



Risk mitigation and disease control challenges of SARS-CoV-2 multidirectional transmission at ski resorts

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Background: During the COVID-19 pandemic, skiing venues were labeled high-risk, and in Colorado, ski resorts were considered the epicenter of the COVID-19 outbreak. The aim of this study is to examine trends in COVID-19 outbreaks at ski resorts and restaurants near ski resorts in Colorado during the 2020 to 2021 ski season to explore the potential multidirectional influence of COVID-19 within local communities. Furthermore, this study identifies potential high-risk settings associated with ski resorts and details infection control and risk mitigation strategies to inform future response planning.

Methods: COVID-19 ski resort and restaurant outbreak data reported by the Colorado Department of Public Health and Environment during the 2020 to 2021 ski season was evaluated. The number of outbreaks and cases were described by county and month. Means described the number of cases and duration of outbreaks by setting type and differences were assessed using Welch's Two Sample *T*-tests.

Results: A total of 57 COVID-19 outbreaks and 429 COVID-19 cases from seven counties with ski resorts were reported. Of the ski resort-related outbreaks, the majority of outbreaks occurred in maintenance and operation settings accounting for 39.0% (n=22) of the total outbreaks reported. However, 62.0% (n=266) of the total number of cases were reported from lodging settings. Of the total 429 cases, 425 (99.1%) were reported in resort workers, including one death. Additionally, 66 restaurant-related outbreaks were detected, yielding 266 COVID-19 cases in restaurant-related settings potentially associated with ski resort tourism.

Conclusions: The results of this study suggest that COVID-19 ski-resort related outbreaks were highest in settings that typically involved close and frequent contact between individuals. There is little evidence to support increased transmission of SARS-CoV-2 and the activity of skiing outdoors. Nearly all the reported outbreak-related cases occurred among workers, suggesting the potential for multidirectional disease transmission between guests and workers within the community. This study highlights the importance of implementing improved disease monitoring and surveillance measures, as well as establishing multilayered infection control and risk mitigation strategies to prepare for future public health challenges.

Keywords: COVID-19; SARS-CoV-2; ski resorts; risk mitigation, disease control

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Introduction

During the COVID-19 pandemic, recreational skiing facilities were labeled as high-risk venues because of the spread of SARS-CoV-2, a highly transmissible respiratory virus responsible for causing COVID-19, among guests and the local communities in which the resorts operate (1-3). The categorization of “high-risk” occurred because of several “superspreading” events in Europe (3,4), and the United States (U.S.) (1), including at ski resorts in the state of Colorado (5,6). In fact, across industries and businesses in Colorado, ski resorts were considered the epicenter of the COVID-19 outbreak, after having the first confirmed case of COVID-19 occurring in March, 2020, identified in an international traveler visiting Summit County, Colorado on a ski trip (7). Given the “high-risk” categorization of ski resorts across the globe, several factors likely contributed to the potential for increased disease transmission among guests, workers, and the local community, especially given the multitude of human interaction factors present in resort communities.

Ski resorts face complex challenges when developing and implementing robust communicable disease response plans. Depending on the resort, these challenges may include hosting guests from a variety of domestic and international locations, fluctuations in seasonal staffing (e.g., the need to consistently educate new workers about health and safety policies and practices), shared worker housing, various indoor and outdoor congregate settings, and frequent interactions between workers, guests, and community members (8). Additionally, ski resorts face an overall lack of applicable standards in terms of managing communicable diseases. General guidance was released during the COVID-19 pandemic for ski resorts; however, this guidance was often broad and inconsistent (5,9-15). These resorts, therefore, may grapple not only with various government regulations and guidance at the local, state, national, and international level, but must also balance additional requirements and guidance from corporate policies, property management, and trade associations, resulting in assorted disease prevention practices. Implementing these various different guidelines, policies, and requirements can be difficult, resulting in ski resorts having industry wide inconsistencies and increased disease transmission risk.

Epidemiological data on ski resort outbreaks supports the conclusion that SARS-CoV-2 spread is rooted in the unique multidirectional points of transmission, or, in other words, the interpersonal exchange occurring between workers,

guests, and local communities. The multidirectional spread of SARS-CoV-2, for example, was observed during a COVID-19 outbreak at an Idaho ski-resort. Dunne *et al.* (2021) reported that, “The start of the outbreak in Blaine County was likely linked to travel to the ski resort, high rates of seasonal residence, and three events held during late February and early March 2020 that attracted numerous out-of-state attendees” (p. 8). Subsequently, the situation led to significant community spread in Blaine County, which, at the time, reported one of the highest rates of COVID-19 cases per capita (1,959/100,000) in the U.S. (1).

In the absence of uniform industry standards, resorts and associated communities have undertaken varying approaches to try to mitigate SARS-CoV-2 spread. These varying approaches, though, may have created inconsistencies and potential vulnerabilities related to overall resort risk management. Developing a comprehensive, science-based, disease mitigation plan that emphasizes a multilayered risk management framework, prioritizes visitor and worker safety, and ensures business continuity is therefore key not only to overcoming current pandemic hurdles, but also to helping to adequately prepare and respond to the next public health challenge.

