DIG CLOSE, DIG FAST. A STUDY ON THE CONSEQUENCES OF EXCAVATION START POINT CHOICE IN AVALANCHE COMPANION RESCUE

Davide Rogora[1]*, Gianni Perelli Ercolini[2]

[1] *Centro Studi Materiali e Tecniche, Club Alpino Italiano, Milano, Italy*
[2] *Scuola Centrale di Scialpinismo, Club Alpino Italiano, Milano, Italy*

ABSTRACT: An effective avalanche companion rescue requires acting against the clock. Analysis of intervention protocols has long pointed out that the most time-consuming phase is the excavation to free the airway of the buried subject. The best point to begin the excavation still seems to be a controversial topic. The so-called Conveyor Belt method clearly sets it as being close to the probe, where the successful hit has been made. Other sources, from professional guides or members of rescue organizations, firmly state to begin at a distance from the probe equal to at least one and a half times the burial depth. The objective of this work is to measure if and what are the differences in the time required to reach the buried subject when the only variant in the excavation technique is the starting point: either "canonical" (near the probe) or "from far". By means of controlled field tests, a sample of practitioners dug pairs of pits using both approaches. The differences between the recorded excavation times appeared statistically significant: dig "from far" requires, on average, two minutes and thirty seconds more than using the canonical method. When applied to the decreasing trend in survival probability with time, this implies losing seven or more percentage points. The results of field test support the recommendation for the adoption of the "canonical" method, and it is believed that, when proposing the option "from far", one should also warn the user of the potential adverse consequences on the probability of survival.

KEYWORDS: Digging Distance, Burial Depth, Companion Rescue.

1. INTRODUCTION

The time a person remains buried below an avalanche is critical to their chances of survival. Following a transceiver-assisted search, once the probe has hit the subject, digging following a clearly structured protocol is crucial in order to maximize the potential for a successful rescue. Over time, several methods have been proposed and developed to improve the efficiency of the rescue operation.

Based on field test comparisons, the Italian Alpine Club (CAI) selected the Conveyor Belt method for its educational syllabus, as formalized in the completely revised avalanche companion rescue chapter of the ski mountaineering handbook (edited in 2018) for all CAI schools to support training.

A leading feature of this technique is that the rescuers are always working at a distance of one shovel length from each other and the first rescuer is positioned one shovel length away from the probe that hits the target. This is the case apart from special cases, where there is shallow soft snow or there is an insufficient number of rescuers in relation to the burial depth.

* *Corresponding author address:*
Davide Rogora, Centro Studi Materiali e Tecniche, Club Alpino Italiano, via Petrella 19, 20124 Milano, Italy
tel.: +39 320 0947482
e-mail: daviderogora@iol.it

Since the date of publication of the handbook it was noticed that various sources, including equipment manufacturers' booklets, pro magazine articles, and some rescue organizations, disagree with this approach, categorically stating that excavation must initiate at least 1.5 times the burial depth away from the probe.

The work presented in this article investigates the potential differences in outcomes when following each of these approaches, from a buried subject perspective.

2. METHODS

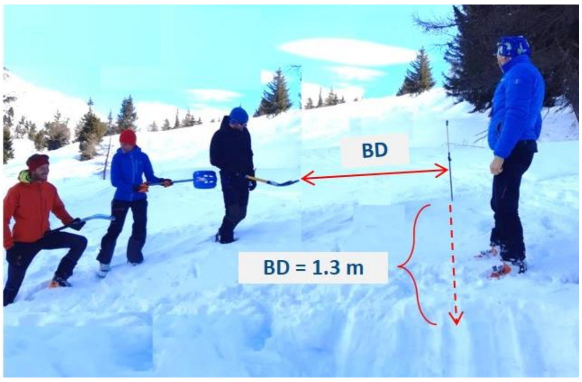
For this study, we asked groups of practitioners to perform a pair of excavations, each representative of an avalanche companion rescue, differentiated only by the chosen starting point. The first one taken as the reference, called the control group, placed *close-to-probe*, as per canonical protocol of the Conveyer Belt method, according to Genswein et al. (2008) and CAI handbook #31 (2018). The second one under investigation, called the treatment group, placed *far-from-probe*, at a distance from the probe equal to the burial depth.

The data for this study was collected during four different field-training sessions organized for practitioners with a wide variation in skill level, ranging from beginner to advanced and up to candidate ski mountaineering instructors.

