

**PAPER****General**

# Distinguishing between homicide and suicide knots and ligatures: A comparative analysis of case and survey data

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Email: chisnall@kingston.net**Abstract**

Distinguishing between suicide and homicide can be challenging owing to ambiguous and confusing case details. In particular, there is a paucity of useful information comparing homicide and suicide knots and ligatures in the literature. Multiple knot and ligature characteristics have not been recognized previously because complete and accurate information has been lacking. Ninety external tying cases (mainly homicide) and 56 cases involving self-tying (mainly suicide) were reviewed to compare multiple knot and ligature characteristics. Additionally, 189 survey volunteers performed four standardized external tying tasks and two self-tying tasks, yielding comparison data from more than 1500 knots. Using all available data, it was determined that the differences between external and self-tying included types of knots, ligature configurations, ligature tensions, wrist gaps, wend lengths, knot access, external anchoring, and other indicators. These differences are presented in a proposed analysis checklist inspired by medical and psychiatric protocols. The checklist contains 14 potential characteristics for head and neck bindings, 14 potential characteristics for wrists and arms, nine ankle and leg characteristics, and four linkage details. The proposed checklist can be expanded and fine-tuned as more data are accumulated. It offers experienced knot analysts an additional tool to assist in drawing conclusions, which then can be related to other case evidence by investigators.

**KEYWORDS**

asphyxia, autoerotic fatality, forensic science, hanging, knots and ligatures, strangulation

## 1 | INTRODUCTION

Distinguishing between homicides and suicides can be challenging when knots and ligatures are involved. This is particularly true for cases involving decedents who have been bound. If subtle telltales are ignored, foul play may be assumed. In contrast, the discovery of a hanged decedent may lead to a conclusion of suicide. That determination could be premature in the absence of relevant evidence and a thorough analysis of the knots and ligatures. As several authors note, the analysis of equivocal cases must include all collateral evidence, not only the scene evidence but family and decedent history, the overall context, and the death scene circumstances [1–6]. can

tying performed by an assailant be distinguished from knots and ligatures tied by decedents on their own bodies?

To answer these questions, survey and case data were analyzed and compared to discern any useful differences. These observations were incorporated into a proposed checklist of contrasting characteristics, which will be outlined near the end.

## 2 | BACKGROUND AND RATIONALE

In the United Kingdom during the late 1970 s, Underwood investigated an unusual case in which three children were discovered

strangled to death with ligatures and the mother had hanged herself [7]. Based on case details, it was determined that she had murdered her family before taking her own life. Being attuned to the details of knots, Underwood noted that the children's neck ligature knots were the mirror image of those found on the mother. He speculated that when an individual self-ties around his or her own neck, natural tying habits may be reversed. Eight police women were asked to provide knot samples demonstrating their external tying and self-tying habits. All of the participants in this small, informal study produced mirror-image versions of their habitual knots when tying around their own necks. It was concluded that self-tying causes knot chirality reversal.

In a more formal study, Nute observed that 20 out of 27 survey participants switched the chirality of their knots, and 10 switched from the Reef Knot to Granny Knot and vice versa when tying overhead [8]. The tendency to change knot chirality according to unusual orientations was found to be noteworthy albeit inconsistent. However, no specific distinction was made between tying tasks requiring one working end or two working ends. Subsequent research has demonstrated that tiers can switch chirality when the number of wends changes [9–12]. Nute's survey tying tasks were not standardized, making certain comparisons impossible or unreliable. Also, there may have been a transposition error in the labeling of knot mirror images. The reported data pattern is opposite to the pattern outlined in other studies pertaining to tier handedness and knot chirality [9–12].

The extent to which the phenomenon of chirality reversal during self-tying occurs—its frequency and parameters—is poorly understood and has not been studied more extensively. Such insights could assist knot analysts when comparing control samples to scene evidence. More important, chirality reversal is just one phenomenon to consider in equivocal cases [1–6,13–20].

The essence of the problem is distinguishing between self-tying and external tying. Some general aspects of ligatures are understood to a certain extent, and they are mentioned throughout the forensic literature [9,21–24]. The differences in many specific knot and ligature characteristics are unknown. Further, the knot data reported in the literature are inconsistent, and numerous details have not been examined in case reports and international retrospective studies [1–6,13–20,25–74]. Published knot and ligature data acquired from homicides are not abundant. Most retrospective studies that mention knots and ligatures focus on suicides and hanging. This may be because hanging is the easiest and most common method of suicide, while ligature strangulation in homicides occurs less often [69–73].

Suicide methods can differ from culture to culture depending on social acceptability, the availability of suitable materials, and the technical means to perform the act [25–47,70–73]. Some suicides are extremely unusual and ostensibly equivocal [1–6,13–20]. Occasionally, both homicide and suicide cases can involve subterfuge. Homicides may be staged as suicides to divert guilt, while suicides can be disguised as homicides to implicate someone else [13–20,75–79]. Suicide may be performed in a variety of unique ways for reasons known only to the decedents [78–93].