The aim of this study, then, is to descriptively analyze the COVID-19 outbreak data among ski resorts in Colorado based on publicly available data from seven counties that reported outbreaks during the 2020 to 2021 ski season. This study also reviews COVID-19 restaurant outbreak data occurring within a 10-mile radius of each ski resort to demonstrate the multidirectional influence of COVID-19 within the local communities. Restaurant outbreaks within this radius can indicate local community spread of SARS-CoV-2, particularly if cases occur among restaurant workers. Restaurant visitors likely may also be guests or workers from nearby ski resorts or reside in the local community, thereby highlighting the influence of multidirectional transmission at ski resorts. Furthermore, this study seeks to identify settings with higher transmission risk within and around ski resorts in order to inform future disease control and outbreak response planning. Additionally, this study discusses the importance of implementing health protection programs guided by integrating the hierarchy of controls and the chain of infection in order to help provide a more unified, holistic, and targeted disease control approach at local ski resorts, based on their facility and/or operational risk. We present the following article in accordance with the STROBE reporting checklist (available at <https://jphe.amegroups>).

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Methods

To examine epidemiologic trends in outbreak-related COVID-19 cases potentially associated with ski resorts in Colorado for the 2020 to 2021 ski season, COVID-19 outbreak data was obtained from the Colorado Department of Public Health and Environment's (CDPHE) online database (16). As defined by CDPHE, a confirmed COVID-19 outbreak includes "[t]wo or more confirmed cases of COVID-19 in a facility or (non-household) group with onset in a 14-day period" (17). The CDPHE outbreak dataset includes epidemiologic surveillance data for each recorded outbreak in the state, including the number of cases and deaths; whether the cases or deaths were among residents, workers, or attendees; business name and 'COVID-19 Setting Type'; outbreak location; and investigation status and reporting dates.

The primary inclusion criteria for an outbreak included the following: date of reporting between November 1, 2020 and May 1, 2021; county with ski resort(s); and COVID-19 Setting Type of "Outdoor Entertainment/Rec", "Hotel/Lodge/Resort", "Restaurant – Sit Down", "Bar/Tavern/Brewery", "Restaurant – Fast Food", "Restaurant – Buffet", and "Restaurant – Other." All active and resolved outbreaks that met the primary inclusion criteria were manually reviewed in order to identify outbreaks potentially associated with ski resorts. Additionally, for the COVID-19 Setting Types of "Restaurant – Sit Down", "Bar/Tavern/Brewery", "Restaurant – Fast Food", "Restaurant – Buffet", and "Restaurant – Other", the distance (in miles) from the closest ski resort was calculated. Food and beverage establishments more than 10 miles away from a ski resort were excluded in order to decrease the potential misclassification of outbreaks likely unrelated to ski resort tourism. Outbreaks meeting the inclusion criteria occurred in the following seven counties: Chaffee, Eagle, Grand, Pitkin, Routt, San Miguel, and Summit. All outbreaks were categorized into two main categories: (I) Ski Resort-Related; and (II) Restaurant-Related (see *Figure 1*).

Ski resort-related outbreaks

Ski resort-related outbreaks included outbreaks in the COVID-19 Setting Type of "Outdoor Entertainment/Rec". These were further subdivided into author-defined setting types (i.e., winter sport-related and maintenance

and operations). The main purpose of this categorization framework was to identify specific locations in which outbreaks occurred within ski resorts and adjacent communities. The author-defined winter sport-related settings included any outbreaks associated with ski schools, ski rental shops, winter sports clubs, ski checks, and ski patrols. Maintenance and operations included all other on-the-mountain activities, such as lift maintenance, lift operations, mountain safety, ticket scanning, and ticket sales. Lodging settings included any outbreaks that were defined by the 'COVID-19 Setting Type' as "Hotel/Lodge/Resort."

Restaurant-related outbreaks occurring near ski resorts

Restaurant-related outbreaks occurring near ski resorts were based on the 'COVID-19 Setting Type' as defined by the CDPHE. Sit down restaurants, bars and breweries, fast food restaurants, buffets, and other restaurants included any outbreaks that were defined by the 'COVID-19 Setting Type' as "Restaurant – Sit Down", "Bar/Tavern/Brewery", "Restaurant – Fast Food", "Restaurant – Buffet", and "Restaurant – Other", respectively.

Descriptive statistics

Descriptive statistics included the number of outbreaks and associated cases by county, and mean number of cases and mean duration of outbreaks by setting type. Welch's Two Sample T-test was used to compare the mean cases per outbreak among ski resort-related settings and separately among restaurant-related settings. Welch's Two Sample T-test was also used to compare ski-related and restaurant-related outbreaks and cases within each county. Figures, including bar charts, were generated in Excel and RStudio in order to illustrate descriptive trends in the number of outbreaks and outbreak-related cases per month.

