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Collisions Against Obstacles in Winter Sport Ski Areas

Short title: Ski Collisions Against Obstacles

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26 **Abstract**

27 **Introduction.** Collisions against obstacles (CAO) on ski areas account for a large proportion of
28 deaths of skiers and snowboarders but are poorly documented. We aimed to characterize the risk
29 factors and injuries of CAO and to compare CAO with 2 control groups. **Methods.** Between 2015
30 and 2019 in France, data were collected on the injured population by ski areas doctors and ski
31 patrollers. Systematic counts were also made to describe the non-injured population on ski slopes.
32 Cases (CAO injured: 3391 victims) were compared with 2 controls (non-CAO injured: 198,302
33 victims and the non-injured population: 121,227 people). Crude and adjusted logistic regressions
34 were performed ($P<0.05$). **Results.** Males, high-skilled participants, skiers and <26 y-old had
35 higher risks of being injured after a CAO than a non-CAO. CAO more frequently occurred off-
36 slopes and on very easy slopes; lifts were more often involved. Injuries to the head and neck and
37 trunk were more likely to occur after CAO than non-CAO. Medical helicopters were more often
38 used for CAO than non-CAO. Compared to the non-injured population, no age, sex or sport group
39 appeared clearly at risk of CAO. **Conclusion.** Typical victims of CAO are males, skiers, young
40 and high-skilled participants. This population was previously identified for moving fast on the
41 slopes and having risk-seeking behavior, putting them at risk of high-energy accidents. There is a
42 need for adequate prevention such as awareness campaigns, and protection, such as individual
43 device and padding on obstacles that focus on protecting against injuries to the head, neck, and
44 trunk.

45 **Keywords:** epidemiology; snow sport; accident; injury; causes

46 **Introduction**

47 Alpine snow sports are popular activities, with over 53 million skier days in France in 2018-2019.
48 Natural obstacles such as trees and rocks, and manmade obstacles such as tower lifts and snow
49 guns are located on or close to ski slopes. They are responsible for a small percentage of accidents
50 (5% of ski patrol reports ¹) but can lead to severe injuries. Collisions against obstacles (CAO) cause
51 between 35% and 73% of deaths on ski slopes ^{2,3} and 48% of moderate and severe traumatic brain
52 injuries (TBI) ⁴.

53 The most recent studies focusing on CAO were performed before 1994 ⁵⁻⁷. These studies provided
54 a first description of CAO: victims were often males and high-skilled skiers. Since then, several
55 changes occurred in the design of ski equipment such as the size and shape of skis and the
56 development of parabolic skis, with the development of snowboard which was not included in the
57 initial studies ⁵⁻⁷ and in the slope environment such as the changes in grooming and the
58 development of protection devices attached to obstacles to protect people in case of a CAO. The
59 more recent epidemiological studies did not target specific accident mechanisms such as CAO.
60 These studies only mentioned percentage of CAO as the cause of accidents on slopes ¹, head
61 injuries ^{4,8} or deaths on slopes ^{2,3}.

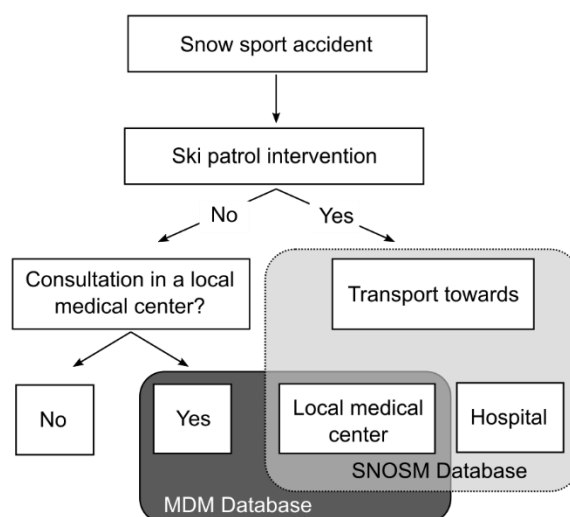
62 A better characterization of CAO was required in order to improve the prevention of some of the
63 most severe accidents on ski areas. The goal was to investigate the distinctive characteristics of
64 CAO injured: the types of injuries, the differences between victims of CAO and other accidents
65 and the risk factors for CAO.