FIGURE 1 Ordinary Knots: Overhand Knots (top), Half Hitches (middle), Half Knots (bottom), S enantiomorphs (left), Z enantiomorphs (right)

## 2.1 | A basic overview of knots and ligatures

Knot terminology is inconsistent and sometimes confusing throughout the mainstream literature. However, standardized knot nomenclature has been employed in forensic science [9–12,21]. What follows is a very brief summary of terms and concepts established in the literature that will be utilized here. More extensive discussions of basic forensic knot terminology and principles have been published previously [94,95].

Most tiers produce commonplace formations, some of which are called marginal or ordinary knots by Miles [96]. They include the simple Overhand Knot and its topological variants, the Half Hitch and Half Knot, which have S and Z mirror images or enantiomers. For this reason, they are recognized as chiral knots [9–12]. The phenomenon of chirality is observed in case evidence [9–12,94], and the enantiomers of these three basic knots are illustrated in Figure 1. (Enantiomer is a general term for mirror-image knots. A specific mirror-image form is referred to as an enantiomorph [12]) Further, S enantiomorphs occur more frequently and are weakly associated with right-handedness, depending on the tying task and the number of working ends involved [9–12].

Some knots are usually tied using one working end or wend, like Overhand Knots and Half Hitches. Half Hitches can be tied singly, or multiple Half Hitches can be tied in sequence (Figure 2). Binding, parceling, or packing knots usually require two or more knot components or factor knots called Half Knots. Half Knots require the manipulation of two wends simultaneously. The tying of two Half Knots in succession usually produces one of the four cardinal knots, which are frequently encountered in case work: S/S and Z/Z Granny Knots, and S/Z and Z/S Reef Knots (Figure 3). Granny Knots contain two identical Half Knots, while Reefs contain two opposite Half Knots. The shorthand terminology employed to encode the four cardinal

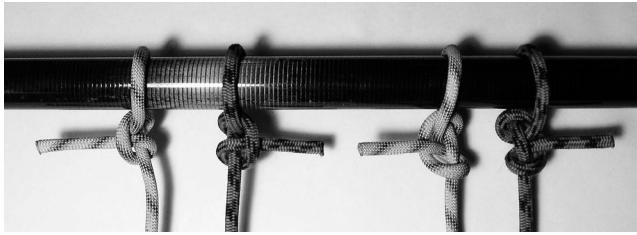


FIGURE 2 Pairs of Half Hitches, from left to right: S/S, Z/Z, S/Z, Z/S

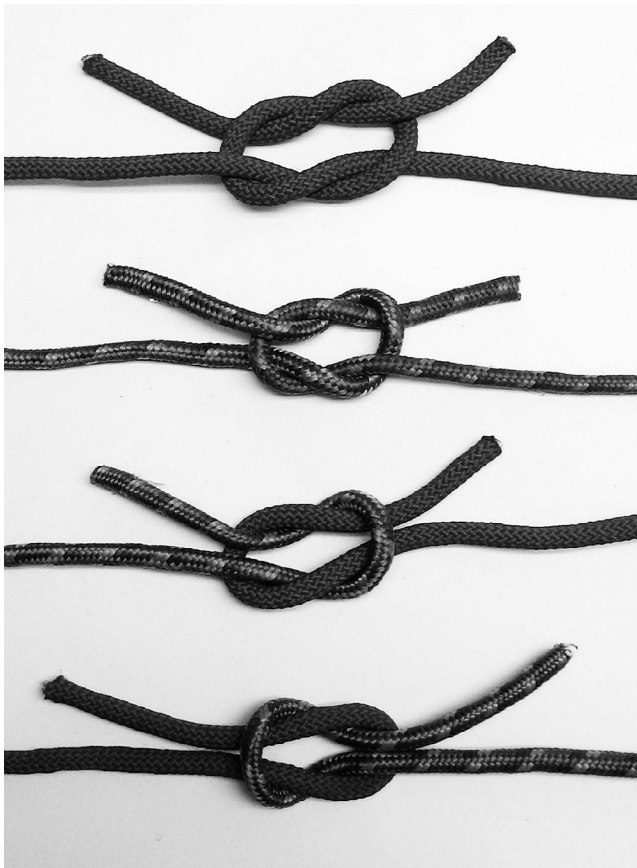


FIGURE 3 Cardinal Knots; from top to bottom: S/S Granny Knot, Z/Z Granny Knot, S/Z Reef Knots, Z/S Reef Knot

knots is straightforward. The capital letter in front of the forward slash indicates the chirality of the first Half Knot tied. The second Half Knot tied is represented by the letter following the slash.

Research and experience have shown that tiers tend to display the same habits, producing knots of the same chirality fairly consistently during similar tasks [9–12]. It has been observed that tying habits can change under unusual circumstances, such as overhead and self-tying, and interference [9–12,94]. These situations are known as chirality reversal factors. Chirality consistency is the extent to which a tier will produce knots of equal chirality—either S or Z (Figure 1)—or the degree to which knots or factor knots of the same chirality appear in one ligature or one set of ligatures. Some tiers will produce either S or Z knots practically every time, whether they are tying with one wend or two

wends. Other individuals will switch chirality when moving from one-wend to two-wend tying tasks—Half Hitch to Half Knot tying, for example [9,10,12]. Chirality reversal can be caused by self-tying. A small percentage of tiers can be consistent mixed tiers under certain circumstances, producing equal numbers of S and Z Half Knots in the same order. This can occur when a mixed tier produces pairs of opposite Half Knots to produce either S/Z or Z/S Reef Knots consistently (Figure 3) [10].