Results

Ski resort-related outbreaks

A total of 57 COVID-19 outbreaks and 429 COVID-19 cases were reported in ski resort-related locations during Colorado's 2020 to 2021 ski season (*Figure 1*). Potential ski resort-related outbreaks were observed in seven counties, including Chaffee, Eagle, Grand, Pitkin, Routt, San Miguel, and Summit County. Grand County had three outbreaks,

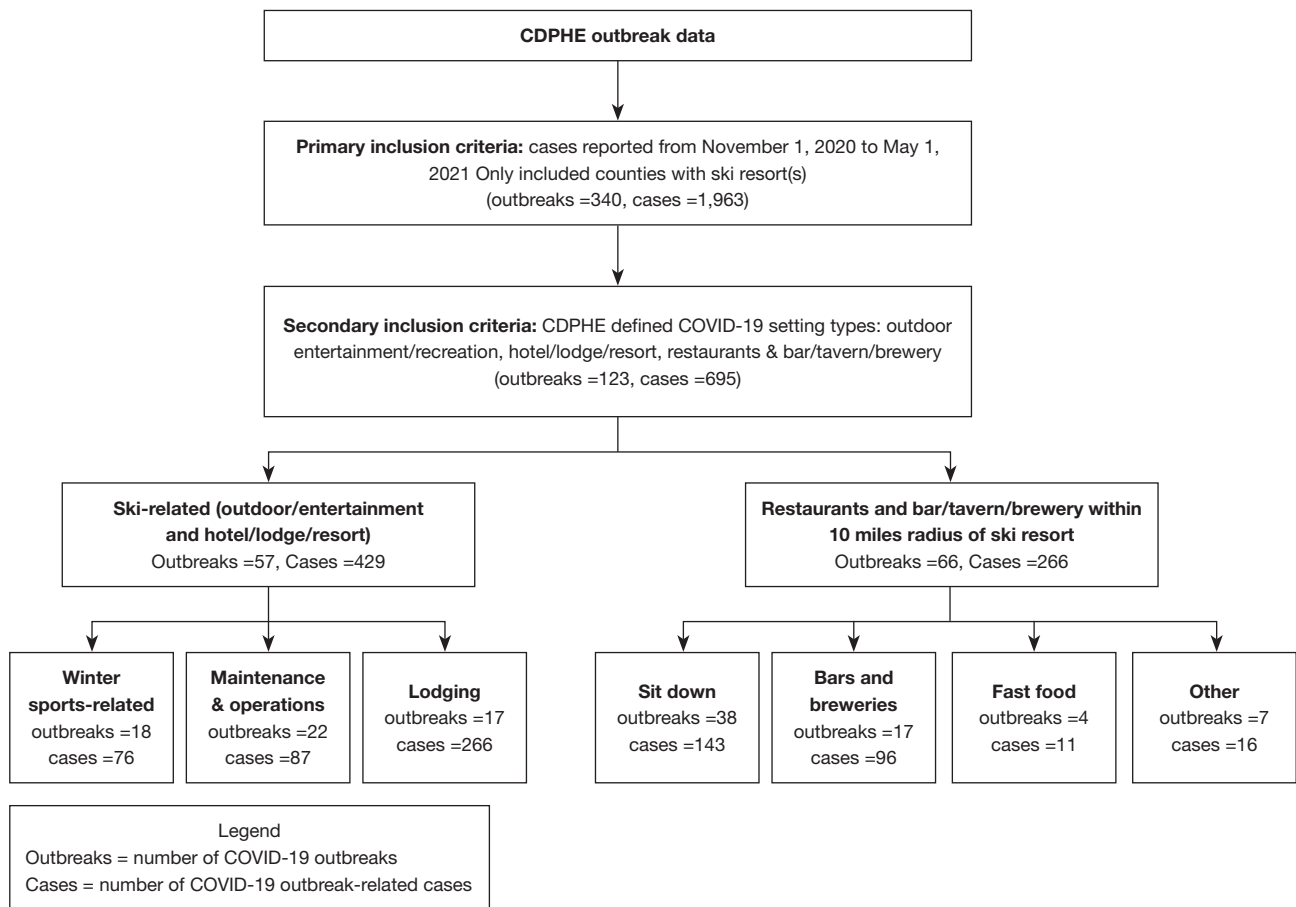


Figure 1 Inclusion criteria for ski resort- and restaurant-related outbreaks & outbreak-related cases including setting types.

Table 1 Ski resort-related COVID-19 outbreaks and cases by county

County	Outbreaks, n (%)	Cases, n (%)
Chaffee	1 (1.8)	21 (4.9)
Eagle	4 (7.0)	11 (2.6)
Grand	3 (5.3)	196 (45.7)
Pitkin	2 (3.5)	31 (7.2)
Routt	8 (14.0)	33 (7.7)
San Miguel	1 (1.8)	4 (0.9)
Summit	38 (66.7)	133 (31.0)
Total	57 (100.0)	429 (100.0)

accounting for 5.3% of the total outbreaks, but almost half (45.7%) of all cases were seen in Grand County, primarily because of one large outbreak in February, 2021 (Table 1).

Additionally, 38 of the 57 outbreaks (66.7%) occurred in Summit County, resulting in 133 cases (average: 3.5 cases/outbreak, minimum: 2 cases/outbreak, maximum: 17 cases/outbreak) and 31.0% of the total case load. Only one outbreak occurred in Chaffee County and one in San Miguel County each accounting for 1.8% of the total outbreaks.

Of the 429 cases, 425 (99.1%) were reported in resort workers, including one death reported in November, 2020. Of the remaining four cases, all were classified under the winter sports-related category, with two occurring in winter sports club attendees and two occurring in community residents at a ski rental service (data not shown).

Ski resort-related outbreaks peaked in December, 2020 (n=17; 29.8%), and steadily declined from January, 2021 to March, 2021 (n=14; 24.6% to n=2; 3.5% respectively). April, 2021 saw a slight increase in ski related outbreaks (n=5; 8.8%) (Figure 2).

