PREFERRED KNOTS FOR JOINING HOLLOW BRAID POLY ROPE

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ABSTRACT: Ski patrollers disagree about which is the most secure knot for joining two pieces of hollow braid polypropylene rope. This shiny, diamond-patterned rope, commonly called "hollow braid" and used in ski areas for closing unsafe trails, is so springy and slippery that most knots in it come untied. I have surveyed patrollers in several ski areas to find a knot that will stay tied in this rope. I handed participants two pieces of hollow braid and asked them to show me the knot they would use to join two pieces of it. Then I asked them to tell the criteria they used for selecting their knot and to explain what makes it hold tight in this rope. So far in this continuing survey, fifty patrollers have selected and tied twenty different knots. No knot was selected by a majority, but the Double Fisherman's Knot (Ashley #1415) was selected most frequently. Tests of these knots and analysis of the way their structure creates friction also show this knot to be the most suited to the task. Results of this survey can help ski patrols decide which knots to use. In addition, tying and testing knots in this slippery stuff teaches practical lessons about knot security that would be difficult to gain by other means.

KEY WORDS: Avalanche risk management; Knot security; Knots for polypropylene rope; Ski area management; Hollow braid polypropylene rope

Trust me, a good knot.

William Shakespeare
The Merry Wives of Windsor

1. INTRODUCTION

The Search for a Suitable Knot

The practice of knot tying has come a long way since the time when even the best popular knot books recommended the Square Knot for joining two ropes and the Bowline for making a permanent loop. Most advanced knot tyers today know that the Square Knot was never intended for joining two ropes and is secure only when there is a constant tension on it, as when reefing sails or tying up packages (Ashley 1944). They realize that the Bowline has structural flaws which cause it to deform in some applications (Raleigh, Budworth). The best knot books today reject some of these traditional knots, or they warn users of their limitations and suggest the use of backup knots (Vines & Hudson, Luebben, Raleigh, Budworth).

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To replace many of the old standard knots, some groups of professional knot tyers have adopted or devised other knots, such as the Münter Hitch and members of the Figure Eight family of knots (Raleigh). Much of the impetus for discarding the traditional knots and replacing them with others came from the need for security under adverse conditions. Professionals who rely on knots for their livelihood or their sport (such as sailors, mountaineers, rescue personnel, and ropes course managers) have re-examined the security of traditional knots, the situations where they use knots, and the abilities of people to tie them. As Duane Raleigh put it, they are always on the lookout for "a better knot for the job." By dint of hard study (and a lot of hard knocks), the best knot tyers today have solved problems that former generations of knot tyers seem to have ignored. Anyone who ties knots for serious purposes today benefits from their diligence.

For ski patrollers, a further impetus for finding a replacement for the simpler traditional knots comes from trying to join two pieces of "hollow braid," a kind of braided rope made of polypropylene and widely used for general utility applications in ski areas. Since most of us learned to tie knots in ordinary ropes made of sisal, cotton, manila, or nylon, which will hold almost any standard knot snug, we find it hard to tie knots in hollow braid polypropylene rope. Hollow braid is notoriously kinky, springy, and resistant to bending; its surface supplies so little friction that many traditional knots hardly hold at all in the stuff.

The Aim of This Study

The aim of this study is to find a knot that will not slip and will stay tied when used to join two pieces of hollow braid polypropylene rope. A survey among ski patrollers and others who use rope shows that while there is a wide range of views about which knot works best for joining two pieces of hollow braid, there is evidence that some knots are more secure than others.

Re-Defining Knot Security

Because many people confuse the *security* of a knot with the *strength* of a knot, it is important to distinguish these two concepts. "The security of a knot," Clifford Ashley wrote, "is determined by the stress it will endure before it slips," while "the *strength* of a knot is determined by the stress it will endure before it breaks" (1944,16). Security pertains to slipping, strength to breaking. Since hollow braid is many times stronger than required for general utility applications, we do not have to take the strength of the knot into consideration, and data about working loads is not relevant to this study. The major cause of breakage of trail rope, I understand, is groomers.

Some knots tied in hollow braid come undone almost as soon as they are tied. In Geoffrey Budworth's phrase, such a knot will "spring or shake itself apart" when unloaded (36). *Slipping* is not the appropriate word for the behavior of knots that spring apart under your fingers or immediately loosen on their own.