Herein, the term “external tying” will refer to knots and ligatures “externally tied” by an assailant, as in homicide and sexual assault cases, for example. Those knots and ligatures tied by the decedent around his or her own body in suicide and autoerotic death cases will be called artifacts of “self-tying” and are “self-tied.”

### 3 | METHOD

#### 3.1 | Case data collection

Over a period of three decades, 146 cases involving knots and ligatures were analyzed in detail firsthand, or case reports were assessed according to whatever data were documented. Unresolved or equivocal cases were not considered. Data from victims who were packaged in other materials—such as tarps, carpets, and garbage bags—were excluded. Along with neck ligatures and related details, attention was paid to the presence of limb bindings—particularly ligatures around the wrists and arms. A breakdown of the cases analyzed is shown in Table 1. Data were compiled from an examination of 90 external tying events (mainly homicides and some sexual assaults) and 56 self-tying events (mainly suicides and some autoerotic fatalities). Not all fatalities were caused by asphyxia via hanging or strangulation, and equivocal cases were not considered. Information pertaining to every characteristic analyzed was not always available for many cases, and specific characteristics were not applicable in each instance. (For example, some bound homicide victims were not strangled, and some bound suicides did not hang themselves). Ligature and knot case variables were tabulated, and a comparison was made between external and self-tying characteristics. The following details were examined:

- The occurrence of bound limbs,
- The presence of padding, gags, and blindfolds,
- Decedent suspension and external anchoring,
- The number of knots and ligatures used to bind the neck, wrists, and legs,

TABLE 1 Breakdown of the 146 cases analyzed

External tying cases		Self-tying cases	
Homicide	75	Suicide	51
Attempted Homicide	1	Attempted Suicide	2
Sexual Assault	10	Autoerotic Fatality	2
Forcible Confinement	4	Staging (Faked Robbery)	1
Total	90	Total	56

Note: The numbers of individuals who were tied are indicated.

- Binding configurations and whether ligatures were linked or not (Figures 4 and 5),
- The number and kinds of turns or wraps around the neck and limbs (Figures 6 to 9),
- Types and positions of factor knots that made up larger knots,
- Whether those knots were fixed (not sliding) or running (slip) knots,
- Ligature and knot tension,
- Limb position and separation,
- The proximity of knots and working ends or wends to the hands,
- And the relative lengths of the working ends.

### 3.2 | Survey data collection

Seven separate groups of volunteers were surveyed over four years. There were a total of 189 participants who produced 500 knot samples and at least 1,500 individual knots or factor knots. Only two of the 189 volunteers claimed to have knot-tying experience, which is consistent with prior research [10,11]. The majority of the survey volunteers could be classified as “innate” or “practical” tiers, according to an established scale of knot-tying skill [12]. Additionally, none of the knots analyzed during the survey were sophisticated or indicated any sort of knot-tying expertise. All were ordinary factor knots. Each volunteer tied two to six knots or knot groups for each survey task. Not all volunteers completed the surveys adequately to provide

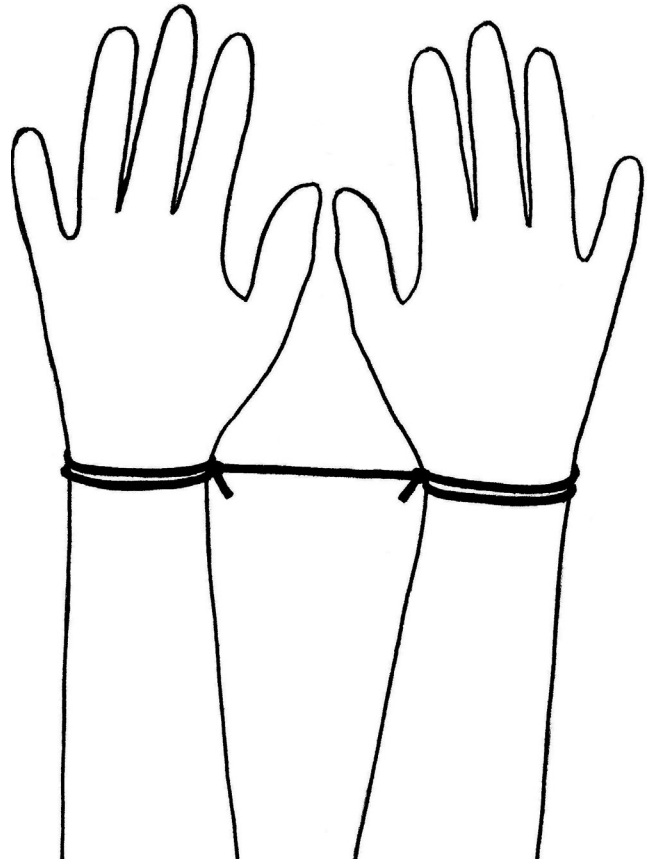


FIGURE 5 Wrists wrapped and tied separately but linked. Can be external or self-tying