66

67

68 Methods

69 The Association des Médecins de Montagne (MDM) is a French epidemiological network of ski
 70 areas doctors created in 1992. It collects information on snow sport accidents from 14 ski areas.
 71 The Système National d'Observation de la Sécurité en Montagne (SNOSM) is an entity that has
 72 been collecting ski patrol reports from 65 ski areas since 1996. The combination of the 2 databases
 73 included all the accidents requiring immediate treatment (Figure 1). In light of the redundancy of
 74 some accidents (those rescued by ski patrollers and brought to local ski area medical offices) and
 75 the anonymity of the databases which prevented us from excluding these accidents, we chose to
 76 conduct a separate analysis on these 2 databases.



77

78

Figure 1. Organization of data collection

79 An accident was included in the analysis when a victim suffered an accident while alpine skiing or
 80 snowboarding at ski areas, including on-slope, off-slope and terrain parks. We included only
 81 accidents with a mechanism of CAO (including natural and manmade obstacles but excluding
 82 skiing and snowboarding equipment), collision with another person (skier or snowboarder) or a
 83 non-collision such as a jump or a fall that led to a ski patrol rescue or a consultation at a ski area

84 medical office. We analyzed accidents reported from the winter seasons 2014-2015 to 2018-2019.
85 Both databases provided information on the victims (sex, age and sport) and the injury location
86 (head/neck, trunk, upper extremities, lower extremities, knee and multiple). An injury was
87 classified as multiple when the victim sustained injuries in different anatomical areas, except for a
88 knee injury associated with another lower extremity injury which was recorded as a lower extremity
89 injury. The SNOSM database also included specific information on the slope difficulty and on the
90 type of area where the accident occurred. The accident area was defined as lift when a lift was
91 involved in the accident, accident at lift departure, arrival, collision against a lift tower, etc. It also
92 included information on the rescue services requested by the ski patrollers after their first
93 evaluation of the victim such as an on-field intervention of a doctor and the transport of the victim
94 by a medical or a non-medical helicopter (i.e. with or without a doctor in the helicopter). The MDM
95 database contained additional information on the population (helmet use, back protector use and
96 proficiency level in skiing or snowboarding self-estimated by the victim), on whether the ski patrol
97 transported the patient to the medical facility and on the injury type (TBI included skull fractures,
98 concussions and severe TBI). The proficiency level was summarized as “experienced” when the
99 people estimated their proficiency level as advanced or professional. This work was based on a
100 database who obtained the approval of the regional ethical research committee (Comité de
101 Protection des Personnes Sud Méditerranée I, Committee reference: RO-2016/01).

102 The Association des Médecins de Montagne also performed observations from the bottom of the
103 slopes of representative French ski areas to approximate the population on ski areas. These visual
104 observations were conducted at various times of the winter season and in several ski areas (8 areas
105 in 2014-2015 and 2015-2016, 6 in 2016-2017, 3 in 2017-2018 and 2 in 2018-2019) to estimate the
106 ages (child, teenager, adult), sex, sport and helmet use of people on slopes.

107 Data preparation was performed using R (R Core Team (2015), Vienna, Austria) and Matlab 2020
108 (MathWorks, Natick, Massachusetts, USA). To characterize the types of CAO injuries and the
109 differences with other accidents, 2 case control studies were performed using multiple logistic
110 regressions (odds ratio (OR), 95% confidence interval and associated *P*-value). The analysis was
111 performed on the MDM database with CAO injured (MDM-CAO) as cases and non-CAO injured
112 (MDM-NonCAO) as controls. A similar analysis was conducted on the SNOSM database (cases:
113 SNOSM-CAO, controls: SNOSM-NonCAO). The dependent variable was the occurrence of a
114 CAO. Factors for the crude OR (OR_{cr}) were related to the population, the rescue services, the
115 accident environment and the injuries. Only factors associated with the occurrence of the accident
116 were kept for the adjusted OR (OR_{adj}) (sex, age, sport, helmet use, back protector use, self-
117 estimated proficiency level, accident area and slope type).