To take into account this and other peculiar properties of hollow braid polypropylene rope (described below), I have broadened the concept of *knot security*. By the *security* of a knot I mean not only how well it prevents slipping but also how well it stays tied. A *secure* knot will not fail or come untied on its own. It will not accidentally come loose when either relaxed or under tension, or when tension is repeatedly applied and released, as when the rope flaps in the breeze. It will not slip or slide unless it is supposed to.

Security in knots is, of course, a relative concept; all knots slip more or less. So if we say that one knot is more secure than another, that means that under typical conditions of use it slips or comes untied less readily than the other knot. Holding fast and staying tied or slipping and coming untied are the important things.

Tests of the Security of Knots

Ashley undertook the classic tests of knot security. His tests consisted of successive jerks on weighted strands tied with various knots (16–17; 273). Knot-tying historian Charles Warner (1996b) pointed out some limitations in Ashley's tests, but reported at length on them, suggesting that he found them significant. In fact, Ashley's tests are still considered standard in the industry (Tasjian 1998). But Ashley's results were published in 1944, long before polypropylene became a commercial product, and they may not apply to hollow braid.

I have found no reports of tests on security of knots tied in hollow braid polypropylene rope, but only in polypropylene sutures. Rosin and Robinson (1989) evaluated the security of knots in sutures used by veterinarian surgeons. Defining a secure knot as "one which broke rather than being untied by slippage," they determined that for polypropylene sutures, the "minimum snug throws [individual knots (Sweet 1998)] for secure square knot" was three, the same as for three other suture materials. Granny knots tied in polypropylene were not as secure as square knots, but only in polypropylene and polydioxanone (one of the other materials they tested) were loose square knots as secure as snug square knots. Based on their research, they recommend that surgeons tie "accurate, snug knots with 4 throws minimum for interrupted suture patterns and 6 throws for continuous suture patterns."

The knots that Rosin and Robinson tested were *binding* knots; that is, they were knots used for tying up tissues. They did not test knots for joining two pieces of cordage. Moreover, the sutures they tied the knots in were very thin filaments. Despite these differences, their concept of knot security—will it slip?—was essentially the same as Ashley's. They were dealing with artificial filament, which is similar in its slickness and stiffness to poly rope. In many ways, their experience with poly sutures is similar to our experience with hollow braid.

2. RATIONALE FOR A SURVEY ON KNOTS IN HOLLOW BRAID POLYPROPYLENE ROPE

Although testing of knots in hollow braid polypropylene rope may not be as significant as tests of surgical sutures or mountaineering knots, this is a suitable subject for study because ski patrollers so often tie knots in it. Typically, a patroller will ski out on the slopes with a hank of the rope, tie it to a tree or post at the top of a trail, and close or open the trail when conditions warrant. If the rope breaks, or part of it has to be replaced, a patroller will have to join two or more pieces. There are several other applications at ski areas for hollow braid: for corrals to shunt skiers onto a lift, for temporary fences to mark hazards, and for marking an area used by racers. In many of these

applications, patrollers join two pieces of hollow braid with a suitable knot. Some of those knots are expected to hold all season.

It is understandable, of course, why professional organizations would not conduct tests of security in hollow braid. This rope is used for non-critical tasks, not for life support. The people who tie knots in it have made do for years without knowledge of comparative security of knots, and they are not crying for research now. It is a small-volume and low-impact problem. Persons concerned with knots and ropes for life support do not, of course, discuss hollow braid, and some would consider research on knots in hollow braid polypropylene trivial. But many patrollers do not.

The Case for Splicing Hollow Braid Rope

Because of the peculiar properties of hollow braid polypropylene rope, some specialists in rope and climbing gear entirely dismiss the idea of tying knots in it. Bill Tasjian, a dealer in technical climbing and high-angle rescue equipment at Hawill's Ltd., Westborough, Massachusetts, refers to hollow braid as a "terribly non-functional rope." It was never intended, he points out, to be knotted. No knot he knows of is appropriate for this rope. One possible solution is to tie a knot and to tape it, but no knot will hold over time in hollow braid. "People who knot it," Tasjian says, "are not knowledgeable about the product they are using." Hollow braid is intended not to be knotted but to be spliced; that is the only acceptable way, in his view, to join two pieces of polypropylene rope (Tasjian 1998). This is well-considered advice, and it comes from a person with over thirty years of experience with ropes.