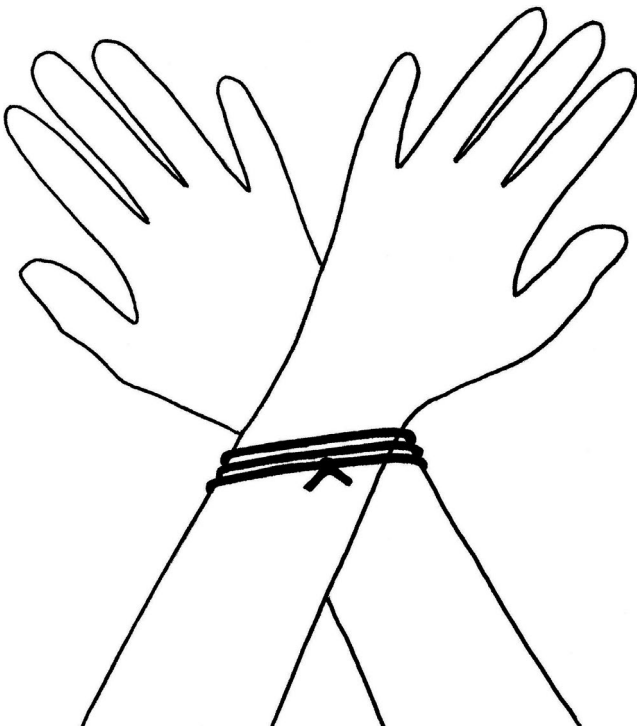


FIGURE 4 Wrists wrapped and tied together. Can be external or self-tying

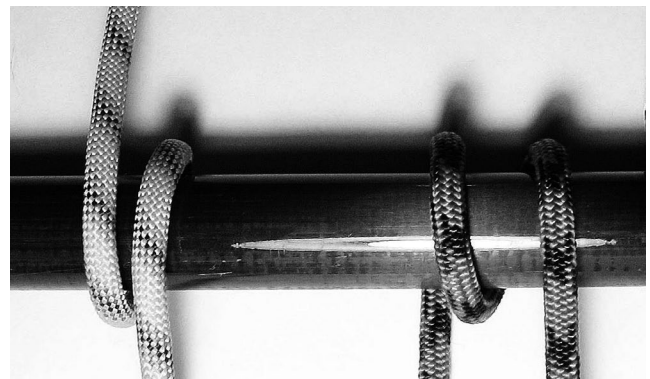


FIGURE 6 A Turn or Wrap (left), Round Turn (right)

useful data for each task, so the individual task totals are less than 189. The sample population consisted of both men and women ranging from 18 to 46 years of age. The study participants were asked to perform the following tasks at least three times: 1. Tie a simple Overhand Knot using one end of cord; 2. tie two or more Half Hitches to anchor one end of a cord; 3. tie two or more Half Knots as if securing a parcel or package (thus

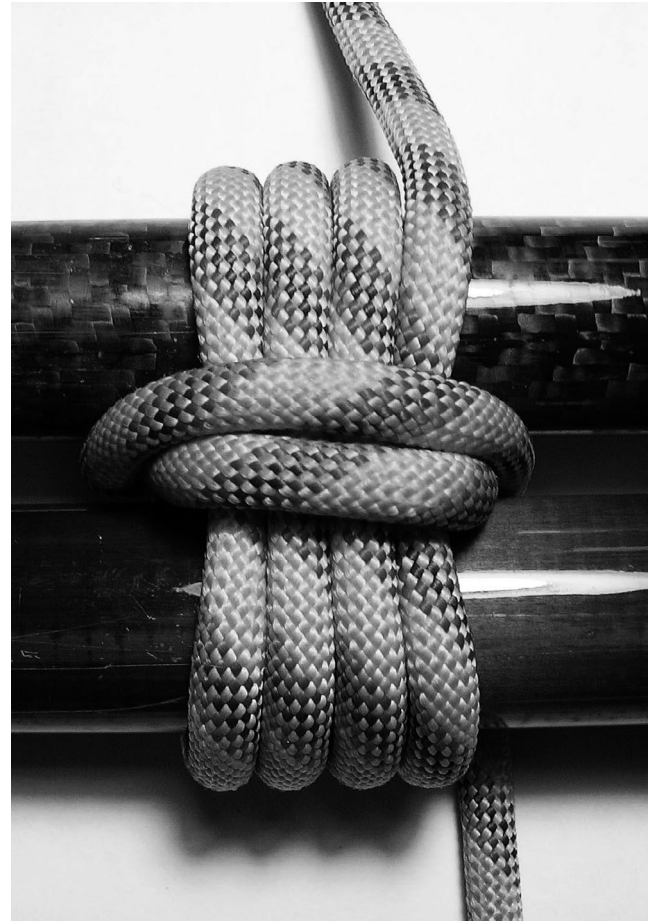


**FIGURE 7** Collective Round Turns, which are used to secure limbs together as shown in Figure 4

producing a Reef or Granny Knot, or a series of Half Knots); and 4. tie a loose Half Knot using a narrow, rectangular scarf around the neck. Other than a conventional winter scarf for the latter task, braided or kernmantle nylon or polypropylene cords were utilized for the other tasks, and these cords ranged from four to seven millimeters in diameter and from one to two meters in length.