Of the ski resort-related outbreaks, the majority of

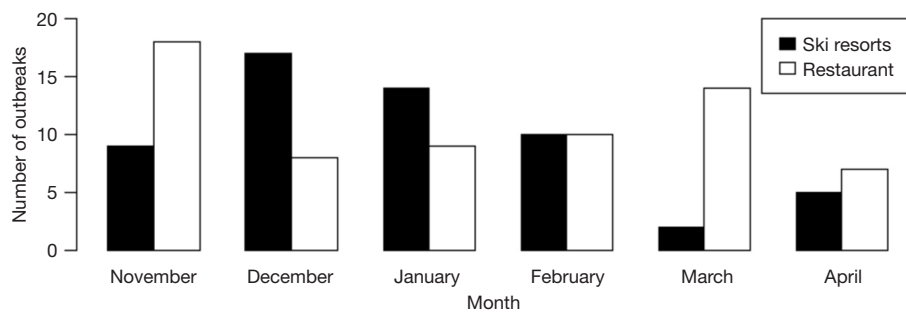


Figure 2 Ski resort- and restaurant-related COVID-19 outbreaks by month.

Table 2 Ski resort-related COVID-19 outbreaks and cases by setting

Setting type	Outbreaks, n (%)	Cases, n (%)	Cases per outbreak, mean (SD)	Duration (in days), mean (SD)
Winter sports-related	18 (32.0)	76 (18.0)	4.22 (4.23)	30.28 (14.16)
Maintenance & operations	22 (39.0)	87 (20.0)	3.95 (3.72)	22.10 (11.04)
Lodging	17 (30.0)	266 (62.0)	15.65 (43.09)	27.88 (21.15)

outbreaks (not individual cases) occurred in maintenance and operation settings (i.e., maintenance; lift operations; mountain safety; ticket scanning; and ticket sales), accounting for 39.0% of the total outbreaks reported (Table 2). However, 62.0% (n=266) of the total number of cases (not outbreaks) were reported from the lodging setting among the seven counties included in the current study (again, primarily due to the large outbreak in Grand County). Among winter sport-related (e.g., ski schools; ski rental shops; winter sports clubs; ski checks; and ski patrols) outbreaks (n=18; 32% of the total outbreaks), four outbreaks (22.22% of winter sport-related outbreaks) occurred in ski rental areas, eight outbreaks (44.44% of winter sport-related outbreaks) occurred among ski schools, two outbreaks (11.11% of winter sport-related outbreaks) occurred among winter sports clubs, and one outbreak (5.55% of winter sport-related outbreaks) occurred among ski checks and ski patrols (data not shown). The average number of cases per outbreak ranged from 3.95 (SD =3.72) to 15.65 (SD =43.09), and the average outbreak duration ranged from 22.10 days (SD =11.04) to 30.28 days (SD =14.16). Welch's Two Sample *t*-tests revealed no significant difference between mean cases per outbreak (i.e., $P > 0.05$) among winter sport-related, maintenance and operations, and lodging settings (winter-sport related *vs.* lodging $P = 0.3065$; winter-sport related *vs.* maintenance and operations $P = 0.8393$; maintenance and operations *vs.* lodging $P = 0.295$).

Restaurant-related outbreaks occurring near ski resorts

During the 2020 to 2021 Colorado ski season, 66 restaurant-related COVID-19 outbreaks were detected among six counties (no restaurant-related outbreaks occurred in Chaffee County), yielding 266 COVID-19 cases in restaurant-related settings potentially associated with ski resort tourism. Of the 266 cases, 94.7% (n=252) were reported in restaurant workers, and the remaining 14 cases occurred among guests in Routt County only. There were no deaths from COVID-19 during these outbreaks. The majority of the outbreaks occurred in Summit County, with 35 (53.0%) reported outbreaks resulting in 133 COVID-19 cases (average: 3.8, minimum: 2; maximum: 22) (Table 3).

As noted in Figure 2, November had the largest number of COVID-19 restaurant outbreaks (n=18; 27.3%), and March had the second largest number of restaurant outbreaks (n=14; 21.2%). November also had the largest number of recorded COVID-19 outbreak-related cases (n=56; 21.1%), while January had the second most outbreak-related cases (n=53; 19.9%) (March had 52 cases; see Figure 3). The remaining months had between 7 and 10 outbreaks and between 27 and 48 outbreak-related cases (Figures 2 and 3, respectively).

Of the 133 COVID-19 cases reported in Summit County, most were reported in sit down restaurants (n=59; 44.4%). A similar number of COVID-19 cases were also reported in bars and breweries in Summit County (n=53;

39.8%). Fewer cases were reported in other restaurants in Summit County (n=14; 11% and n=7; 5.3%). In Grand County, there were only two reported outbreaks, both in bars and breweries (n=6 cases). Only one outbreak (n=2 cases; 0.8%) was reported in Pitkin County at a sit-down restaurant (see Table 4). No outbreaks were reported within a buffet setting among these counties, and no outbreaks were reported in Chaffee County.