Methods of splicing hollow braid are well known. Merry (1987) presents a thorough treatment of splicing in many kinds of rope (laid, braided, natural, and synthetic), and describes the methods and tools for splicing. Splicing ordinarily entails use of tape and a tool, which may be either a special tapered or tubular splicing fid, a modified knitting needle, or a piece of coat hanger wire. To splice, you cut the tail end of the rope at a 45° angle, slide the end over the fid, and insert the fid into the hollow of the other end of the rope. You then thread the fid and the end of the rope through and bring it out again a few inches along. Finally, you repeat the same process in the other end of the rope. Kenyon and Sampson describe similar procedures. In a simpler manual method of splicing that requires no tools, you melt down one end of the rope, make it into a needle, and weave it back and forth between the braids (Tasjian 1998). Splicing hollow braid rope by either of two methods is easier than splicing laid or twisted rope.

As Merry points out, "splices in hollow braid work on the same principle as the Chinese finger puzzle" (60), the "Chinese handcuffs" you get as a prize at a carnival. Pulling lengthwise on the strands causes them to constrict, making the hollow smaller and pressing the braids of the outer strand against those of the inner strand.

Several rope manufacturers and dealers mention splicing of hollow braid in their literature, and none mentions tying knots. But although Merry recommends splicing for joining ropes of all kinds, she comments that knots serve in "light-duty situations not requiring the exceptional strength of a well-constructed splice" (91). She refers to a knot as "a weak substitute for a splice," but she never mentions security of knots, nor does she condemn the use of knots in any material. She shows, in fact, several knots, and recommends both the Sheet Bend and the Double Carrick Bend for some applications. She gives no special caution or warning about using them in synthetic rope or in hollow braid.

Drawbacks of Splicing Hollow Braid Rope

Splicing of hollow braid rope has some drawbacks that make it unsuitable for patrol work. Splicing ordinarily requires some specialized tools, which are easy to forget or mislay. Splicing requires several manual steps and is often not practical under the conditions patrollers work in, which may entail standing alone in the cold on a windswept trail, pelted by snow, sleet, or rain. Learning the technique of splicing requires training, and however much you may practice the technique, making a splice requires more time than tying a knot. When splicing is not feasible, patrollers have no option except to tie a knot.

Most patrollers have apparently never considered splicing as a way to join two pieces of hollow braid. Because they tie knots in hollow braid, and they tie them frequently as a regular part of their duties, it seems appropriate to find out which knots work best in this rope.

3. MATERIALS OF THIS SURVEY

Hollow Braid Polypropylene Rope

The stuff I used in the survey was two pieces of the rope commonly used for utility work in a ski area, quarter-inch hollow braid polypropylene rope. In the industry, it is referred to simply as "hollow braid." This rope is made of extruded monofilament polypropylene. Even when hollow braid is clean, dry, and free of lubricant, it feels slightly oily and slick. Since it is a monofilament, it has no hairy fibers. Inspection shows that it is not

twisted three-strand rope but braided of eight strands made up of about forty individual fibers, each fiber as fine as the hair in a horse's tail.

What is Polypropylene?

Hollow braid is made of polypropylene, an artificial petroleum-based polymer belonging to a group called *olefins*. In the 1950s, scientists discovered a way to link molecules of polypropylene in long chains to produce fibers. Polypropylene was first used commercially in 1957 and produced in fiber form in 1961. Through four decades, it has been continuously improved. Billions of pounds of polypropylene are produced every year by more than twenty companies in seven countries and marketed under some two dozen trade names such as Ulstron, Propathene, Noblen, and Carlona P.