Further, two subsidiary tying tasks involving 93 volunteers were performed in conjunction with the survey described above. Under close observation and appropriate safety conditions, participants were asked to tie other volunteers' wrists. They were also instructed to tie their own wrists. Not all volunteers were successful with the latter task. The general patterns and methods of tying were noted—whether the wrists were tied together or with separate loops adjoined by a segment of cord (Figures 4 and 5). These activities were observed firsthand to note methods of tying, ligature tensions, and the relative gaps between wrists. The separation between self-tied and externally tied wrists from 37 participants was precisely measured for comparison. The remaining 56 either could not or would not complete the subsidiary tasks. Further, some ligatures were untied before measurements could be made or verified.

The data accumulated from participant surveys were then evaluated and compared to the case data.



**FIGURE 8** Frapping Turns at right angles to Round Turns

## 4 | RESULTS: CASE DATA

### 4.1 | Head and neck, and suspension

Data for head bindings and neck ligatures are summarized in Table 2. Hanging was observed less frequently in homicides. Neck ligatures were present in about half the external tying cases because strangulation did not occur in every homicide, and there were several instances of forcible confinement and sexual assault which did not involve neck ligatures. In contrast, most suicides were discovered hanging with a neck ligature.

The majority of hanging suicides involved partial or complete suspension. Most suicides were found partially suspended by their neck ligatures, with their feet or knees touching the ground or nearby furniture. Some decedents were discovered in a slumped position with the neck ligature supporting only the weight of the head. In one case, a prison inmate was able to commit suicide using a towel as a neck ligature while lying in his bed.

Where neck bindings appeared in suicide cases, usually one ligature was utilized. External tying had a slightly higher incidence of double neck ligatures. In most cases, whether external or self-tying



**FIGURE 9** Racking Turns, consisting of a figure eight pattern around the wrists

was indicated, the ligature comprised a single neck wrap. However, multiple neck wraps appeared more often in external tying situations. Gags and blindfolds were present in a minority of homicide and suicide cases but figured more prominently in external tying.

Fixed or immovable knots were prevalent in external tying cases and sliding knots, generically referred to as slip knots, appeared in self-tying cases. Suicide neck ligatures usually had a single factor knot, but some self-tying cases had up to three factor knots. External tying was more often characterized by two factor knots, but three or more knots had been used. Neck ligatures were knotted more frequently at the front in self-tying situations and more frequently at the back with external tying.

In all homicides involving strangulation with knotted ligatures, the neck ligatures were tight or extremely tight—smaller than the relaxed circumference of the neck and often embedded in the soft tissue of the neck. (Some unknotted ligatures were employed in manual strangulation and then released). Suicides were more frequently characterized by loose neck ligatures and the presence of an inverted “V” mark in the soft neck tissue at the point of suspension where the knot was located. The incidence of tight, self-tied neck ligatures was lower than loose ligatures.

The data summarized near the bottom of Table 2 indicate long hair was entangled in neck ligatures in both homicides and suicides. Entangled necklaces were also observed. Data for accidental strangulation deaths in children were not included in the tables presented. However, it was noted that such events typically featured disorderly tangles of cord or rope but no discernible knots.

**TABLE 2** A comparison of external and self-tying characteristics in neck and head bindings. Numbers of individuals tied are indicated where the ligature characteristics apply

Neck and head ligature characteristics		External tying	Self-tying
Neck ligature present (all cases)	Yes	46 (51.1%)	44 (78.6%)
	No	44 (48.9%)	12 (21.4%)
Number of ligatures	1	39 (84.8%)	42 (95.5%)
	2	7 (15.2%)	2 (4.5%)
Ligature tension	Loose	3 (6.5%)	16 (36.4%)
	Tight	32 (69.6%)	12 (27.3%)
	Unknown	11 (23.9%)	16 (36.4%)
Number of neck wraps	1	20 (43.5%)	28 (63.7%)
	2	14 (30.4%)	3 (6.8%)
	≥3	11 (23.9%)	3 (6.8%)
	Unknown	1 (2.2%)	10 (22.7%)
Sliding or fixed Knots <sup>a</sup>	Slip Knots	15 (36.6%)	22 (50%)
	Fixed Knots	24 (58.5%)	12 (27%)
	Unknown	2 (5.9%)	10 (23%)
Number of factor Knots <sup>a</sup>	0	5 (10.9%)	0 (0.0%)
	1	6 (13.0%)	15 (36.6%)
	2	17 (37.0%)	9 (22.0%)
	≥3	14 (30.4%)	5 (12.2%)
	Unknown	4 (8.7%)	12 (29.3%)
Position of Knot or Knots on Decedent's neck Typical: back Atypical: front, right, left	Back	10 (24.4%)	4 (9.8%)
	Front	7 (17.1%)	8 (19.5%)
	Right	7 (17.1%)	4 (9.8%)
	Left	6 (14.6%)	1 (2.4%)
	Unknown	11 (26.8%)	24 (58.5%)
Suspension	Partial	2 (100%)	19 (57.6%)
	Full	0 (0.0%)	7 (12.2%)
	Unknown	0 (0.0%)	7 (12.2%)
Hair entanglement	Yes, Short hair	0 (0.0%)	0 (0.0%)
	Yes, Long hair	9 (19.6%)	1 (2.3%)
	No, Short hair	8 (17.4%)	7 (15.9%)
	No, Long hair	1 (2.2%)	0 (0.0%)
	Unknown	28 (60.9%)	36 (81.8%)
Gag or blindfold present (All cases)	Yes	17 (18.9%)	5 (8.9%)
	No	73 (81.1%)	51 (91.1%)

