

Improved Probing for Avalanche Victims¹

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Introduction

Probing for buried avalanche victims is very slow compared to searching with transceivers or trained dogs. Although the absence of transceivers or a search dog sharply reduces the odds of live recovery, accident reports indicate that some avalanche victims are found alive by probing.

This paper focuses on the coarse probing patterns for avalanche victims that may still be alive. Finer, slower, patterns used to find bodies are not discussed in this paper. Also, the hasty or random probing done by one or two people prior to setting up a probe line are not discussed.

The objectives of this study are to:

- develop more realistic method of estimating the probability of probing a buried victim,
- compare the probability of probing a victim for various coarse probing methods, including a recently developed method, and
- calculate and compare the time required for various coarse probing methods.

Literature Review

Traditionally, coarse probing (Schild, 1963, 1974) used a 0.75 m by 0.70 m grid of probe holes. One effective way of achieving the 0.75 m-spacing between probes was to stand elbow to elbow with both hands holding the probe vertically. After probing once in front of each person, probers stepped forward 0.70 m. This one-hole-per-step pattern (1-HPS) became the standard, and remains in use in many countries. The number of probers in a probe line ranged from 3 to over 20. Guidon cords with markers to control the spacing between holes are sometimes used.

As an alternative to the 1-HPS method, Perla and Martinelli (1976) and McClung and Schaerer (1993) included a two-hole-per-step method (2-HPS). To achieve the 0.75 by 0.70 spacing between holes, probers stood with 1.5 m from sternum to sternum. Each person probed once to their left and once to their right before stepping ahead 0.70 m. Some references suggested this spacing could be achieved by standing fingertip to fingertip. However, for people of average size, fingertip-to-fingertip spacing results in a sternum-to-sternum distance of 1.75 m and a 0.87 by 0.70 m grid of holes. 2-HPS probing is faster than 1-HPS probing and, with care, can achieve the same density of holes. It became popular with rescuers in the USA but, for reasons unclear to us, not in Canada.

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Schild (1963, 1974) proposed that a prone or supine victim had an area of 0.5 m^2 exposed to vertical probes. For victims positioned on their side or vertically, the exposed areas are 0.4 m^2 and 0.1 m^2 respectively. Since the 0.75 by 0.70 m grid results in a probe hole every 0.525 m^2 , Schild calculated that the probability of probing a prone/supine victim as $0.5/0.525 = 0.95$. By the same ratio-of-areas method, the probabilities of probing a victim positioned on their side or vertically are 0.76 and 0.19 . The probabilities were rounded to 95% , 75% and 20% and widely used in texts on avalanche rescue.

Perla (1967) assumed that avalanche victims were evenly distributed in the top 3 m of a deposit and concluded that there was no advantage in limiting probing to the top 2 m . However, recent statistics from Switzerland (Falk and Brugger, 1995) and the USA (Logan and Atkins, 1996) show that avalanche victims are concentrated in the top 2 m .

Auger and Jamieson (1997) proposed a three hole-per-step method (3-HPS) shown in Figure 1. Probers make holes in front of their sternum and to their left and right. By reaching to right and left, the angle of the lateral holes is kept to 10° from the vertical. The lateral spacing between holes ranges from 0.75 to 0.35 m between the surface and a depth of 2 m . Their field studies also showed that deeper probing was slower. Since most live victims are found within the top 2 m of the deposit, they proposed that search leaders consider probing less than 3 m when searching for a live victim.

In field trials on level compact snow, we found the 3-HPS method to be about 30% faster than the 1-HPS method while probing 1.5 m . By assuming the angle of the probes had little effect, they found that the 3-HPS method increased the probability of probing a victim compared to the 1-HPS method for the avalanche victims positioned vertically, prone/supine or in their side.