118 Another case-control study was conducted to investigate the risk factors of CAO injured with
119 MDM-CAO and SNOSM-CAO as cases and the non-injured population as controls. To better
120 understand the differences observed between MDM-CAO, SNOSM-CAO and the non-injured
121 population, the MDM-CAO case was divided in 2 cases: MDM-CAO rescued by ski patrollers
122 (MDM-CAO-SP) and MDM-CAO not rescued by ski patrollers (MDM-CAO-NonSP). Crude and
123 adjusted multiple logistic regressions were performed with CAO as the dependent variable and
124 population parameters (sex, age groups, sport and helmet use) as adjustment factors. To match the
125 age group definition of the non-injured population (child, teenager and adult), the CAO population
126 was divided into children (<11 y-old), teenagers (11-15 y-old) and adults (>15 y-old).

127 The statistical analysis was performed using R. A parameter was deemed to have a significant
128 effect if the *P*-value was less than 0.05.

129

130 **Results**

131 During 5 winter seasons, 88,351 accidents were analyzed in the MDM database (3% CAO,
 132 n=2568), 111,342 accidents in the SNOSM database (1% CAO, n=823) and 121,227 people on
 133 slopes were observed (Figure 2, Table 1). CAO victims were most often male ($\geq 57\%$), younger
 134 than 26 y-old ($\geq 53\%$), skiers ($\geq 85\%$), experienced (42%), helmeted (70%) but not wearing a back
 135 protector (87%). Among the victims who consulted in a medical facility (MDM-CAO), only 35%
 136 were brought in by ski patrollers. Among the ski patrol rescues (SNOSM-CAO), a doctor was
 137 present for 27% of rescues. 13% of rescues required a medical helicopter.

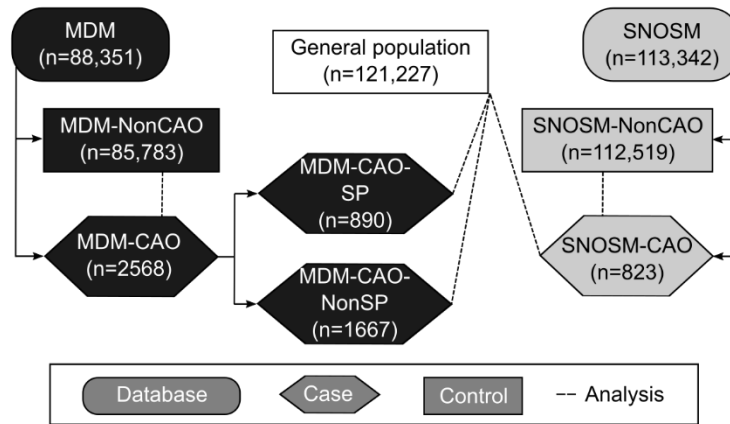


Figure 2. Description of cases and controls

141 Table 1: Demographics of snow sport accidents and general population (n(%))

		MDM-CAO	MDM-NonCAO	SNOSM-CAO	SNOSM-NonCAO	Non-injured population
Occurrence		2568	85,783	823	112,519	121,227
Sex	Female	935 (36)	39,847 (46)	350 (43)	60,346 (54)	47,498 (39)
	Male	1590 (62)	44,670 (52)	466 (57)	50,729 (45)	73,729 (61)
	Unknown	43 (2)	1266 (1)	7 (1)	1444 (1)	-
Age	Mean	29	34	25	32	-
	SD	17	18	17	18	-
	Children	-	-	-	-	16,506 (14)
	Teenagers	-	-	-	-	20,262 (17)
	Adults	-	-	-	-	84,459 (70)
Age (y-old)	11<	215 (8)	4887 (6)	159 (19)	9493 (8)	-
	11-15	453 (18)	12,165 (14)	166 (20)	16,618 (15)	-
	16-25	689 (27)	16,611 (19)	174 (21)	22,268 (20)	-
	26-55	974 (38)	39,937 (47)	249 (30)	48,118 (43)	-
	>55	237 (9)	12,183 (14)	56 (7)	13,887 (12)	-
	Unknown	-	-	19 (2)	2135 (2)	-
Sport	Skiing	2172 (85)	70,772 (83)	760 (92)	98,873 (88)	102,953 (85)
	Snowboarding	396 (15)	15,011 (17)	63 (8)	13,646 (12)	18,274 (15)
Helmet	No	715 (28)	26,069 (30)			34,413 (28)
	Yes	1810 (70)	58,058 (68)			86,814 (72)
	Unknown	43 (2)	1656 (2)			-
Back protector	No	2233 (87)	77,879 (91)			
	Yes	162 (6)	2319 (3)			
	Unknown	173 (7)	5585 (7)			
	Beginner	316 (12)	14,170 (17)			