The average number of cases per outbreak ranged from 2.29 (SD =0.45) to 5.65 (SD =4.64), and the average duration

of each outbreak ranged from 20.43 days (SD =1.99) to 28.76 days (SD =19.27). Welch’s Two Sample *t*-tests revealed significant differences between mean cases per outbreak among sit down restaurants compared to other restaurants (P=0.0016) and bars and breweries compared to other restaurants (P=0.011). No other restaurant setting showed a significant difference between mean cases per outbreak (P>0.05) (see Table 5).

Comparison of ski resort-related and restaurant-related outbreaks and cases

No significant difference between total number of outbreaks at the county-level was found between ski resort- and restaurant-related outbreaks (P>0.05). Additionally, no significant difference was found between total number of cases at the county-level when comparing ski resort- and restaurant-related cases (P>0.05).

Discussion

Ski resort-related outbreaks and restaurant-related outbreaks occurring near ski resorts

The current study describes COVID-19 outbreaks and outbreak-related cases associated with Colorado ski resorts

Table 3 Restaurant-related COVID-19 outbreaks and cases by county

County	Outbreaks, n (%)	Cases, n (%)
Chaffee	0 (0.0)	0 (0.0)
Eagle	6 (9.1)	19 (7.1)
Grand	2 (3.0)	6 (2.3)
Pitkin	1 (1.5)	2 (0.8)
Routt	14 (21.2)	73 (27.4)
San Miguel	8 (12.1)	33 (12.4)
Summit	35 (53.0)	133 (50.0)
Total	66 (100.0)	266 (100.0)

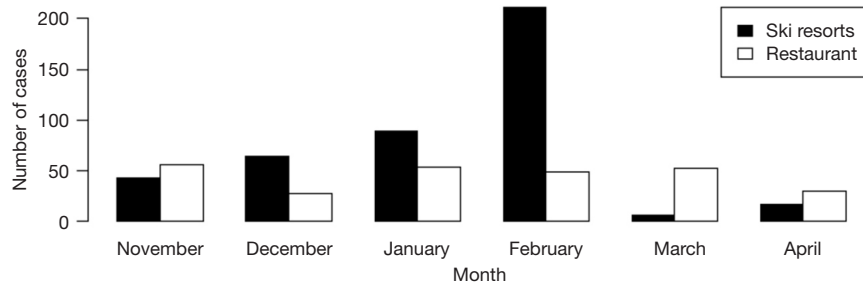


Figure 3 Ski resort- and restaurant-related COVID-19 cases by month.

Table 4 Restaurant-related COVID-19 cases by county and setting

Setting	Counties, n (%)						
	Chaffee	Eagle	Grand	Pitkin	Routt	San Miguel	Summit
Sit Down Restaurants	0 (0)	13 (68.0)	0 (0)	2 (100.0)	53 (72.6)	16 (48.5)	59 (44.4)
Bars and Breweries	0 (0)	0 (0)	6 (100.0)	0 (0)	20 (27.4)	17 (51.5)	53 (39.8)
Fast Food Restaurants	0 (0)	4 (21.0)	0 (0)	0 (0)	0 (0)	0 (0)	7 (5.3)
Other Restaurants	0 (0)	2 (11.0)	0 (0)	0 (0)	0 (0)	0 (0)	14 (10.5)

Table 5 Restaurant-related COVID-19 outbreaks and cases by setting

Setting type	Outbreaks, n (%)	Cases, n (%)	Cases per outbreak, mean (SD)	Duration (in days), mean (SD)
Sit down restaurants	38 (57.6)	143 (53.8)	3.76 (1.83)	24.61 (9.92)
Bars and breweries	17 (25.8)	96 (36.1)	5.65 (4.64)	28.76 (19.27)
Fast food restaurants	4 (6.1)	11 (4.1)	2.75 (1.30)	20.50 (6.80)
Other restaurants	7 (10.6)	16 (6.0)	2.29 (0.45)	20.43 (1.99)

and nearby restaurants during the 2020 to 2021 ski season. Of the reported Colorado outbreaks, ski resort-related outbreaks most frequently occurred in maintenance and operations settings (e.g., lift maintenance; lift operations; mountain safety; ticket scanning; and ticket sales) (39.0%). The largest number of individual cases, however, occurred in lodging settings (62.0%). The maintenance and operations settings included in this study were mostly outdoors, and involved guest-facing (e.g., ticket scanning) and non-guest-facing activities (e.g., lift maintenance). Activities with frequent interactions between workers and guests create new opportunities for disease spread among two different populations (18). Further, many maintenance and operations tasks are carried out by a finite number of seasonal workers, who, as a common practice in U.S. based ski resorts, may live together in communal accommodations, leading to a higher transmission potential for a limited group of individuals. The natural increased airflow from conducting these tasks outdoors, however, likely had an effect on the size of these outbreaks, which may explain the lower average number of cases per outbreak (4.95), as compared to the lodging setting (15.65) (19). Similar results were found within restaurant-related settings, with sit down restaurants, as well as bars and breweries, having a greater number of average cases per outbreak (3.76 and 5.65, respectively), as compared to fast food restaurants (2.75) and other restaurants (2.29), which included coffee shops and cafeterias. The higher number of average cases per outbreak among sit down restaurants and bars and breweries is potentially due to reduced airflow and longer durations spent indoors with increased numbers of individuals (19). Additionally, the high number of cases occurring within lodging settings of ski resorts may be driven by close and frequent contact among workers, as well as the work occurring in confined indoor spaces with varying degrees of ventilation. Furthermore, the quality, enforcement, and adherence to infection control policies, particularly in indoor settings, likely had an impact on the number of COVID-19 cases.