A random mix of gender, age, body fitness, and excavation methods knowledge characterized the breakdown of the rescuers' sample. Wherever interviewed subjects declared little to no experience, a specific short training session was performed before test initiation to ensure the proper technique was used.

The pace each group was called to action included sufficient rest time to prevent fatigue-induced bias. Moreover, the order of the technique each group initiated with was chosen randomly.

a) rescuers setup *close-to-probe*



b) rescuers setup *far-from-probe*

Figure 1: The configuration distances assumed by test participants in *a)* the "close to" reference approach or *b)* the "far from" approach.

Some parameters such as the burial depth (BD), slope inclination, and the number of team members were fixed.

The recorded measures consisted of two very specific time instants during the execution of the excavation task.

The first event, t_1, was the elapsed time to reach the probe tip, which represents, also for the simplified test setup, the amount of time used to get the first visual contact with the buried subject. This is normally a crucial step, as it is the instant where the rescuers are firstly in the position to determine the actual setting of the buried subject relative to the probe location, and to decide precisely how to direct the excavation effort towards the subject's airways.

The second event, t_2, was the time needed to enlarge the pit at the probe level up to a given width, a priori fixed and constant for each excavation, simulating the key criterion of successful completion of the airway-access.

2.1 Burial depth

The simulated burial depth was 130 cm for all of the excavations. This figure was deemed a reasonable balance between providing a challenging effort for the teams, involving sufficient time to deploy team interaction effects, and avoiding, on the other hand, excessive single test duration. This value is the 73th percentile for subjects fully buried by avalanches in Switzerland, recorded from 1973–1974 to 2012–2013 in the SLF avalanche database, as shown in a previous article by Reiweger et al. (2017).

2.2 Slope inclination

The sites where the experiments were to be conducted were chosen in such a way as to limit the maximum inclination of the excavation areas to five (5) degrees, relative to the horizontal. Special precautions were also taken to maintain sufficient untouched snowpack in the immediate vicinity of the first pit dug by each team to ensure the greatest possible homogeneity of both the inclination as well as the equally important local snow hardness.

Greater inclinations, related to the typical burial depth set for the experiments, would have exceedingly simplified the excavation task while potentially masking the comparison effects, the subject of this research. Hence, this bias was attempted to be minimized in the design of the experiments.

2.3 Team size

The number of participants in each team was limited to three (3). This choice was made at the test design stage to attempt to best represent two features of the terrain action considering real-life examples of companion rescue.

The first aspect challenges the concept of an "ideal" number for a ski mountaineering team. Not too large (say < 5), so as not to run into typical safety problems related to the difficulty of communication, forming a common view, and, in general, everything included in the so-called human factor issues. Neither too few (say ≤ 3) to the point of being with only one or two survivors (in case of just a single caught/buried person) with consequently limited intervention power due to the low number of active people remaining. Hence, this led to the selection of the "ideal" team size of four.

Secondly, in a large team excavation effort, a greater difficulty - and thus reduced effectiveness - in coordination can reasonably be expected merely from the digging technique standpoint, despite the greater amount of rescuers. So, it was deemed undesirable to emphasize this type of bias, given the goal of the experimental campaign.

2.4 Size of the excavation target

As soon as a width of 80 cm at the level of the tip of the probe has been achieved, it was considered to meet the criterion of being able to have access to the airway of the buried subject. Thus, as soon as this point was reached, the timer was stopped. This width choice reflects the buttock-eye distance taken as the mean between the female and male 95th percentile values, according to Gordon et al. (2014) and MIL-STD-1472D (1989).

Whether to enlarge the pit towards the left or right side, relative to the probe tip, was randomly left up to who was leading the team of rescuers at the time of the first visual contact.

Figure 2: The measured parameters t_1 at probe tip reaching and t_2 at pit enlargement up to a constant dimension gauged with a dummy body.

3. RESULTS

In the timeframe December 2019 – January 2020 four (4) sessions of field testing took place at different sites in the Alps. Two of them in the vicinity of Passo del Tonale - I 1880 m ASL (46.25761, 10.57757), on 1st and 2nd January, 2020; one just below Passo del Sempione - CH 1890 m ASL (46.24289, 8.01209), on 28th December 2019, and one on top of the dismissed ski area in San Bernardino – CH 2250 m ASL (46.46005, 9.15619), on 15th December 2019.