Self-estimated proficiency level	Intermediate	1032 (40)	39,222 (46)			
	Advanced	1023 (40)	28,573 (33)			
	Professional	50 (2)	671 (1)			
	Unknown	147 (6)	3147 (4)			
Injury location	Head/neck	588 (23)	5373 (6)	185 (22)	7520 (7)	
	Trunk	440 (17)	8216 (10)	194 (24)	9437 (8)	
	Upper extremities	679 (26)	29,003 (34)	88 (11)	26,158 (23)	
	Lower extremities	297 (12)	10,098 (12)	154 (19)	15,739 (14)	
	Knee	518 (20)	32,188 (38)	70 (9)	45,092 (40)	
	Multiple	46 (2)	905 (1)	71 (9)	2058 (2)	
	Unknown	-	-	61 (7)	6515 (6)	
Injury type	Contusion	902 (35)	18,525 (22)			
	Sprain	473 (18)	33,492 (39)			
	Fracture	497 (19)	20,260 (24)			
	MTI	114 (4)	6186 (7)			
	Dislocation	50 (2)	3378 (4)			
	Laceration	451 (18)	2718 (3)			
	TBI	74 (3)	1021 (1)			
	Unknown	7 (0)	203 (0)			
Ski patrol rescue	No	1667 (65)	53,224 (62)			
	Yes	890 (35)	32,344 (38)			
	Unknown	11 (0)	215 (0)			
Doctor	No			603 (73)	90,918 (81)	
	Yes			220 (27)	21,601 (19)	
Helicopter	No			659 (80)	102,715 (91)	
	Medical			111 (13)	2866 (3)	
	Non-medical			53 (6)	6938 (6)	

Accident area	On-slopes			630 (77)	102,093 (91)	
	Off-slopes			55 (7)	1327 (1)	
	Lift			100 (12)	3459 (3)	
	Other			38 (5)	5640 (5)	
Slope	Very easy			104 (13)	10,956 (10)	
	Easy			284 (35)	52,349 (47)	
	Medium			161 (20)	25,954 (23)	
	Difficult			37 (4)	5241 (5)	
	Other			237 (29)	18,019 (16)	

142 MTI: muscle or tendon injury

143 Among all CAO injuries, the most frequent injuries were knee sprains (11%), head/neck lacerations
144 (11%) and trunk contusions (11%). Knee injuries were less frequent in CAO accidents ($\leq 20\%$)
145 compared to non-CAO (about 40%) (Table 1). In CAO accidents, injuries to the head/neck (OR_{cr}
146 6.8 for the MDM database and 15.8 for the SNOSM database), to the trunk (OR_{cr} 3.3 and 13.2) and
147 to multiple areas (OR_{cr} 3.2 and 22.2) were more frequent than knee injuries (Table 2 and Table 3).
148 These injuries represented more than 42% of CAO injuries compared to 17% of non-CAO injuries.
149 Head/neck injuries were often lacerations (48%) or contusions (31%), while trunk injuries were
150 mostly contusions (64%) or fractures (28%).

151 Table 2. Multiple logistical regressions on MDM-CAO compared to MDM-NonCAO

		MDM-CAO – MDM-NonCAO: OR [95% CI]	
		Crude OR	Adjusted OR
Sex	Female	0.7 [0.6-0.7] *	0.7 [0.6-0.8] *
	Male	Ref.	Ref.
Age (y-old)	11<	1.8 [1.5-2.1] *	1.9 [1.6-2.3] *
	11-15	1.5 [1.4-1.7] *	1.7 [1.5-1.9] *
	16-25	1.7 [1.5-1.9] *	1.7 [1.5-1.9] *
	26-55	Ref.	Ref.
	>55	0.8 [0.7-0.9] *	0.7 [0.6-0.8] *
Sport	Skiing	Ref.	Ref.
	Snowboarding	0.9 [0.8-1.0] *	0.8 [0.7-0.9] *
Helmet	No	0.9 [0.8-1.0] *	1.1 [1.0-1.2]
	Yes	Ref.	Ref.
Back protector	No	Ref.	Ref.
	Yes	2.4 [2.1-2.9] *	1.7 [1.4-2.1] *
Self-estimated proficiency level	Beginner	0.8 [0.7-1.0] *	0.8 [0.7-0.9] *
	Intermediate	Ref.	Ref.
	Advanced	1.4 [1.2-1.5] *	1.4 [1.3-1.5] *