Everyone today is familiar with polypropylene in various uses, whether or not they recognize it or know its name. It is produced in many forms (film, sheet, pipe, fibers, and injection molding), and it is widely used for making carpets, upholstery, drapery, webbing, outdoor furniture, and clothing. Tough varieties of polypropylene are also used for milk crates, tool kits, chairs, luggage, and parts of appliances (Meikele 1995, 191). In its fiber form, polypropylene cloth has been widely used for sports clothing. Its wicking properties (ability to transport moisture away from the skin) make it especially suitable for winter sports underwear, and its ability to pass vapors of perspiration make it suitable for the tight weaves required for windproof and waterproof outer garments. Along with polyethelene, its chemical cousin, polypropylene has been so successful in commercial applications that a molder of plastics has called them the industry's "old workhorses" (Meikele 191).

General Properties of Polypropylene Rope

Polypropylene has several of the properties of synthetic fibers that affect its characteristics as rope. Its density of about .9g/cm^3 makes it one of the lightest plastics and the lightest synthetic rope (Merry 1987, 5) and means it will float on water. It is resistant to most chemicals, both acids and bases, as well as to dyes. It has a low to medium melting point (150–170°C). Although polypropylene is degraded by exposure to sunlight, other substances can be mixed with it to produce some resistance to ultraviolet light.

According to one statement by the plastics industry, polypropylene is "probably the most versatile general purpose rope available for the price" (Aquatic 1998). Several of its properties make it suitable for outdoor work. Although moisture will collect between the fibers of hollow braid during a snow or rain storm, the fibers themselves will not absorb water. This means that it does not become sodden after a dousing or stiff after a freezing. (Dunk a length of it in water, then freeze it. It will remain just as flexible and as warm to touch as ever.)

Polypropylene is cohesive; it does not tend to adhere to other objects or to itself. It is tough; it is not easily pulled apart. It is firm in texture and durable, but not brittle. It withstands strain. It is twice as strong as natural fibers of the same weight. (NSPS 1987). It withstands tension and compression and abrades slowly. Its color and bright surface make it easily visible. It resists mildew and rot, which means that, unlike natural fibers, it can be safely stored wet. Most importantly, perhaps, it is cheap (about 4.6 cents a foot in 1998). (All except the references noted are from van Oss *passim*; and Kirk–Othmer *passim*.)

Undesirable Properties of Hollow Braid

Rope made of polypropylene has some properties that make it less desirable than nylon rope for some purposes. It is inferior to nylon in resistance to abrasion and ultraviolet light degradation, strength, shock load, elasticity, and durability. These weaknesses account for the fact that it is not used for rescue or critical loading.

The structure of hollow braid polypropylene rope significantly affects is characteristics. The strands are woven on the bias in "two sets of continuous yarns, one clockwise and the other counterclockwise . . . in a continuous spiral pattern." Each of the eight braided yarns is "coiled into a helix just like wire in a spring," and each yarn interlocks with the other seven (A & P 1998). With four strands laid Z and four strands laid S (right and left), the braid structure creates both a distinctive diamond pattern of alternating colors (often yellow and black) and longitudinal compressibility of the rope. The structure of this rope is significant because its form changes under pressure, tension, and compression. This changeability makes it difficult to tie a secure knot in hollow braid.

The structure of hollow braid is, however, just one of the properties that make it difficult to use. Because it is so stiff, it is not as easy to handle as hemp, nylon, sisal, or cotton. Because it resists stretching, it springs back to its original shape. But after a knot has been tied in it for a few hours, it becomes kinky and resists manipulation. Most importantly, its slick surface means low friction, so that ordinary knots used for joining two pieces of this rope do not hold well. Just as it resists rotting, it resists knotting.

4. METHOD OF THE SURVEY

I polled fifty patrollers from several ski areas in the northeastern and northwestern United States. In each case, I handed the patroller a piece of the hollow braid and asked, "Given this kind of rope, what knot would you use to tie two pieces of rope together?" All of the patrollers were aware that the rope would not be used for rescue work or for load-bearing tasks but for utility such as marking a hazard or closing a ski trail. No other conditions were specified. I also asked, "What is the name of the knot you tied? and "Why did you select it?"

5. RESULTS OF THE SURVEY

For joining two pieces of hollow braid, the patrollers I polled selected a total of twenty knots, as shown in the Table below.

Choices of Knots for Joining Two Pieces of Hollow Braid

The following table lists the twenty knots that patrollers selected for joining two pieces of hollow braid polypropylene rope.