Overall, 24 teams, made of 72 participants, dug 48 pits. Hence, the database consists of 24-paired observations: one for the pit dug "canonically" and one for the correspondent pit dug "from far" by the same team.

Through a quick interview recorded before the start of the field trials, each of the participants was identified according to the characteristics most impactful for the purposes of the study. Overall, 78% were male and 22% female. 44% of the participants confirmed to practicing an active (A) lifestyle, while the other 56% described themselves as sedentary (S). 74% already knew the Conveyor Belt excavation method compared with the remaining 26% for which the method was unknown. 67% declared to have already tried to apply the method at least once, while 33% had never used it before.

The team's gender mix was 54% all males, 29% two males one female, 13% two females one male, and 4% all females.

3.1 Demographics

The age of the team members ranged from 17 to 67 years, with an average value of 43.6 (IQR 16.5).

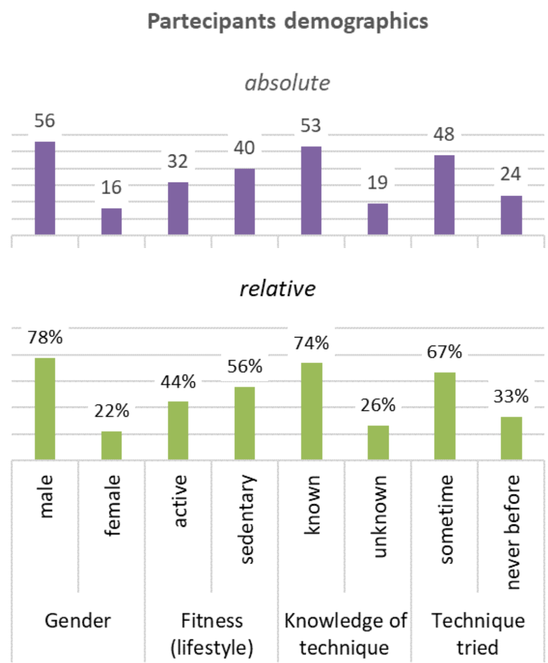


Figure 3: The composition characteristics of the participant's sample.

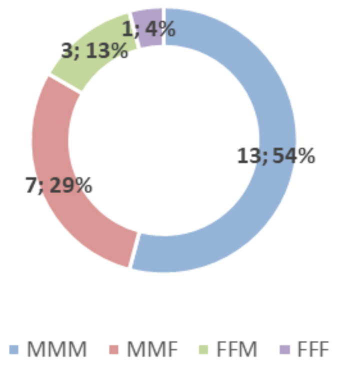


Figure 4: The teams' gender mix.

3.2 Time to reach the buried body

In the test setup the first contact to the buried subject corresponds to the moment the probe tip becomes visible to the shoveler working in the most forward position of the conveyor belt. This is named time t_1. Over the 24 trials constituting the sample, in average it took 356 seconds (SD 83, CoV 23%) for the "canonical" method and 495 seconds (SD 103, CoV 21%) for the "from far" method.

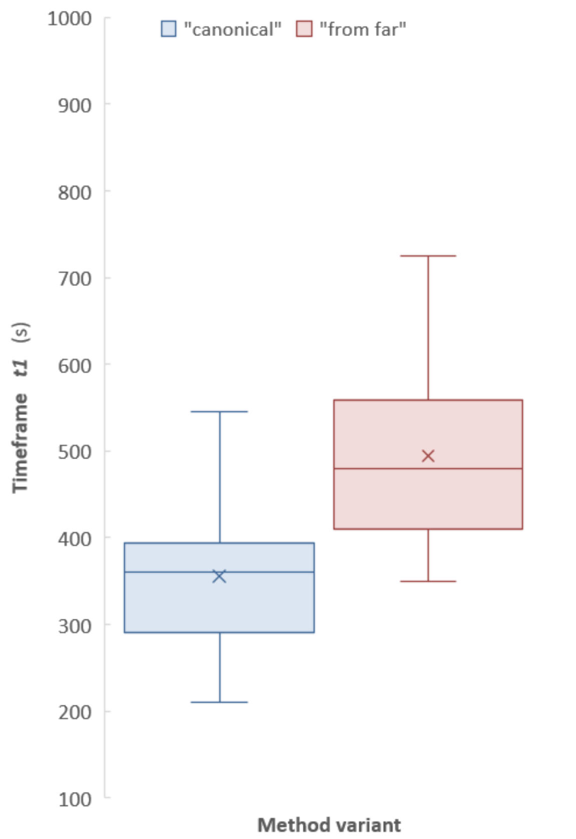


Figure 5: Time to reach the buried body results - dataset comparison.