<sup>a</sup>No knots were present in some of the neck ligatures analyzed.

## 4.2 | Arms and wrists

Case data summarized in Table 3 highlight observed characteristics for wrist and arm ligatures. The binding of hands or arms occurred more frequently in external tying events, but it did appear

**TABLE 3** A comparison of external and self-tying characteristics pertaining to hand and arm ligatures

Hand and arm ligature characteristics		external tying	Self-tying
Hands or arms bound (All cases)	Yes	62 (68.9%)	19 (33.9%)
	No	28 (31.1%)	37 (66.1%)
Number of ligatures	1	46 (74.2%)	17 (89.5%)
	≥2	16 (25.8%)	0 (0.0%)
	Unknown	0 (0.0%)	2 (10.5%)
Ligature tension	Loose	1 <sup>a</sup> (1.6%)	14 (73.7%)
	Tight	44 (71.0%)	0 (0.0%)
	Unknown	17 (27.4%)	5 (26.3%)
Number of wraps	1-2	30 (48.4%)	10 (52.6%)
	≥3	26 (41.9%)	2 (10.5%)
	Unknown	6 (9.7%)	7 (36.8%)
Sliding or fixed knots	Slip Knots	7 (11.3%)	9 (47.4%)
	Fixed Knots	53 (85.5%)	4 (21.0%)
	Unknown	2 (3.2%)	6 (31.6%)
Number of factor knots	1-3	27 (43.6%)	4 (21.0%)
	≥4	27 (43.6%)	3 (15.8%)
	Unknown	8 (12.9%)	12 (63.2%)
Location of knots on wrists	Back	23 (37.1%)	3 (15.8%)
	Front	2 (3.2%)	3 (15.8%)
	Left	0 (0.0%)	1 (5.3%)
	Right	0 (0.0%)	1 (5.3%)
	Between	1 (1.6%)	3 (15.8%)
	Mixed	7 (11.3%)	0 (0.0%)
Wrist gap	Large	16 <sup>b</sup> (25.8%)	12 <sup>c</sup> (63.2%)
	Small	28 (45.2%)	0 (0.0%)
	Unknown or Not applicable	18 (29.0%)	7 (36.8%)
Wrists crossed	Yes	11 (17.7%)	0 (0.0%)
	No	18 (29.0%)	12 (63.2%)
	Unknown or Not applicable	33 (23.2%)	7 (36.8%)
Hands, fingers touching ligature wends	Yes	2 (3.2%)	3 (15.8%)
	No or Not applicable	60 (96.8%)	16 (84.2%)
Wend lengths	Long (≥1 m)	1 <sup>d</sup> (1.6%)	8 (42.1%)
	Short (≤30 cm, most ≤10 cm)	31 (50.0%)	0 (0.0%)
	Unknown	30 (48.8%)	11 (57.9%)

Note: Numbers of individuals are indicated where ligature characteristics apply.

<sup>a</sup>One homicide victim's hands were tied twice. The first wrist ligature had worked loose. A second, tighter ligature overlaid the first and was applied to enhance security.

<sup>b</sup>Eight pairs of wrists were tied with separate loops connected with a segment of cord or rope. Six pairs of upper arms or elbows were tied behind the back. Two pairs of wrists were tied directly to thighs or ankles.

<sup>c</sup>Gaps measured from 6 cm to 17 cm, where data were available.

<sup>d</sup>One long wend was tied to the ankles.

in about one-third of the self-tying cases examined. External tying featured one or multiple ligatures. Single ligatures occurred in self-tying cases.

A significant indicator of self-tying was the relative looseness of the ligatures around the wrists. Most externally tied wrist ligatures were tight or extremely tight. However, in one case a decedent had two ligatures—a very tight ligature overlying a loose one. (Two assailants were involved, and there was evidence indicating the victim struggled to get free, necessitating the application of a second more secure wrist binding). In two multiple homicide cases, one victim was compelled by an assailant to tie up the other victims. The wrist ligatures were not tightened with as much force as one would expect from an aggressive attacker intent on securing the victims. Then, the perpetrator tightly secured the victim who did the initial tying. Hence, the tensions and tying patterns differed.