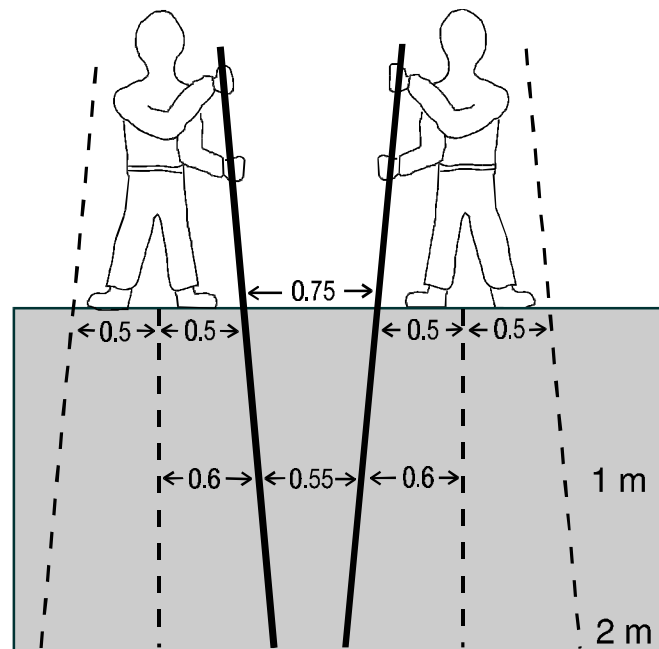


Figure 1. Side view of three hole-per-step probing.

The Monte Carlo model

In contrast to the ratio-of-areas method which assumes that avalanche victims expose a square area to the vertical probes, we used a Monte Carlo method of calculating the probability of probing a buried avalanche victim, P_v .

We chose to model the area exposed to the probes as ellipses of areas $A_V = 0.1$, $A_S = 0.4$ and $A_P = 0.5 \text{ m}^2$ (Figure 2, Table 1) for victims oriented vertically, on their side or prone/supine, respectively.

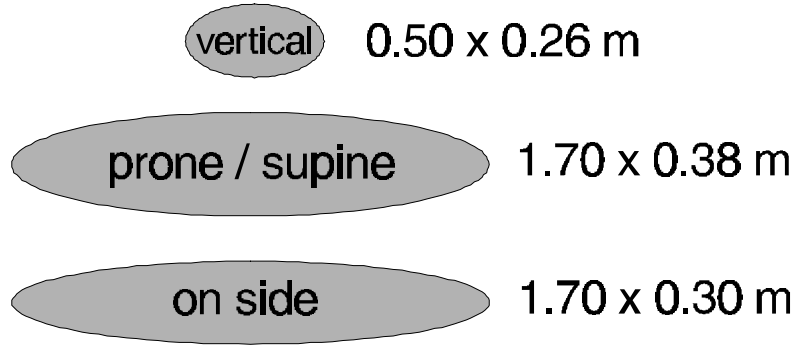


Figure 2 Ellipses and dimensions used to model areas of avalanche victims exposed to vertical probes.

Our Monte Carlo model has a clear physical analogy. Consider a grid of dots representing a particular pattern of probe holes on a transparent sheet of plastic. Drop the plastic sheet onto an ellipse for an avalanche victim drawn to the same scale as the probe holes. Score a hit if at least one of the holes lies on the ellipse. Repeat the procedure allowing the grid of dots (probe holes) to shift randomly in both directions and to rotate randomly. After many repetitions, the number of hits divided by the number of trials is an estimate of P_V for the particular ellipse and pattern of probe holes.

We implemented the model on a personal computer and used 10,000 trials for each run. Twenty runs with the same parameters (area of victim and pattern of probe holes) gave values of P_V with a standard deviation of 0.005. We expect 95% of the values for particular parameters lie within 0.01 of the mean.

Model validation

To validate the model, we used square areas for A_V , A_P and A_S and the 0.75 by 0.70 m spacing for the probe holes. When the coordinate system for the probe holes (analogous to the transparent sheet) was allowed to translate in two directions but not rotate with respect to the coordinate system of the victim, the Monte Carlo model gave values of P_V within 0.01 of the values obtained from the Ratio-of-Areas method (Table 1). Thus, the model was able to reproduce the traditional calculations.

Table 1 Probability of Strike for 70 by 75 cm probe spacing and victim with square projected area				
Victim Orientation	Area (m ²)	Ratio of Areas (Schild, 1963)	Monte Carlo	
			No rotation	Rotation
Vertical	0.10	0.19	0.19	0.19
Prone/Supine	0.50	0.95	0.94	0.89
Side	0.40	0.76	0.76	0.75
Average	0.37	0.70	0.70	0.70

Comparison with previous calculations

When the grid of probe holes was allowed to rotate with respect to the (square) victim, the Monte Carlo model gave a lower value for P_V for the prone/supine victim (largest square). As the square area of the victim approaches the almost square area between the probe holes, rotation decreases the probability of a hit.