3.3 Time to reach the subject's airways

In the test setup, reaching the subject's airways is the key event and corresponds to achieving 80 cm of width at the level of the probe tip. This was verified by inserting a fixed dimension, cylindrically shaped test dummy. This is named time t_2. Over the 24 trials constituting the sample, in average it took 508 seconds (SD 103, CoV 20%) for the "canonical" method and 661 seconds (SD 120, CoV 18%) for the "from far" method.

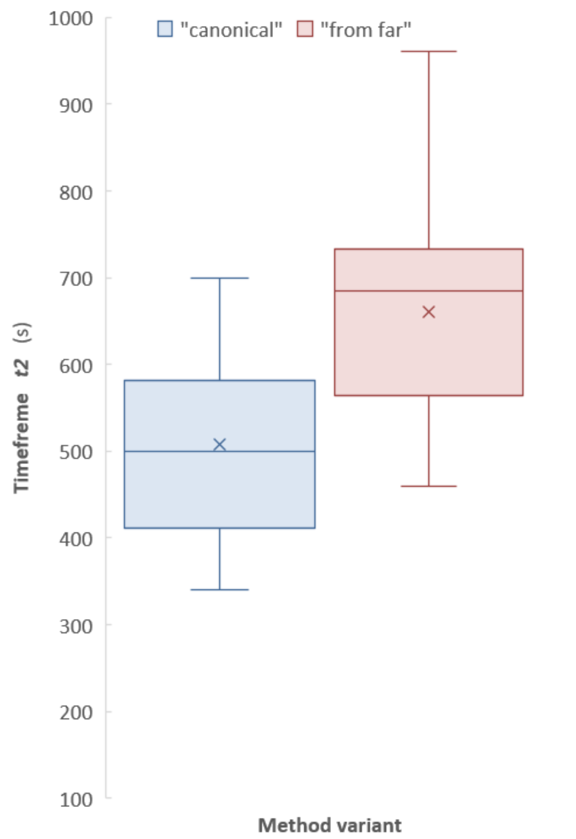


Figure 6: Time to reach the subject's airways results - dataset comparison.

It is worth noting that the snow hardness over the 48 pits ranged between the *fist* and *finger* hardness degree, with a prevalence of the *four-finger* hardness.

4. DISCUSSION

During the evaluation, the results were primarily grouped in accordance with the need to check if any significant difference in elapsed time emerged between the two excavation approaches and which type of consequences this may imply, if any.

The statistical analyses were processed with the aid of R software. Refer to the R Project (2023) documentation for theoretical foundations and manuals.

4.1 Getting to the buried subject

Since these are data from paired experiments, let us define the variable $t_{1\text{-}d}$ as the difference between the following two times:

```
t1_d = t1_c - t1_ff
```

Given the p-value of the Anderson-Darling test, carried out on the $t_{1\text{-}d}$ variable is equal to 0.58, it is difficult to deny the hypothesis of normality of the variable. The following Q-Q plot supports this thesis.

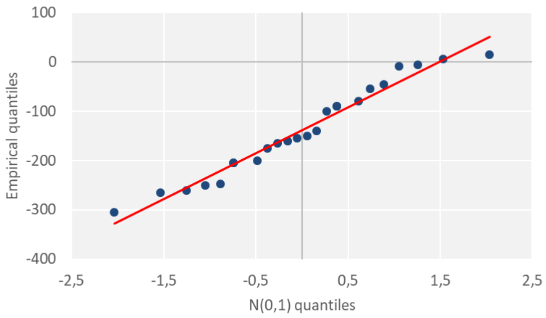


Figure 7: Q-Q plot for t_{1_d} variable.

Performing a t-test (α=0.05) on the $t_{1\text{-}d}$ variable, equivalent to a t-test for paired data, with the following hypotheses:

$$H0: \mu = 0 \quad ; \quad Ha: \mu \neq 0$$

it was found that the p-value of the t-test was equal to 2.2E-7, clearly indicating that it is not possible to accept the null hypothesis that the mean of the t_{1_d} variable is equal to zero. Therefore, leading to accept that there is a statistically non-negligible difference between the mean of the "canonical" method ($t_{1\text{-}c}$) and the mean of the "from far" method ($t_{1\text{-}ff}$).