Professional	2.8 [2.1-3.8] *	2.5 [1.7-3.4] *
Injuries		
Head/neck	6.8 [6.0-7.7] *	
Trunk	3.3 [2.9-3.8] *	
Upper extremities	1.5 [1.3-1.6] *	
Lower extremities	1.8 [1.6-2.1] *	
Knee	Ref.	
Multiple	3.2 [2.3-4.3] *	
Injury type		
Contusion	Ref.	
Sprain	0.3 [0.3-0.3] *	
Fracture	0.5 [0.5-0.6] *	
MTI	0.4 [0.3-0.5] *	
Dislocation	0.3 [0.2-0.4] *	
Laceration	3.4 [3.0-3.8] *	
TBI	1.5 [1.2-1.9] *	
Ski patrol		
No	Ref.	
Yes	0.9 [0.8-1.0] *	

152 Ref.: reference; MTI: muscle or tendon injury; *: $P < 0.05$

153 Table 3. Multiple logistical regressions on SNOSM-CAO compared to SNOSM-NonCAO

		SNOSM-CAO – SNOSM-NonCAO: OR [95% CI]	
		Crude OR	Adjusted OR
Sex	Female	0.6 [0.5-0.7] *	0.6 [0.6-0.7] *
	Male	Ref.	Ref.
Age (y-old)	11<	3.2 [2.6-3.9] *	3.2 [2.6-3.9] *
	11-15	1.9 [1.6-2.3] *	2.1 [1.7-2.5] *
	16-25	1.5 [1.2-1.8] *	1.6 [1.3-1.9] *
	26-55	Ref.	Ref.
	>55	0.8 [0.6-1.0]	0.7 [0.5-1.0] *
Sport	Skiing	Ref.	Ref.
	Snowboarding	0.6 [0.5-0.8] *	0.5 [0.4-0.6] *
Location	On-slopes	Ref.	Ref.
	Off-slopes	6.7 [5.0-8.8] *	8.1 [5.5-11.8] *
	Lift	4.7 [3.8-5.8] *	5.8 [4.2-8.1] *
	Other	1.1 [0.8-1.5]	1.1 [0.7-1.6]
Slope	Very easy	1.7 [1.4-2.2] *	1.6 [1.3-2.0] *
	Easy	Ref.	Ref.
	Medium	1.1 [0.9-1.4]	1.2 [1.0-1.4]
	Difficult	1.3 [0.9-1.8]	1.3 [0.9-1.8]

Other	2.4 [2.0-2.9]	1.0 [0.8-1.4]
Injuries		
Head/neck	15.8 [12.1-21.0] *	
Trunk	13.2 [10.1-17.5] *	
Upper extremities	2.2 [1.6-3.0] *	
Lower extremities	6.3 [4.8-8.4] *	
Knee	Ref.	
Multiple	22.2 [15.9-31.0] *	
Doctor		
No	Ref.	
Yes	1.5 [1.3-1.8] *	
Helicopter		
No	Ref.	
Medical	6.0 [4.9-7.4] *	
Non-medical	1.2 [0.9-1.6]	

154 Ref.: reference; *: $P < 0.05$

155 Adjusted logistic regressions highlighted that being <26 y-old, experienced and wearing a back
156 protector were risk factors of sustaining CAO injuries rather than non-CAO injuries (Table 2 and
157 Table 3). Females, >55 y-old, beginners and snowboarders were at lower risk of CAO injuries. Off-
158 slopes ($OR_{adj}=8.1$) and very easy slopes ($OR_{adj}=1.6$) were areas of greater risk for CAO. Lifts were
159 more often involved in CAO ($OR_{adj}=5.8$). After adjustment, only helmet use was not different
160 between CAO victims and non-CAO victims. CAO victims were less likely to go to medical
161 facilities with ski patrol rescue ($OR_{cr}=0.9$) (Table 2). When CAO injuries led to ski patrol rescue

162 (Table 3), a doctor was more frequently involved ($OR_{cr}=1.5$), as was the use of a medical helicopter
 163 ($OR_{cr}=6.0$).