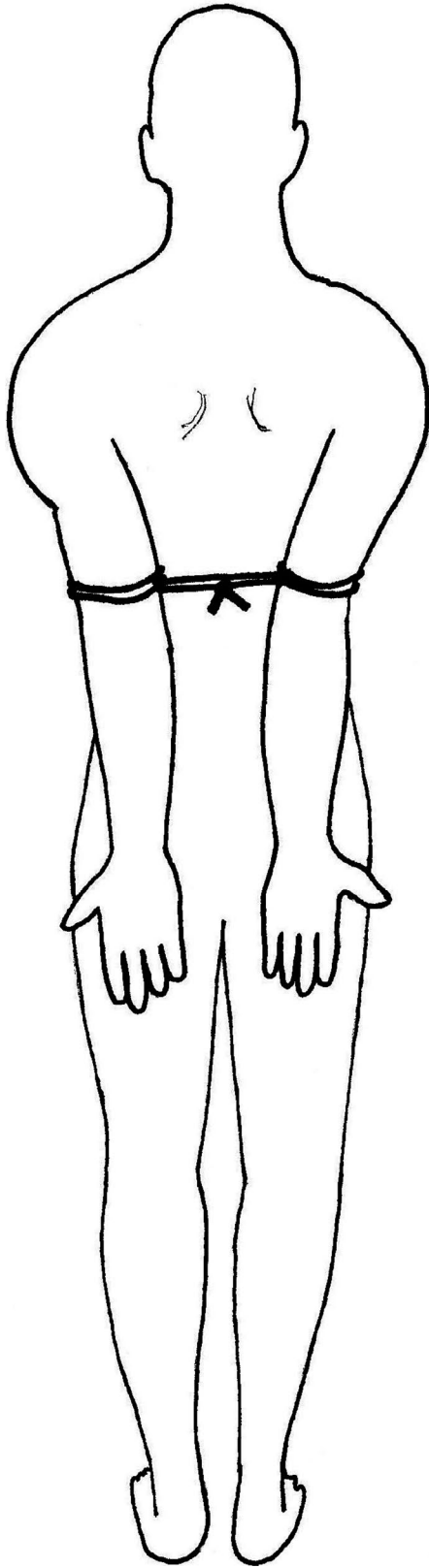
As the case data indicate, hand proximity was more consistent with external tying. This observation is specific to the tying method utilized to secure both wrists together (Figure 4). It does not apply to upper-arm tying and the securing of wrists using separate loops (Figures 5 and 10). (The upper arms were tied with separate loops in one homicide case with a gap of 20+ cm). All self-tied wrist ligatures featured a significant gap between the hands.

Externally bound hands were more frequently positioned behind the decedent, but both external and self-tying produced wrist ligatures in front and behind. No self-tied wrists were crossed. A significant number of externally tied wrists were crossed, but in eight cases the wrists were tied separately, the elbows or upper arms were tied, or the wrists were tied to the legs, torso, or external anchors. The remainder were tied with the palms together with the volar side of the wrists touching. In seven homicides, the upper arms were bound tightly behind the back (Figure 10)—a configuration clearly indicating external tying because the ligatures and knots were not accessible to the victims and escape would have been impossible.

Self-tying featured sliding knots more frequently, while most homicide wrist knots were fixed. Self-tied and externally tied knots were observed in a variety of locations. Significantly, it was noted that externally tied knots were usually at the back of the hands or in a location inaccessible to the victim. In contrast, self-tied wrist knots were at the front of the hands or between the palms, where they were accessible to manipulation, or the hands could have rotated within the loose ligatures to access the knots and ends.

Self-tied wrist ligatures usually had one or two wraps, depending on the length of tying material employed, and they were secured with just one set of terminal knots. External tying could have one, two, or multiple turns around the wrists, and there were multiple sets of knots distributed between the wraps for increased security.

One distinctive difference between external and self-tying was residual wend length. All externally tied wrist ligatures had short wends, usually less than 10 cm in length. One homicide



**FIGURE 10** Upper arms tied behind back. An example of external tying

case was the exception wherein a long wend had been linked to the ankles in order to hogtie the decedent (Figure 11), but it had been untied.

Wrist ligatures from the suicides analyzed consistently featured long wends, which were often more than one meter in length. Minimal tying occurred, and excess rope or cord remained unused.

#### 4.3 | Legs and ankles

Case data pertaining to ankle binding characteristics are summarized in Table 4. Bound ankles were more often found in homicides, but they did occur in ten suicides. The ankle gap was usually smaller in external tying cases. Externally tied ligatures applied to the ankles were tight, and self-tied bindings were comparatively loose. Self-tying cases entailed one ankle ligature only, whereas external tying could feature multiple ankle ligatures. Similarly, the number of wraps in self-tying was generally low compared to external tying, depending on ligature length.

Like wrist ligatures in the cases examined, externally tied ankle and leg ligatures had fixed knots and often more than three nonslip factor knots were involved in securing the binding. Self-tying was characterized by one to three terminal factor knots that could slip. Externally tied ankle knots occurred more frequently at the back of the legs, but both externally tied and self-tied knots were observed in multiple locations.