Schild's Ratio of Areas method assumes

1. that the victim presents a square area to the probes, and
2. that the square is aligned to the grid of probe holes.

The second assumption only over-estimates P_V for values larger than approximately 0.80.

We assessed the effect of Schild's first assumption (victim presents square area) by running the Monte Carlo model with square and elliptical areas. Our ellipses had dimensions chosen to represent an average adult (Figure 2, Table 2). For each orientation of the victim, the areas of the ellipses were the same as the squares.

Victim Orientation	Projected Area (m ²)	Ellipse		Monte Carlo	
		Long axis	Short axis	Ellipse	Square
Vertical	0.10	0.50	0.260	0.19	0.19
Prone/Supine	0.50	1.70	0.375	0.75	0.89
Side	0.40	1.70	0.300	0.63	0.75

For the smallest area (vertically oriented victim), P_V was the same for the square and the ellipse. However, for the larger areas (victim prone/supine or on side) the ellipse gave lower values than the square. Clearly, there are more ways to fit an oblong ellipse than a square with the same area into a square grid of holes without touching the holes. Since these oblong areas (ellipses) are more realistic than squares, the Ratio of Areas method overestimates P_V . The ellipses are used for the study of tilted probes and the comparison of different probing patterns.

Effect of tilted probes

We used the Monte Carlo model to study the effect of the tilted probes. In 3-HPS probing, the distance between the centre hole and the lateral hole, X_L is different that the distance between the lateral holes from adjacent probers, X_P . The total distance between adjacent centre holes is $2X_L + X_P = 1.75$ m. Both X_L and X_P vary with depth.

For a grid consisting of holes X_L by 0.7 m apart, we denote the probability of probing the victim as P_L . Similarly, for the grid of holes X_P by 0.7 m, the probability of probing

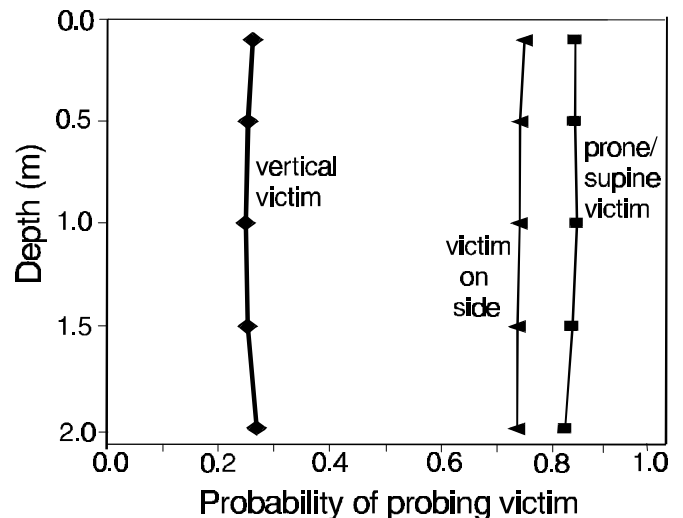


Figure 3 Effect of burial depth on probability of probing a victim for 3-HPS method.

the victims is P_P . Ignoring the edge effect at the side of the probe line, 3-HPS probing will create a pattern of holes with twice as many lateral spaces between holes of X_L as X_P . So, the probability of probing the victim is $P_V = (2P_L + P_P)/3$ which, of course, varies with depth.

We calculated P_L , P_P and P_V for depths of 0.1, 0.5, 1.0, 1.5 and 2.0 m in Table 3 and plotted them in Figure 3. This approach assumes the victims are horizontal at the various depths. With the recommended technique in which the probes are tilted at 10° or less, the effect of the tilted probes on P_V is limited to 0.01.