Since the value of the sample mean of the variable $t_{1\text{-}d}$ turns out to be negative and equal to -139, we also test the following hypothesis:

$$H0: \mu \geq 0 \quad ; \quad Ha: \mu < 0$$

The p-value of the t-test of 1.1E-7 clearly indicates that it is not possible to accept the null hypothesis that the mean of the $t_{1\text{-}d}$ variable is greater than or equal to zero. Therefore, leading to accept that there is a statistically non-negligible negative difference between the mean of the canonical method ($t_{1\text{-}c}$) and that of the distance method ($t_{1\text{-}ff}$). That is, the "canonical" method appears to be faster than the "from far" method.

The strength of the test, assessed by assuming a delta between $t_{1\text{-}c}$ and $t_{1\text{-}ff}$ equal to 120 seconds, turns out to be well beyond the usual value of 80% (99.9%).

4.2 Clearing the subject's airways

Since these are data from paired experiments, let us define the variable $t_{2\text{-}d}$ as the difference between the following two times:

```
t2_d = t2_c – t2_ff
```

Given the p-value of the Anderson-Darling test, carried out on the $t_{2\text{-}d}$ variable is equal to 0.13, it is difficult to deny the hypothesis of normality of the variable. The following Q-Q plot supports this thesis.

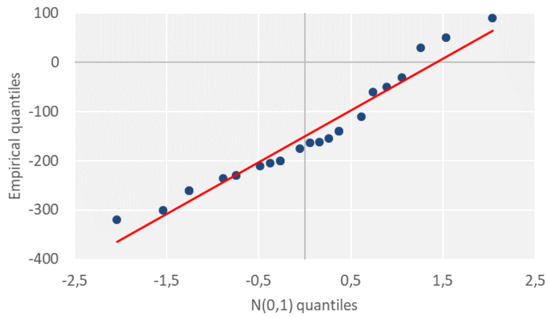


Figure 8: Q-Q plot for $t_{2\text{-}d}$ variable.

Performing a t-test (α=0.05) on the $t_{2\text{-}d}$ variable, equivalent to a t-test for paired data of following hypotheses:

$$H0: \mu = 0 \quad ; \quad Ha: \mu \neq 0$$

it was found that the p-value of the t-test was equal to 5.2E-7, clearly indicating that it is not possible to accept the null hypothesis that the mean of the $t_{2\text{-}d}$ variable is equal to zero. Therefore, leading to accept that there is a statistically non-negligible difference between the mean of the "canonical" method ($t_{2\text{-}c}$) and the mean of the "from far" method ($t_{2\text{-}ff}$).

Since the value of the sample mean of the variable t_{1_d} turns out to be negative and equal to -153, we also test the following hypothesis:

$$H0: \mu \geq 0 \quad ; \quad Ha: \mu < 0$$

The p-value of the t-test of 2.6E-7 clearly indicates that it is not possible to accept the null hypothesis that the mean of the $t_{2\text{-}d}$ variable is greater than or equal to zero. Therefore, leading to accept that there is a statistically non-negligible negative difference between the mean of the canonical method ($t_{2\text{-}c}$) and that of the "from far" method ($t_{2\text{-}ff}$). That is, the "canonical" method appears to be faster than the "from far" method when considering clearing of the subject's airways.

The strength of the test, assessed by assuming a delta between $t_{2\text{-}c}$ and $t_{2\text{-}ff}$ equal to 120 seconds, turns out to be well beyond the usual value of 80% (99.9%).

4.3 Time and the probability of survival

The field test and the recorded data analysis indicate that a team engaged in a companion rescue effort, on average, spent 2.55 minutes (2' 33'') more to free the buried subject's airways after successfully locating the subject, if starting to dig "from far" compared to the "canonical" case close to the probe.

When considering the fifth percentile of the sample performance, the overall additional time increases to the alarming figure of 4.33 minutes (4' 20'').

The longer the excavation time, the lower the probability of survival. Therefore, it is essential to question the actual representativeness of the scenario used in the tests and, no less important, to estimate the consequences that such an increase in rescue time implies for the probability of survival of the buried subject.

It is worth noting that "from far" in the test setup was limited to *1x* the burial depth, in spite of the minimum advocated by some that is at "*1.5x* or more". Hence, it is clearly predictable that eventually further experiments based on that larger distance will only exacerbate the extra time needed to clear the subject's airway.