No.	*1st choice*	*Altern. choice*	*Kind of Knot*
1.	21	8	Double Fisherman's Knot (#294, 1415)
2.	5	3	Double Overhand Knot (Parallel ends tied in an Overhand) (#1410)
3.	5	1	Single Fisherman's Knot (#1414)
4.	3		Sheet Bend (Single Becket Bend) (#1431)
5.	3	4	Figure Eight Follow Through Bend (Flemish Bend) (#1411)
6.	2	1	Square Knot (#75, 76, 77)
7.	2		"Slip Splice" (One end inserted up the other, like "Chinese handcuffs")
8.	1		Granny Knot (#1405)
9.	1	2	Water Knot (#296)
10.	1	1	Double Sheet Bend (#1434)
11.	1		Single Fisherman's Knot, backed up with a Half Hitch in each end
12.	1		Two Bowlines, interlocking (#1455)
13.	1		Double Overhand Knot backed up with an Overhand Knot on top
14.	1		* "Double Figure Eight Follow Through"
15.	1		Square Knot backed up with one Overhand Knot and one Half Hitch
16.		2	Square Knot backed up with a Grapevine
17.		2	Double Figure Eight Knot (Parallel ends tied in a Figure Eight)
18.		1	Bowline in one end interlocking with Two Half Hitches in the other
19.		1	Double Overhand Loop in one end, Two Half Hitches in the other
20.		1	Square Knot backed up with an Overhand Knot in each end

Table. Choices of Knots for Joining Hollow Braid Polypropylene Rope

This table lists the twenty knots that patrollers selected for joining two pieces of hollow braid polypropylene rope. Numbers in the first column indicate the order of preference for the knot. The second column gives the number of times that patrollers selected the knot as first choice, and the third column the number of times that patrollers selected the knot as an alternative (second, third, or fourth choice). Five of the alternative knots were not selected as first choice; they are numbered 16–20 here. One effort produced no workable knot. The sign # in parentheses indicates the Ashley number of the knots. Names for the knots varied; I give only the most common names here.

*Note: The "Double Figure Eight Follow Through" is an unconventional knot. Tie a Figure 8 in the end of each rope, being sure to leave long tails; then thread the tails through to make two Figure Eight Follow Throughs (Flemish Bends). This creates a bypass loop between the two Figure Eight Follow Throughs.

6. DISCUSSION

This survey of ski patrollers reveals several points about the choice of knots for joining two pieces of hollow braid polypropylene rope:

1. Patrollers Selected Only Practical Knots.

All of the fifty patrollers that I polled assumed that the aim of the survey was to select a *practical* knot. Implicit in their selection of knots and in their comments on them were three functional criteria:

- Will the knot work? Will it remain secure whether the rope is slack or taut?
- Can I tie it? Will I be able to tie this knot under adverse weather conditions?
- Can I trust it? Do I know it will work? Does my experience give me confidence that it will work?

Some other patrollers added an aesthetic criterion: does it look good?

2. Patrollers Selected a Variety of Knots.

Patrollers selected a wide variety of knots (twenty in all). The knots ranged from the simple and well-known traditional knots, such as the Square Knot and the Sheet Bend, to the special rescue knots such as the Figure Eight Bend (Flemish Bend), to seldom-seen knots such as the "Double Figure Eight Follow Through." Six of the twenty knots were backed up with an Overhand Knot, one or two Half Hitches, or a Grapevine.

3. The Double Fisherman's Knot Was the Favorite.

Twenty-one of the patrollers (almost half of them) selected the Double Fisherman's Knot as the best knot for joining two pieces of hollow braid under ordinary circumstances. Although there was not a majority for any knot, this was the clear favorite.

4. The Double Fisherman's Knot Was Frequently the Second Choice Knot.

Though many patrollers did not select the Double Fisherman's Knot as their first preference, it was the second choice of eight patrollers. More than half of the patrollers were competent at tying it. Two patrollers used half of this knot (which I refer to here as a *Grapevine*) to back up another knot.

5. The Double Overhand Knot Was a Weak Runner-Up for First Choice.

Five patrollers selected the Double Overhand Knot as their first choice. For use under adverse conditions, but for the same purpose, one patroller mentioned the Double Overhand Knot as a substitute for the Double Fisherman's Knot. "When I'm cold, or in a hurry," he said, "I use a Double Overhand."