164 The population injured after a CAO and rescued by ski patrollers was not the same as the population
 165 going directly to a medical facility (Table 4). CAO victims who went to the doctors without the ski
 166 patrol (MDM-CAO-NonSP) were more likely to be males and adults compared to those rescued
 167 by ski patrollers (MDM-CAO-SP and SNOSM-CAO). Helmet use was not significant in the crude
 168 logistic regressions and was excluded from the adjusted regressions. Crude ORs were similar to
 169 adjusted ORs.

170

171 Table 4. Adjusted multiple logistical regressions on CAO compared to the population on slopes

	MDM-CAO - Non-injured population		SNOSM-CAO – Non-injured population
	OR [95% CI]		
	MDM-CAO-NonSP	MDM-CAO-SP	OR [95% CI]
Sex			
Female	0.8 [0.7-0.9] *	1.2 [1.1-1.4] *	1.1 [1.0-1.3]
Male	Ref.	Ref.	Ref.
Age groups (y-old)			
<11	0.4 [0.4-0.5] *	0.9 [0.7-1.1]	1.7 [1.4-2.0] *

	11-15	0.8 [0.7-1.0] *	1.4 [1.2-1.6] *	1.5 [1.2-1.8] *
	>15	Ref.	Ref.	Ref.
Sport				
	Skiing	Ref.	Ref.	Ref.
	Snowboarding	1.1 [1.0-1.3]	0.8 [0.6-0.9] *	0.5 [0.4-0.6] *

172 Ref.: reference; *: $P < 0.05$

173

174 Discussion

175 We performed a double analysis to get an overall vision of snow sport accidents requiring urgent
 176 treatment, from accidents in which the victim went to a medical facility on their own, to accidents
 177 in which the victim had to be transported to a hospital by helicopter. Medical consultations outside
 178 ski areas were not included as these accidents did not require an urgent consultation and were
 179 therefore likely to be associated with mild injuries. We analyzed 2 databases as each database offers
 180 a partial overview of accidents on the slopes. The MDM database covered a wide spectrum of
 181 injuries (from mild to severe) requiring medical consultations. The accidents included in the
 182 SNOSM database required immediate interventions by ski patrollers. Injuries ranged from
 183 moderate to severe requiring medical transport by helicopter to a hospital. The MDM database did
 184 not include the most severe accidents directly transferred to a hospital while the SNOSM database
 185 did not include accidents in which the victim visited local medical facilities on their own. The 2
 186 databases were also complementary, as the SNOSM database provided general information on
 187 victims, accident conditions, injuries and rescue services and the MDM database provided more

188 detailed information on victims and injuries. The analysis of these 2 databases gave an overall
189 picture of the situation in France. This situation can be generalized to other alpine countries. They
190 have similar snowfall patterns, slope difficulties and speeds on the slopes^{9,10}. Generalizing results
191 on a global level would require further analysis that considering the characteristics of each country.

192 Only 9% of non-CAO were collisions with another person. The differences between CAO and
193 collisions with another person were not investigated. This study highlighted the differences
194 between CAO and other accidents on slopes, especially the higher risk of CAO injuries for young
195 people <26 y-old, skiers, males, experienced people and back protector users. Males, skiers and
196 experienced people generally have higher speeds^{9,10}. This population and people <26 y-old more
197 often estimate to have a risk-seeking behavior on slopes^{11,12}. One possible explanation is that these
198 experienced and risk-seeking skiers/snowboarders might ski off-slopes more frequently than
199 beginners and cautious people. Obstacles at ski areas such as snow guns, lift towers, trees, and
200 rocks are mostly found off ski slopes and rarely on ski slopes. This might explain the higher risk
201 of CAO injury for males, skiers, people <26 y-old and experienced people. The risk factor of being
202 injured after a CAO with a back protector might not be caused by the protection device itself, but
203 may be associated with the population that uses it. People who use back protectors are often
204 experienced people with risk-seeking behaviors. This population is identical to the population with
205 a higher risk of CAO. The use of back protector might be an indicator of risk-seeking behavior,
206 although this factor was not included in previous studies^{11,12}. On very easy slopes, there is a higher
207 risk of CAO injuries than of other accidents injuries. These slopes are often crowded, frequented
208 by all types of people, from beginners to experts. High speeds are recorded in these areas¹⁰. There
209 is a need for preventive measures against CAO on very easy slopes. All the characteristics of CAO
210 are key elements for future public awareness campaigns which should highlight the risks.