Within restaurant settings, COVID-19 outbreak-related cases occurred most frequently among individuals in sit-down restaurants (n=143), followed by bars and breweries (n=96), with relatively few cases occurring in fast food restaurants (n=11) and establishments categorized as other restaurants, which included coffee shops and cafeterias (n=16). Similar to lodging, most sit-down restaurants and bars and breweries likely operated indoors during the winter season, thereby increasing the likelihood of disease transmission, as compared to outdoor settings. Close and frequent contact among workers at dining establishments may have also played a part in increasing transmission risk. Further, more frequent interactions between workers and guests likely occur at sit-down restaurants and bars and breweries, as compared to at fast food restaurants and dining establishments categorized as other restaurants. While the demographics of guests visiting the restaurants included in this study is unknown, restaurant guests likely may also be guests or workers from nearby ski resorts or residents in the local community, thereby highlighting the influence of multidirectional transmission.

This study's findings suggest that close and consistent contact with others, particularly in indoor settings, may lead to increased COVID-19 transmission within ski resorts and nearby restaurants, which aligns with the findings of another recent publication (2). In a rapid systematic review of COVID-19 and recreational ski resorts, Gianfredi *et al.* (2021) concluded that little evidence supports an association between transmission of SARS-CoV-2, a highly transmissible respiratory virus responsible for causing COVID-19, and the activity of skiing outdoors itself. The typical behavior and group activities present at ski resorts (e.g., restaurants; rental areas; shared lodging), however, present an ideal opportunity for respiratory pathogen transmission. In fact, Gianfredi *et al.* (2021) reported that participating in these types of indoor and group activities was responsible for the COVID-19 cases identified in their review. This study has similar findings showing that the greatest number of

COVID-19 outbreaks occurred among resort operations and maintenance, while the greatest number of individual COVID-19 cases occurred among lodging settings (2).

The results of this study illustrate that ski resort-related outbreaks decreased over time between December 2020 and March 2021, with a slight increase in April 2021. While the decrease may be due to several factors, including vaccinations or improved risk management approaches, it may also be partially due to a reduction in ski resort guests as the season neared an end. The increase in COVID-19 cases in April may be influenced by or the result of 'Spring Break' where significant increases in resort tourism typically occurs. This phenomenon has been observed in other resort communities and on college campuses during the COVID-19 pandemic (20,21). Further, restaurant-related outbreaks did not show a trend over time, but were highest in November and March. The trends among restaurants possibly may be more reflective of transmission within the local community and less related to ski-resort guests. Notably, nearly all the COVID-19 outbreak-related cases identified in this analysis occurred among workers for both ski resorts (99.1%) and restaurants (94.7%). Although it might be possible that nearly all COVID-19 cases occurred among workers, this may also highlight a significant gap in COVID-19 outbreak and individual case reporting at Colorado ski-areas and restaurants (22). According to the CDPHE, outbreak cases among guests may be "very hard to detect" and, as a result, the CDPHE suggested that the reported number of cases may be "an underestimate" (22). Given the considerable number of national and international travelers visiting the resorts, many acquired illnesses may not be captured by local routine disease surveillance or reporting. Assuming that nearly all cases of COVID-19 occurred among workers, particularly given the transmissibility of the SARS CoV-2 virus and the extremely transient ski tourism population, may therefore be incorrect. As previously mentioned, close, frequent, and consistent interaction among workers may partially explain these results. If these results are taken at face value, they suggest that SARS-CoV-2 transmission may be sustained among worker populations at ski resorts and nearby dining establishments, and most plausibly are the result of the multidirectional transmission upsurge occurring locally from an influx of seasonal travelers over a narrow time period (e.g., November to April). Understanding the populations most at risk for SARS-CoV-2 exposure, and, therefore, the potential for subsequent transmission, can help resort operators and health and safety professionals better design, implement, and enforce effective infection

control plans and procedures.

Infection control and risk mitigation strategies

The primary goal of risk mitigation measures for chemical, biological, and physical hazards is to reduce the risk of adverse health effects by controlling exposure to a hazard, regardless of population (e.g., consumer; general; occupational) (23). When controlling a hazard is complex because of evolving scientific understanding and variable risk sources and fluctuations, implementing a combination of measures for a multilayered and flexible risk mitigation approach becomes necessary. Such an approach is commonly referred to as the Swiss Cheese Model (24). Industries such as health care have implemented this multilayered approach, and, as a result, have seen a reduction of SARS-CoV-2 transmission during the COVID-19 pandemic (25).