6. Four Knots Were Also Runner-Up First Choices.

Five patrollers selected a traditional Scout knot (the Single Fisherman's Knot) as their first choice. Other first choices were also Scout knots: the Sheet Bend (three patrollers) and the Square Knot (two patrollers). Three patrollers also selected the Figure Eight Bend (Flemish Bend) as first choice.

7. The Double Fisherman's Knot Elicited Some Statements of Strong Preference.

Some patrollers expressed a strong preference for the Double Fisherman's Knot. Many of them pointed out the distinctive structure that makes this knot work well. A few patrollers use it because a person in authority had told them to. None of them selected it merely out of habit, and most had learned it fairly recently as an adult in an organized course or training session. None of the people I surveyed had learned to tie the Double Fisherman's Knot as a child.

8. The Double Fisherman's Knot was the First Choice of Skillful Knot Tyers.

The Double Fisherman's Knot was the first choice of many skillful knot tyers, including most of those who were rock and ice climbers. By *skillful* knot tyers, I mean patrollers who tied several knots, who tied them confidently, who knew the name of the knots they tied, who could explain why their first choice knot was secure, and who tied the knots quickly and without fumbling. While the Double Fisherman's Knot was not the first choice among all of the proficient knot tyers, it was in the repertory of most of them.

9. A Quarter of the Knots Were Unsuitable.

More than a quarter of the knots selected were less than optimal or were entirely insecure for joining two pieces of hollow braid. These were (4) the Sheet Bend, (5) the Figure Eight Follow Through Bend (Flemish Bend), (6) the Square Knot, (8) the Granny Knot, and (10) the Water Knot. One knot, the "Double Figure Eight Follow Through" (14), described in the Table, is so complicated to tie that it is impractical.

10. Two Patrollers Mentioned Splicing of Rope.

One patroller described merely slipping one end of the rope into the other for several inches and relying on the friction of one rope against the

other. Another described a more elaborate splicing, which entailed weaving one end through the braids of the other. I use the term "Slip Splice" for the product of these simple splicing techniques.

11. Ropes Under Tension Present a Special Problem.

One patroller pointed out the difficulty of tying two ropes together when they are under tension, such as when they are tied between two trees or posts. In this situation, it is feasible to tie a Bowline in the end of one rope, slip the end of the other rope through the loop, pull it back, and tie it off with Two Half Hitches.

12. Ability to Tie Knots Varied.

Many patrollers revealed considerable skill at knot tying and at explaining the rationale for choosing a particular knot. Others were weak in knot tying skill. On two occasions, the knot failed. On one occasion, the attempt failed to produce a knot. Likewise, confidence in ability to tie a suitable knot varied. Some patrollers said apologetically, "I'm lousy with knots," or "I trust my luck."

13. Some Patrollers Named the Knots Correctly.

Ability to name the knots varied as well. Several patrollers were unable to name the knot or knots they tied. Ability to name a knot correlated highly with ability to select and tie an effective knot.

14. Patrollers Had Learned the Knots in Various Settings.

Several patrollers told where they had learned the knots: in the Scouts, from a parent or sibling, in a ropes or rock climbing course, in an EMT course, in a search and rescue course, in a backpacking course, or in Outward Bound. A few of them had learned the knots from other patrollers.

15. Aesthetics Influenced Some Choices.

Aesthetic views sometimes influenced the preference for a knot: "It is neat looking, not a big wob," one patroller said. Others held this criterion irrelevant and disregarded aesthetic qualities: "I tie knots. They work." or "I don't care if it isn't beautiful." "What's that ugly knot?" one patroller demanded. "It won't come out," was the disdainful reply.

16. The Survey Elicited Some Discussion of Knots and Knot Tying.

About half of the patrollers expressed interest in knots, in knot-tying, and in the survey itself. The other half intimated (or expressed openly) boredom or indifference. As might be expected, interest correlated highly with skill.

Varied Assessment of The Double Fisherman's Knot

The Double Fisherman's Knot has received varied assessment in knot books. Few of the early books I have seen, including the Scout manuals, mention it at all. (Exceptions are the books on fishing, which include it in the repertory of complete anglers.)

