sanitizer use regularity on the JMT was also examined alongside other standard backcountry hygiene practices. Regular use of hand sanitizer resulted in a significantly higher reported severity of diarrhea, although regular hand sanitizer use overall was not correlated with a significantly higher incidence of diarrhea. Although we expected incidence to be unaffected by the use of hand sanitizer, the significant difference in severity of diarrhea between user groups was an unexpected finding. Alcohol-based hand sanitizers have been found to work equally well or even significantly better than handwashing with soap and water with respect to reduction of pathogenic bacteria in field settings similar to wilderness backpacking (eg, livestock barns, farms, and homes in developing nations).^{11,12} A previous study has also shown that hand sanitizer is equally efficacious on clean versus dirty or oily hands.¹³ However, to our knowledge, there are no studies examining the effects of hand sanitizer use specifically with recreational backcountry activities. In the absence of comparable data, we considered that one possible explanation for the observed difference in severity of diarrhea may pertain to regular hand sanitizer users following other hygiene practices less stringently. However, further analyses revealed that regular hand sanitizer users demonstrated just as high a compliance with all other recommended standard backcountry hygiene practices as those backpackers not using hand sanitizer regularly (and for some practices, significantly exceeded compliance regularity). Using hand sanitizer after toileting requires the backpacker to

hold the sanitizer bottle with soiled hands, and if the bottle is not appropriately cleansed before being placed back into a backpack, it may result in other items being contaminated with coliform bacteria. How this may affect diarrhea severity but not incidence is unknown, and further research is needed to evaluate this hypothesis.

STUDY LIMITATIONS

As is the nature of retrospective survey studies, participant selection and recall bias are major limitations. The self-reporting nature of symptom severity has a great deal of subjectivity and may have artificially increased the number of backpackers reporting more severe diarrhea. Several backpackers also reported pre-existing conditions (eg, irritable bowel syndrome or inflammatory bowel disease) that may have exacerbated the reported incidence or severity of diarrhea. Soft stool resulting from diet-related changes while backpacking may have been interpreted as diarrhea by some backpackers. Along the JMT, there are several opportunities to dine just off trail at nearby cantinas and restocking points, whereby foodborne pathogens could have theoretically led to diarrhea. Although our exclusion criteria attempted to eliminate backpackers hiking less than 2 days' average mileage, those backpackers acquiring diarrhea just before trip onset on the JMT may have had symptoms persisting past 2 days and may have been included in our study population.

Conclusions

Backpackers on the JMT have a comparatively lower incidence of diarrhea than those on other major long-distance backpacking routes in the United States. A majority of JMT backpackers follow standard backcountry hygiene recommendations, including regular filtration or treatment of drinking water. No statistical significance was found between diarrhea incidence and compliance with standard hygiene recommendations. Regular hand sanitizer use was significantly correlated with more severe diarrhea but was not associated with incidence. Additionally, regular hand sanitizer users showed no significant difference in compliance regularity regarding any of the other recommended standard backcountry hygiene practices.

Acknowledgments: The authors would like to extend particular gratitude to John Ladd for granting permission of use of his 2014 John Muir Trail Hiker Survey data, to Svetlana Bagdasarov for her assistance as liaison with the Institutional Review Board and coordinating meetings, and especially all past, present, and future JMT

backpackers, who continue to inspire generations of hikers both old and new.

Author Contributions: Study concept and design (DJM, SJS); acquisition of the data (SJS); analysis of the data (AC); drafting of the manuscript (DJM, AC, SJS); critical revision of the manuscript (DJM, AC, SJS); approval of final manuscript (DJM, AC, SJS).

Financial/Material Support: None.

Disclosure Statement: None.

References

1. Twombly SE, Schussman LC. Gender differences in injury and illness rates on backpacking trips. *Wilderness Environ Med.* 1995;1:363–376.
2. Gardner TB, Hill DR. Illness and injury among long-distance hikers on the Long Trail, Vermont. *Wilderness Environ Med.* 2002;13:131–134.
3. Crouse BJ, Josephs D. Health care needs of Appalachian Trail hikers. *J Fam Pract.* 1993;36:521–525.
4. Boulware DR. Gender differences among long-distance backpackers: a prospective study of women Appalachian Trail backpackers. *Wilderness Environ Med.* 2004;15:175–180.
5. Boulware DR, Forgey WW, Martin WJ 2nd. Medical risks of wilderness hiking. *Am J Med.* 2003;114:288–293.
6. Boulware DR. Influence of hygiene on gastrointestinal illness among wilderness backpackers. *J Travel Med.* 2004;11:27–33.
7. Derlet RW, Ger KA, Richards JR, Carlson JR. Risk factors for coliform bacteria in backcountry lakes and streams in the Sierra Nevada mountains: a 5-year study. *Wilderness Environ Med.* 2008;19:82–90.
8. Derlet RW. Backpacking in Yosemite and Kings Canyon National Parks and neighboring wilderness areas: how safe is the water to drink? *J Travel Med.* 2008;15:209–215.
9. Ursem C, Evans CS, Ger KA, Richards JR, Derlet RW. Surface water quality along the central John Muir Trail in the Sierra Nevada mountains: coliforms and algae. *High Alt Med Biol.* 2009;10:349–355.
10. Reed BC, Rasnake MD. An assessment of coliform bacteria in water sources near Appalachian Trail shelters within the Great Smoky Mountains National Park. *Wilderness Environ Med.* 2016;27:107–110.
11. Davis MA, Sheng H, Newman J, Hancock DD, Hovde CJ. Comparison of a waterless hand-hygiene preparation and soap-and-water hand washing to reduce coliforms on hands in animal exhibit settings. *Epidemiol Infect.* 2006;134:1024–1028.
12. Pickering AJ, Boehm AB, Mwanjali M, Davis J. Efficacy of waterless hand hygiene compared with handwashing with soap: a field study in Dar es Salaam, Tanzania. *Am J Trop Med Hyg.* 2010;82:270–278.
13. Pickering AJ, Davis J, Boehm AB. Efficacy of alcohol-based hand sanitizer on hands soiled with dirt and cooking oil. *J Water Health.* 2011;9:429–433.