211 In CAO victims are at higher risks of sustaining head, neck and trunk injuries and ski patrollers are
212 more likely to call for a medical helicopter and a doctor than in other accidents. These results agree
213 with the higher severity of CAO compared to other accidents. This point was suggested in previous
214 studies by the higher proportion of CAO among severe accidents (48% among moderate/severe
215 TBI⁴ and 35% to 73% among death^{2,3}) compared to all accident severities (5% among ski patrol
216 rescue¹). The higher risk of head injuries in CAO emphasizes the need to promote helmet use on
217 the slopes to reduce the severity of TBIs: unprotected head impacts against rigid surfaces are at
218 high risks of severe head injuries and helmet use can reduce these risks (depending on the impact
219 speed^{13,14}).

220 CAO victims are more likely to visit medical facilities without ski patrol rescue than victims of
221 non-CAO. The lower proportion of knee and lower extremity injuries in CAO may reduce the
222 proportion of injuries limiting the mobility of the victims and preventing them from going to
223 medical facilities without ski patrol intervention.

224 We analyzed the non-injured population on slopes in order to investigate whether CAO victims
225 were more often males, young people and skiers because this population was at higher risk of CAO
226 or because this population reflected the non-injured population on the slopes. This analysis
227 highlighted the differences observed between CAO victims rescued by ski patrollers and CAO
228 victims not rescued by ski patrollers. It could reflect different types of CAO with more severe
229 accidents or more accidents limiting the victim's mobility among CAO rescued by ski patrollers.
230 It could also indicate a difference in the request of ski patrol depending on the victims.

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233 **Limitations**

234 Our study did not include accidents that could not be identified as CAO, collisions with another
235 person and non-collisions, which could change the distribution of accident scenarios. Accidents
236 leading to a medical consultation outside ski areas or to no consultation were also not included,
237 which might underestimate the number of mild injuries and the overall rate of injury. We did not
238 investigate the influence of the shape of obstacle and the type of protection on the types of injuries.

239 The analysis of 2 independent databases had several limits. The 2 databases shared 12 ski areas,
240 leading to an overlap of the results: the 201,693 documented cases likely corresponded to a lower
241 number of accidents. Working with anonymous databases prevented us from quantifying and
242 removing the duplicates. We could not avoid this overlap without choosing one database over the
243 other and without excluding either the mildest or the most severe accidents. The definition of some
244 factors was also slightly different between the databases. The identification of injuries and their
245 locations were less precisely evaluated in the SNOSM database, which could have affected the
246 multiple and unknown injury locations. The proficiency level was biased by the self-estimation by
247 the victim. This bias was present for both cases (CAO) and controls (non-CAO).

248 Characterization of the general population were based on visual inspection, leading to potential
249 errors in the estimation of sex and age group of people observed. These observations were
250 performed only in 8 ski areas, providing an approximation of the non-injured population on the
251 slopes.

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255 Conclusions

256 CAO victims are more likely to be males, skiers, <26 y-old and experienced compared to victims
257 of other accidents. Previous studies showed that these groups tend to exhibit risk-seeking behavior.
258 They also tend to move at high speed, leading to high-energy accidents. CAO victims sustain
259 head/neck or trunk injuries more often and more frequently need a transfer with a medical
260 helicopter, underlining the severity of these accidents. The profile of CAO victims suggests a need
261 for dedicated public awareness campaigns to prevent these rare, but often severe accidents. It also
262 suggests a need for adequate protection devices such as paddings attached to obstacles.

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266

267 **Author contributions**

268 Study concept and design (PJA, CM, SR); data acquisition (JDL, CJ, the Association des Médecins
269 de Montagne, the Système National d'Observation de la Sécurité en Montagne); data analysis (MD,
270 JLM); drafting of the manuscript (MD); critical revision of the manuscript (all authors); approval
271 of the final manuscript (all authors).

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275

276 **Disclosure Statement**

277 Disclosures: None.

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