For use in nylon rope, some contemporary mountaineers and rescue workers have come to value it highly. (Warner 1996a) comments that "when nylon rope was introduced, the Single Fishermans Knot was largely dropped, and the Double Fishermans Knot became the bend of choice for life-support ropes" (165). Graydon and Hanson (1997) comment that the Single Fisherman's Knot has been replaced to a large extent by the Double Fisherman's Knot (117), which they call "the most secure and preferred knot for tying the ends of two ropes together for a rappel." Although they describe two other bends (a Single Fisherman's Knot and a Square Knot secured at each end with an Overhand Knot), they recommend only the Double Fisherman's Knot. Luebben (1995) lists the Double Fisherman's Knot first among knots for tying ropes and cordage together and comments that it stays tied better than the Ring Bend (Water Knot). Budworth (1997) describes the Double Fisherman's Knot among knots for caving and climbing and notes that it is used to "secure two ropes together and to make endless slings." Mountaineering and rescue personnel, who depend on knots for life support, have strongly influenced this positive assessment of the Double Fisherman's Knot.

Other assessments are not as favorable. Ashley (1944) mentions the Double Fisherman's Knot twice, but only as a knot used by anglers to tie leaders, not for joining ropes. In both entries (#294 and #1414), he expresses a preference for other knots. Bigon and Regazzoni (1981, 1982) comment that the Double Fisherman's Knot is "suitable only for thin line and string, because it is quite bulky." Raleigh (1998) comments that it works well "to join two climbing ropes," but says further that "the Figure Eight Follow-Through is safer because it's a simpler knot." Vines and Hudson (1989) suggest the Double Fisherman's Knot only as an alternative to the Figure Eight Bend (or Flemish Bend, the same knot that Raleigh calls the Figure Eight Follow-Through). "While this knot is very secure," they comment, "it may be more difficult to learn and to tell if it is tied correctly" (59).

My own experience tells me that contrary to what Raleigh and Vines and Hudson say, most people find the Figure Eight Follow Through Bend (Flemish Bend) tricky to tie. It takes some practice to thread this knot so that the strands lie parallel to each other and track properly. On the other hand, most people can learn to tie a Double Fisherman's Knot (and to remember how), and its distinctive tubular appearance makes it hard to mistake for anything except a caterpillar.

"Substantial and Manifest Advantages" of the Double Fisherman's Knot

Knot historian Charles Warner notes that "knotting is usually of minor interest to climbers; they do not wish to spend much time learning new knots unless the advantages are substantial and manifest" (Warner 1996a, 159). The same is true for many patrollers.

The Double Fisherman's Knot has many characteristics which make it the favorite among ski patrollers, especially among the more proficient knot-tyers. What the professionals say in praise of this knot in ordinary rope goes doubly for its use in hollow braid. When snugged down, it holds in the stiff and slippery poly like few other knots. It holds well under most ordinary conditions. It does not tumble when drawn across or around an object such as a rock or a tree. It does not slip or come untied easily, whether the lines are taut and under tension, or whether they are slack (Chisholm 1998a). It is fairly easy to tie and untie, to adjust, and to remember how to tie. Because hollow braid is cheap, if you need to undo a knot, you can just cut it with your knife.

The secret of the Double Fisherman's Knot is in the unusual way it is built. The structure helps it "hold against itself," as one patroller expressed it. The halves lock: each half of the symmetrical two-part structure of the knot increases the holding power of the other half. In both halves, the tail of the rope passes under two wraps (not under just one as in the ordinary Single Fisherman's Knot), and one half pulls up tight against the other half at just the right point to prevent the tails from slipping back through the wraps and coming undone (Chisholm 1998a and 1998b).

For those who care about the appearance of knots, the Double Fisherman's Knot is more attractive than other knots because the tails lie parallel to the standing part of the rope and can be made neater than most knots by taping them down. Not many patrollers, however, seemed interested in this aspect of the knot. They were interested only in its function.

Caution Manufacturers and dealers recommend joining two lengths of hollow braid polypropylene rope by splicing. They do not recommend knots.