In addition, the snow hardness encountered in the field sessions, in average *four-finger* grade, may lead to an optimistic view of what a true avalanche debris pile could be like, indicating that the measured time required to reach and clear the victim's airways was conservative, that is to say it would most likely be greater.

Over time, several researchers have developed curves providing the probability of survival as a function of burial duration. Depending on the reference dataset, the decaying slope may differ. However, the overall survival patterns are reproducible amongst most of them.

Notably, using literature, the following figures have been collated, sufficient to approximate the initial period for a burial time below 15 min, also known as the asphyxia zone (i.e. ignoring traumas as the cause of death):

Swiss	-2.3	%/min	Haegeli et al. (2011)
Swiss	-3.5	%/min	Procter et al. (2016)
Canada	-3.2	%/min	Haegeli et al. (2011)
Austria	-2.2	%/min	Procter et al. (2016)
Italy	-0.9	%/min	Valt (2011)

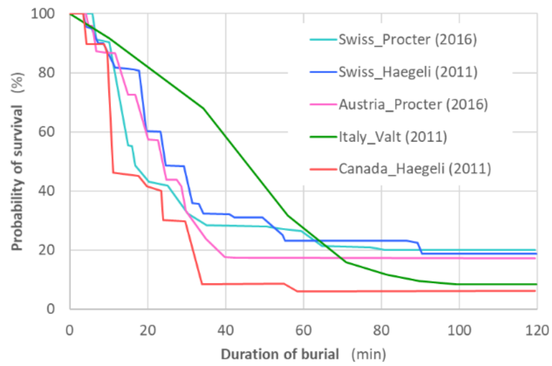


Figure 9: Survival Curves as redrawn from cited references.

Since it was labeled "experimental" by its author (indeed it does not have the conventional Kaplan-Maier's form), the Italian datum has been omitted. The average slope for the other well-established curves results in a -2.8 % probability of survival per each elapsed minute, in the period 0-15 minutes.

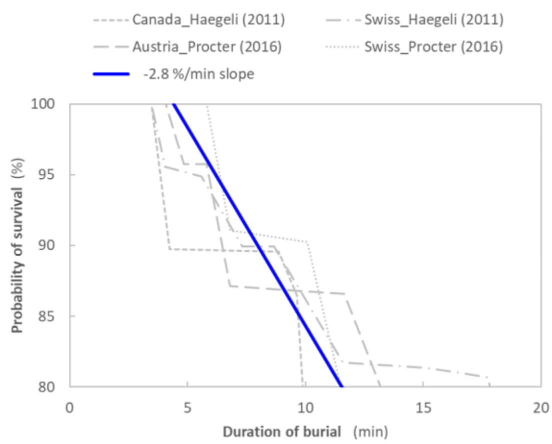


Figure 10: Averaged survival probability slope.

It follows that, on average, if instead of sticking to the "canonical" excavation methodology, with one commenced "from far", the probability of survival would decrease by 7.1 % (2.8 x 2.55).

The chance of survival reduces further, by 12.1 % (2.8 x 4.33) when considering the fifth percentile of the performance from the sample involved in this experiment.

5. CONCLUSIONS

By means of field trials, the impact of the adoption of an excavation start point at 1x the burial depth, in contrast to the canonical close-to-probe instruction of the Conveyor Belt excavation method, has been investigated thanks to 72 participants who dug pits using both approaches.

Although further work with additional trials may provide greater insight into the influence of the involved variables, it appears that the canonical Conveyor Belt excavation method will maximize the potential for a successful rescue in the majority of cases when the rescue team consists of recreational users.

In fact, based on 48-paired pits excavation time measurements, one dug with the canonical method and one dug by initiating “far-from-probe”, in average it took 2 minutes 33 seconds more in the latter case.

In accordance with the available literature, concerning survival curves, expressing the reduction of a subject’s chance to escape asphyxia as a function of time increase when completely buried, such a mean time increase corresponds to squandering 7 % of the probability for survival.

If, instead of considering the average performance of the participant groups, the fifth percentile is assumed, the time increment, and the reduced probability of survival, increases further to 4 minutes 20 seconds and 12 % respectively.

Therefore, it is believed that some caution is necessary when recommending the adoption of the “far-from-probe” variant without considering the actual risk of reducing the chances of survival and without including a clear warning of the potential implications its adoption.