When several risk mitigation measures are implemented simultaneously, transmission risk from guests, workers, and/or local communities can be minimized, leading to multidirectional transmission reduction among these groups. An effective and comprehensive multilayered infection control plan can be created by applying two well-established frameworks: the chain of infection and the hierarchy of controls. The sequence of disease transmission, in which an agent leaves its host reservoir, travels to a new host via some mode of transmission, and enters and infects the new, susceptible host, is often referred to as the 'chain of infection' (26). The hierarchy of controls ranks control measures from most to least effective, beginning with elimination, then substitution, followed by engineering controls, administrative controls, and personal protective equipment. These measures can be tailored as necessary for infection control (*Figure 4*) (27). To disrupt and reduce disease spread, the chain of infection must be broken. To do so, layers of control measures can be applied to each point in the chain, according to the hierarchy of controls (*Figure 5*) (28). While the control measures are not novel, they can be optimized and tailored as needed in order to provide robust enough controls to address the unique and varying needs of different industries, such as ski resort settings, where multidirectional disease transmission is the challenge. Ski resort operators should therefore understand established infection control measures and how to implement them in a well-balanced and effective manner, in order to both reduce COVID-19 spread now, as well as to readily and effectively apply these strategies for future disease outbreaks or pandemics.

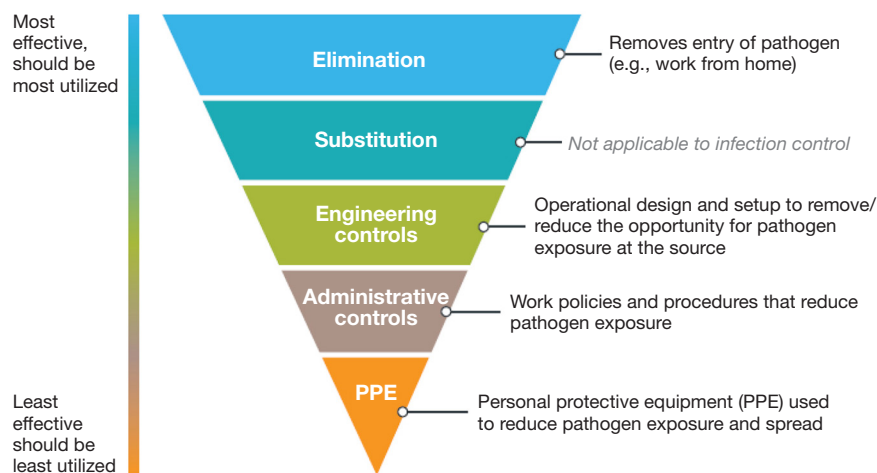


Figure 4 The hierarchy of controls adapted for infection control (adapted from NIOSH 2015) (27).

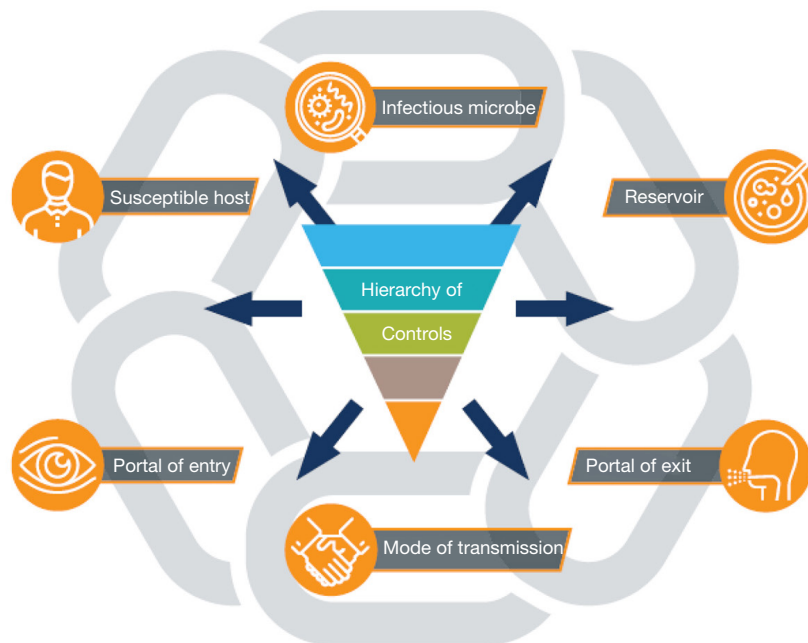


Figure 5 The hierarchy of controls applied to the chain of infection [adapted from NIOSH 2015 (27); Zisook *et al.* 2020 (28)].

Many of the ski resorts in the Colorado counties that are the subject of this study implemented practices during the 2020 to 2021 season that were intended to break the chain of infection and reduce SARS-CoV-2 spread. These practices, however, often differed among resorts (5,9-15,29,30). Specifically, some resorts had detailed plans in place, which included daily health screenings for workers, mandatory face coverings on-site, promotion of physical distancing, and hand sanitizer availability. Resorts also imposed limitations

on the number of lift tickets sold and/or parking spaces, the number of individuals allowed to ride on lifts, and the length of ski lessons. Guests were also restricted from bringing their own food into the resort. Additionally, some resorts restricted or closed on-site services, such as on-site restaurant and bar seating, and childcare facilities. At least one of these resorts even provided a COVID-19 vaccine clinic on-site. Other resorts, however, did not have dedicated infection control plans, but rather stated on their website

that they would be following local public health protocols. These differing approaches utilized across ski resorts may thus have resulted in increased transmission because of a lack of standardized and comprehensive plans. Without comprehensive and multilayered infection control and risk mitigation plans in place that are tailored to each ski resort's specific needs, the ability to control COVID-19 spread within ski resorts and the surrounding community is limited.