Warning Use hollow braid polypropylene rope only for utility purposes such as temporarily closing ski trails and marking hazards. Do not use it for evacuating clients from ski lifts or patients from mountainsides or for lowering pianos from apartment buildings.

Use of the Double Fisherman's Knot

In view of my statements of Caution and Warning and the comments by Tasjian (1998) above, I make no recommendation about which knot to tie in hollow braid polypropylene rope, nor even that a knot should be used. This survey can give no definitive answer to the question but serves only to indicate general preferences and to give some guidelines.

It should be kept in mind that patrollers do not think of knots in hollow braid in the same way as mountaineers do, as links in a chain of safety (Graydon and Hanson 1997,112), nor as sailors do, as ways to move and secure shipboard equipment. Patrollers think of knots in hollow braid rather as a more or less temporary way to direct traffic.

The experience of the patrollers polled in this survey suggests that ski patrols adopt the Double Fisherman's Knot as the knot of preference in most situations where patrollers need to join two pieces of hollow braid. If you have time and skill, you may wish to splice the ropes. If you are in a hurry or your hands are numb, you can always use a Double Overhand Knot.

Suggestions for Further Research

A good deal of research on knot security remains to be done. Knots can fail both because of inadequate structure of the knot itself and because of the tensions in a particular kind of rope: tensile pulls, torsion, and internal friction against the rope's fibers. The loads placed on a rope, the removal of loads, the bending, stretching, twisting,

and chafing within the knot, and the slippery surface of the polypropylene itself—all of these forces affect the security of a knot. Although the structures, forces, and properties of materials that make a knot secure are not well understood, we can apply some practical tests that will help us understand which knots work best—and perhaps lead to insight as to why they do so.

The following are some suggestions for further research on knot security in hollow braid poly rope.

- Tests of knot security for the twenty knots selected by patrollers in this survey. Some tests are described in Chisholm (1998a).
- Analysis of security in knots (structure and friction). The procedure for such an analysis is outlined for the Double Fisherman's Knot in Chisholm (1998b).
- Comparative tests of the Double Fisherman's Knot and the Figure Eight Follow Through Bend (Flemish Bend) for tyability and security.
- Tests and analysis of the "Sennet Bend" and the "River Bend," two knots recommended by Wright and Magowan in an article in the *Alpine Journal* of 1928, which Warner (1996a) praised highly. Like the "Double Figure Eight Follow Through" (number 14 in the Table), these knots may not be practical for patrollers joining hollow braid, but the tests will probably lead to interesting results.
- Tests and analysis of other knots for joining two pieces of rope:
  - Barrel Knot (Ashley #295, 1413, 1416, 1417, 2254, 1439)
  - 2/3/34 (Ashley #1452)
  - Double Carrick Bend (Ashley #1439)
  - Granny Knots (Granny Knot with three backups) (Ashley #1444)
  - Diamond Knot (Ashley #787)
  - Ashley's twenty bends, page 273
  - Other bends in Ashley, Chapter 18

Further Uses of this Research

Research such as this shows not only that patrollers disagree about the best knots for a purpose, but that the experts also disagree. It shows as well that knotting history is not static but that views of knots change with different materials, different applications, and increased experience and study.

There is an additional application of this survey. Tying and testing knots in hollow braid polypropylene rope teaches lessons about knot security that would be difficult to gain by other means. It shows that knots always slip, some more than others. It shows how knots with some kinds of wraps and blocks and tucks create a more secure knot, and that simple knots sometimes hold pretty well. Studying the way knots work—or do not work—in hollow braid provides dramatic lessons in structure and friction, the things that make knots secure. While most competent knot tyers realize that the kind of rope they use always affects the kinds of knots they select, tying knots in hollow braid makes this point with peculiar force.

7. ACKNOWLEDGMENTS

Thanks to Loon Mountain Ski Patrol, Lincoln, New Hampshire, for encouragement and material support in this project. Thanks to patrollers and friends who participated in my survey, especially Bob Vocke, White Tail, Pennsylvania, for criticism and for listening to me prattle about knots. I also wish to thank Gary McCool, Alice Staples, Robert Fitzpatrick, and Bill Kietsman of the Lamson Library staff, Plymouth State College, New Hampshire, and Jean and Laura Chisholm for valuable suggestions.

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