Victim Orientation	Area (m ²)	depth	X_L	P_L	X_P	P_P	P_V
Vertical	0.10	0.1	0.51	0.29	0.73	0.20	0.26
Vertical	0.10	0.5	0.55	0.27	0.65	0.23	0.25
Vertical	0.10	1.0	0.60	0.24	0.55	0.27	0.25
Vertical	0.10	1.5	0.65	0.22	0.45	0.32	0.25
Vertical	0.10	2.0	0.70	0.20	0.35	0.41	0.27
Prone/Supine	0.50	0.1	0.51	0.88	0.73	0.76	0.84
Prone/Supine	0.50	0.5	0.55	0.86	0.65	0.80	0.84
Prone/Supine	0.50	1.0	0.60	0.84	0.55	0.86	0.85
Prone/Supine	0.50	1.5	0.65	0.80	0.45	0.91	0.84
Prone/Supine	0.50	2.0	0.70	0.77	0.35	0.93	0.83
Side	0.40	0.1	0.51	0.80	0.73	0.64	0.75
Side	0.40	0.5	0.55	0.76	0.65	0.70	0.74
Side	0.40	1.0	0.60	0.73	0.55	0.77	0.74
Side	0.40	1.5	0.65	0.69	0.45	0.84	0.74
Side	0.40	2.0	0.70	0.66	0.35	0.90	0.74

Probability of probing a victim for various probing methods

Using the ellipses from Table 2, P_V values for 1-HPS, 2-HPS and depth-averaged values for 3-HPS methods are compared in Table 4. For 1-HPS and 2-HPS with 1.5 m between probers, the $P_V = 0.19$, 0.75 and 0.63 for victims oriented vertically, prone/supine or on their side, respectively. If fingertip-to-fingertip spacing for the 2-HPS method results in 1.75 m between probers then P_V drops to 0.17, 0.68 and 0.56, respectively. The probabilities rise significantly to 0.26, 0.84 and 0.74 for the 3-HPS method. With this method the search leader may feel there is less need to re-probe the same area.

Orientation of Victim	One hole-per-step	Two hole-per-step		Three hole-per-step
	0.70 x 0.75 m	0.70 x 0.75 m (1.50 m between probers)	0.70 x 0.87 m (1.75 m between probers)	0.70 x 0.50-0.70 m
Vertical	0.19	0.19	0.17	0.26
Prone/Supine	0.75	0.75	0.68	0.84
Side	0.63	0.63	0.56	0.74

Time required for various probing methods

The speed of a particular pattern can be expressed in terms of the average time required for one hole and any associated step or portion of a step. Denoting the time for a step as t_s , the time to probe a hole 1.5 m deep as $t_{1.5}$ and the time to probe a hole 2.1 m deep as t_2 , then the times per hole from previous field trials (Auger and Jamieson, 1997) are:

$$1\text{-HPS probing } 2.1 \text{ m deep: } t_s + t_2 = 8.1 \text{ s} \quad (1)$$

$$1\text{-HPS probing } 1.5 \text{ m deep: } t_s + t_{1.5} = 7.5 \text{ s} \quad (2)$$

$$3\text{-HPS probing } 1.5 \text{ m deep: } t_s / 3 + t_{1.5} = 4.5 \text{ s} \quad (3)$$

Solving Equations 1 to 3, we get average times for

$$1 \text{ step } t_s = 4.4 \text{ s}$$

$$\text{probing } 1.5 \text{ m deep } t_{1.5} = 3.1 \text{ s}$$

$$\text{probing } 2.1 \text{ m deep } t_2 = 3.7 \text{ s}$$

Using these values, the time for various probing methods can be estimated. For example, the time for one 2 m-deep hole using the 2-HPS method is $t_s / 2 + t_2 = 5.9 \text{ s}$.

To compare the various methods, the times for 5 people to probe a 50 m by 50 m deposit are calculated in Table 5. The methods with less stepping (2-HPS and 3-HPS) are substantially faster. However, when selecting a probing method, search leaders must consider both speed and the probability of probing a victim.