There are several vital components that should be taken into consideration when developing a robust risk mitigation plan, including problem formulation, risk assessment, controls and prevention measures, communication, and recovery (28,31). As such, the problem must first be identified and summarized in the context of the workplace concern (i.e., transmission at a ski resort). By formulating the problem, a risk assessment of the hazard will be better focused in scope, which aids in determination of appropriate and effective control measures for incorporation into the risk mitigation plan. While local, state, and federal guidance may be used as a starting place for building such plans, industry-specific strategies should also be incorporated (32). Additional categories and considerations relevant to risk mitigation plans for ski resorts may include leadership and management (e.g., defining roles and responsibilities, implementing trainings for staff); worker behavior and hygiene (e.g., PPE, reducing number of staff per shift, vaccinations); facility operations (e.g., reducing hours of operation, limiting number of guests); administrative controls (e.g., staggering shifts); public interactions (e.g., self-service in cafeterias and restaurants, limiting use of commons areas); as well as communications (e.g., creating accessible resources for staff that account for linguistic and cultural barriers) (32). As previously noted, multiple levels of control measures should be implemented according to the hierarchy of controls, and the effectiveness of control measures should be evaluated and updated as necessary (Figure 4). Further, ski resorts may consider developing a staged response to risk mitigation. A framework for this type of response was proposed by Parker *et al.* (2020) and outlines how businesses can "step up" or "step down" the levels of protective controls in a controlled manner, based on the circumstances and current state of the science (32).

Limitations

These findings should be understood in the context of several limitations. Only a small number of counties, with varying populations, were investigated. As a result,

more populous counties may have had a larger number of outbreaks and outbreak-related cases. Additionally, the COVID-19 outbreak data used in the current analysis likely underestimates the true number of COVID-19 cases that occurred in ski resort communities. Of the reported COVID-19 outbreak-related cases, for example, only two occurred in resort guests, two occurred in community members, and four occurred in restaurant guests, which likely underestimates the true number of COVID-19 cases among resort guests and local residents. To better understand how transmission occurs between guests, workers, and communities, comprehensive disease monitoring and surveillance measures that consider all populations of interest should be implemented. These measures can provide key insights into the multidirectional transmission dynamic, which can then be used to inform additional infection control strategies.

Further, the current study only included data over one ski season (i.e., November 1, 2020 to May 1, 2021) and may not capture varying patterns that occurred in subsequent seasons. For example, the Delta and Omicron variants may have created shifts in disease patterns not captured in the current study. Given the potential for a change in disease patterns over time, this highlights the importance of monitoring future trends in SARS-CoV-2 transmission within this population as well as other infectious diseases.

Additionally, categorizing activities associated with ski resorts was inherently subjective, and based on publicly available data reported by the Colorado Department of Public Health and Environment. Ski-related activities, for example, only included ski school and rental setting type, whereas maintenance and operations encompassed a more diverse array of activities. Taking a different categorization approach might have yielded different results. In addition, the limited information available for certain locations in which COVID-19 outbreaks occurred presented a challenge. Within the broader ski resort setting, for example, the specific activities included in the lodging setting were not clear in every instance, thereby limiting interpretation of results. Specific to restaurant settings, establishments within ten miles of a ski resort were included in the current study in order to reasonably capture off-site restaurants where workers, guests, and local residents might more routinely interact. Such inclusion criteria, however, may have led to overestimating or underestimating the number of COVID-19 outbreaks or cases associated with ski resorts. Despite these limitations, though, the current

study has a number of implications related to disease surveillance, as well as infection control and prevention.

Conclusions

Throughout the COVID-19 pandemic, ski resorts have faced a unique set of challenges mitigating SARS-CoV-2 transmission risk, including guests traveling from a multitude of domestic and international locations, shared worker housing, various indoor settings, and frequent interpersonal contact among guests, workers, and local residents. Chief among these challenges, is the potential for multidirectional transmission between guests, workers, and local community populations. In order to shed light on possible transmission dynamics, the present study aimed to characterize and evaluate COVID-19 outbreaks and outbreak-related cases associated with ski resorts and restaurants near ski resorts in seven counties in Colorado during the 2020 to 2021 ski season. The results of this study suggest that outbreaks and cases were highest in settings that typically involve close and frequent contact between individuals, as well as settings that included indoor activities. Nearly all the outbreak-related cases occurred among workers at ski resorts and restaurants, some of whom have guest-facing roles, as well as frequent interactions with other workers through job tasks, social activities, and shared living accommodations. The findings suggest that SARS-CoV-2 transmission may be sustained among workers at ski resorts and nearby dining establishments, which may be due, in part, to the influx of seasonal travelers over a narrow time period, thus creating the potential for multidirectional transmission. While the exact transmission dynamics of SARS-CoV-2 cannot be fully understood from our analysis alone, implementing improved disease monitoring and surveillance measures could help better characterize the potential multidirectional transmission occurring between ski resorts and local communities. This type of enhanced understanding of disease hotspots and transmission dynamics could help inform comprehensive, flexible, and effective infection control plans that include layered control measures tailored to a ski resort's unique conditions. Establishing thorough, well-balanced, and multilayered infection control and risk mitigation strategies that holistically consider all aspects of ski resort activity and surrounding communities can help reduce disease transmission, limit ski season disruption, protect local communities, and better prepare the ski industry for future disease outbreaks.

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