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Finally, we must address the most important aspect: we dedicate this work to our beloved fraternal friend Angelo Panza. Having perished in June on the Lyskamm traverse, at Monte Rosa, he will not be able to read the article that would have interested him so much, as he had dedicated his entire life to teaching ski mountaineering and companion rescue techniques within CAI’s schools. He has been our teacher, and all that remains is for us to try to continue his work.

Excelsior!

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Team	*Tester*	*Gender*	*Fit*	*Method Know*	*Method Tried*	*Age*	t_{1-c} *(s)*	t_{2-c} *(s)*	t_{1-ff} *(s)*	t_{2-ff} *(s)*	t_{1-d} *(s)*	t_{2-d} *(s)*
1	1	M	S	Y	Y	48	405	670	450	700	-45	-30
	2	M	S	Y	Y	48						
	3	M	S	Y	Y	22						
2	4	M	S	Y	Y	36	235	420	500	680	-265	-260
	5	M	S	Y	Y	36						
	6	M	S	Y	Y	60						
3	7	M	S	Y	Y	60	210	360	350	560	-140	-200
	8	M	A	Y	Y	62						
	9	M	A	N	N	62						
4	10	M	A	Y	Y	54	350	410	355	460	-5	-50
	11	F	S	Y	Y	54						
	12	M	S	Y	Y	24						
5	13	M	S	Y	Y	24	320	460	410	670	-90	-210
	14	M	A	Y	Y	24						
	15	M	S	N	N	24						
6	16	F	S	N	N	46	380	460	640	780	-260	-320
	17	M	A	Y	N	46						
	18	M	A	Y	Y	51						
7	19	M	S	Y	Y	27	270	410	475	640	-205	-230
	20	F	S	Y	Y	51						
	21	M	A	Y	Y	39						
8	22	M	A	Y	Y	47	380	500	530	705	-150	-205
	23	F	S	N	N	17						
	24	F	S	N	N	17						
9	25	F	A	Y	Y	45	312	630	560	690	-248	-60
	26	F	S	N	N	52						
	27	M	S	N	N	54						
10	28	F	S	Y	N	42	485	585	540	725	-55	-140
	29	F	S	Y	N	56						
	30	F	A	Y	N	38						
11	31	F	S	Y	Y	43	440	620	434	590	6	30
	32	M	S	N	N	46						
	33	F	A	N	N	38						
12	34	M	S	Y	N	57	550	700	725	960	-175	-260
	35	M	A	Y	Y	59						
	36	M	S	N	N	42						
13	37	M	S	Y	Y	37	385	570	635	770	-250	-200
	38	M	S	N	N	53						
	39	M	A	N	N	53						
14	40	M	S	Y	Y	42	320	500	475	610	-155	-110
	41	M	A	N	N	36						
	42	M	A	N	N	57						
15	43	M	S	N	N	53	395	560	485	735	-90	-175
	44	M	A	N	N	55						
	45	M	S	Y	Y	29						
16	46	M	A	N	N	64	380	485	545	720	-165	-235
	47	M	A	N	N	67						
	48	F	A	N	N	60						
17	49	M	A	Y	Y	59	310	415	410	570	-100	-155
	50	M	A	Y	Y	34						
	51	M	A	Y	Y	44						
18	52	M	A	Y	Y	48	240	340	400	480	-160	-140
	53	M	A	Y	Y	41						
	54	M	A	Y	Y	41						
19	55	F	A	Y	Y	45	285	390	590	690	-305	-300
	56	M	A	Y	Y	43						
	57	M	A	Y	Y	42						
20	58	M	A	Y	Y	34	370	520	355	470	15	50
	59	M	S	Y	Y	47						
	60	M	A	Y	Y	48						
21	61	M	S	Y	Y	47	390	565	590	795	-200	-230
	62	M	S	Y	Y	38						
	63	F	S	Y	Y	39						
22	64	M	S	Y	Y	39	545	660	554	824	-9	-164
	65	M	S	Y	Y	32						
	66	M	S	Y	Y	36						
23	67	M	A	Y	Y	30	330	565	410	475	-80	90
	68	F	A	Y	Y	53						
	69	M	S	Y	Y	38						
24	70	M	S	Y	Y	33	245	400	450	562	-205	162
	71	M	S	Y	Y	32						
	72	M	S	Y	Y	36						

Table 1: The experiment’s recorded dataset