Pattern	Hole spacing	Holes/2500 m ²	Time per 2 m-deep hole (s)	Time for 5 people to probe 2500 m ² (min)	Reduction in time over 1-HPS
1-HPS	0.70 x 0.75	4,763	8.1	128	-
2-HPS ¹	0.70 x 0.75	4,763	5.9	93	27%
2-HPS ²	0.70 x 0.87	4,105	5.9	80	38%
3-HPS	0.70 x 0.50-0.70	6,123	5.2	105	18%

¹ 1.5 m between probers

² 1.75 m between probers

As noted previously, the 2-HPS method with 1.75 m between probers has the lowest values of P_v . Consequently, re-probing the same area becomes more likely and any speed advantage may be negated. The 2-HPS (with 1.5 m between probers) and 3-HPS method are both faster than the 1-HPS method and offer equal or better values of P_v . Based on this analysis, both offer advantages over the traditional 1-HPS method.

The times in Table 5 are based on the level compacted snow used for the trials reported by Auger and Jamieson (1997). For most irregular deposits, stepping would take longer and the 3-HPS method would prove even more advantageous than shown in Table 5.

We note that the probing time for this relatively small deposit is 1.5-2 hours. After such periods, less than 30% of buried avalanche victims remain alive (Falk and Brugger, 1994; Logan and Atkins, 1996).

Summary

Compared to a search with avalanche transceivers or an avalanche dog, a probe search is very slow and the probability of live recovery is reduced.

The traditional calculation for the probability of finding a person with a particular probing pattern assumes that the projected area of the victim is square and aligned with the grid of probe holes. The Monte Carlo method described in this paper allows more realistic projected areas, such as ellipses, and makes no assumption about the orientation of the victim with respect to the probing pattern.

According to the Monte Carlo Ellipse method, the probability of probing a supine/prone victim using the traditional 0.70 x 0.75 m grid is 75%, and a victim on their side is 63%, compared to 95% and 75% for the Ratio-of-Areas method. Since a victim's projected area is closer to an ellipse than a square, the Ratio-of-Areas method over-estimates the probability of probing an avalanche victim with these orientations.

Compared to one-hole-per-step or two-hole-per-step method, the three-hole-per-step method increases the probability of a strike by 7 to 11%. For a victim orientated on their side, which can be considered an average orientation, the three-hole-per-step method increases the probability of a strike from 63% to 74% (based on the improved Monte Carlo calculation).

For the two-hole-per-step pattern, probers should maintain 1.5 m spacing. Probers of average size should be wrist-to-wrist rather than fingertip-to-fingertip apart as suggested by some texts. Using two holes per step and 1.75 m spacing, the probability of probing a victim on their side victim drops to 0.56. Such a low probability creates a dilemma for the search leader: probe the same area again or move on to another likely burial site.

The two-hole-per-step method and three-hole-per step method are faster than the traditional one-hole-per-step method. The three hole-per-step method is both faster and more thorough than the traditional one-hole-per-step method.

To follow this study, better calculations of the probability of probing a victim and survival should be possible by considering:

- the statistical distribution of burial depth,
- survival statistics as a function of burial depth,
- random orientation of buried victims, and
- the effect of limiting probe depth.

References

Auger, T. and B. Jamieson. 1997. Avalanche probing revisited. Proceedings of the October 1996 International Snow Science Workshop in Banff, 295-298. Canadian Avalanche Association, Revelstoke, BC, Canada. May 1996. Also reprinted in *Avalanche News* 49, 16-19.

Burtscher, M. 1994. Avalanche survival chances. *Nature* 371, 482.

Falk, M. and H. Brugger. 1994. Avalanche survival chances. *Nature* 368, 21.

Logan, N. and D. Atkins. 1996. The Snowy Torrents - Avalanche Accidents in the United States 1980-86. (Colorado Geological Survey, Special Publication 39), 275 pp.

McClung, D.M. and P.A. Schaerer. 1993. *The Avalanche Handbook*. The Mountaineers, Seattle, 271 pp.

Perla, R.I. 1967. Optimal probing for avalanche victims. USDA Forest Service Miscellaneous Report 13.

Perla, R.I. and M. Martinelli, Jr., 1976. *Avalanche Handbook*, U.S. Dept. of Agriculture, Agriculture Handbook 489, 238 pp

Schild, M. 1963. Absuchen und Sondieren. Symposium über Dringliche Massnahmen zur Rettung von Lawinenverschütteten, Vanni Eigenmann Foundation, 30-32.

Schild, M. 1974. Previous experience in the practice of avalanche rescue. *Avalanche Protection, Location and Rescue*. Vanni Eigenmann Foundation, p. 51-75.

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