#### 4.4 | Miscellaneous characteristics: Wraps, linked ligatures, and unusual configurations

Wraps or Turns, Collective Wraps or Turns, Racking Turns, and Frapping Turns were observed in external and self-tied case exhibits (see Figures 6 to 9). As Table 5 outlines, no distinctive patterns were apparent. Tying sophistication was not necessarily indicated by the kinds of wraps utilized.

Some suicides attached their wrists to clothing (trouser belt loops, for example), upper thighs, and even ankles. However, ligature linkages were more common in homicides. Several murder victims were hogtied, or their limbs were secured to external anchors such as bed frames, trees, and ground stakes. Limbs linked together or tied to external anchors were observed in homicides and sexual assaults. Hogtying usually indicated external tying (Figure 11). Nevertheless, loose hogtying occurred in one suicide case; however, the limbs were not proximal. The material used was stretchy nylon pantyhose.

A few of the externally tied ligatures analyzed involved rare and unusual ligature linkages. As case data in Table 3 summarize, the decedent's fingers were in contact with the wrist ligature in three suicide cases and two homicides. One homicide featured a wrist ligature linked to the neck from behind. In another external tying case, an unusual binding technique was used by a pedophile on his victim. The youngster's hands were oriented with the palms together. Each pair of corresponding fingers was tied together with string. This amounted to a total of five separate finger ligatures with knots (Figure 12).



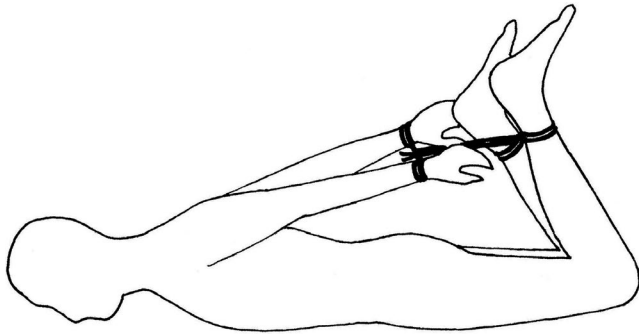


FIGURE 11 Hogtying. An example of external tying

TABLE 4 A comparison of external and self-tying characteristics pertaining to leg and ankle ligatures

Ankle and leg ligature characteristics		External tying	Self-tying
Ankles or legs bound (All cases)	Yes	45 (50.0%)	10 (17.9%)
	No	45 (50.0%)	46 (82.1%)
Ligature tension <sup>a</sup>	Loose	1 (2.2%)	10 (100%)
	Tight	32 (71.1%)	0 (0.0%)
	Unknown	12 (26.7%)	0 (0.0%)
Number of ligatures	1	33 (73.3%)	10 (100%)
	≥3	12 (26.7%)	0 (0.0%)
Number of wraps	1-2	19 (42.2%)	9 (90.0%)
	≥3	21 (46.7%)	0 (0.0%)
	Unknown	5 (1.1%)	1 (10.0%)
Sliding or fixed knots	Slip Knots	1 (2.2%)	5 (50.0%)
	Fixed Knots	40 (88.9%)	3 (30.0%)
	Both	1 (2.2%)	1 (10.0%)
	Unknown	3 (6.7%)	1 (10.0%)
Number of factor knots	1-3	18 (40.0%)	8 (80.0%)
	≥4	23 (51.1%)	1 (10.0%)
	Unknown	4 (8.9%)	1 (10.0%)
Location of knots	Front	8 (17.8%)	1 (10.0%)
	Back	11 (24.4%)	1 (10.0%)
	Left	2 (4.4%)	1 (10.0%)
	Right	0 (0.0%)	0 (0.0%)
	Between	1 (2.2%)	1 (10.0%)
	Mixed	5 (11.1%)	1 (10.0%)
	Unknown	18 (40.0%)	5 (50.0%)
Ankle gap	Large (≥3 cm)	6 (13.3%)	9 (90.0%)
	Small (<<3 cm)	24 (53.3%)	0 (0.0%)
	Unknown	15 (33.3%)	1 (10.0%)

Note: Numbers of individuals are indicated where ligature characteristics apply.

<sup>a</sup>Tight =escape difficult to impossible; Loose =escape not difficult.

### 4.5 | Knot frequencies and sophistication

Out of all the cases analyzed with identifiable knots, there were a total of 474 externally tied knots and 95 self-tied knots. Multiple knot category frequencies are compared in Figure 13.

Paired factor knot combinations were prevalent in self-tying, while higher numbers of factor knots (three to twelve) occurred during external tying. The incidence of the one-wend tying of Half Hitches was similar in both groups of cases. Two-wend tying producing combinations of Half Knots and distorted Half Knots occurred more frequently in external tying cases. (Half Knots can sometimes capsize into Half Hitches and vice versa).

There were some notable differences in certain types of knots observed. Fixed knots comprising two factor knots—such as Reef and Granny Knots (Figure 3)—were more prevalent in external tying. Paired factor knots occurred in both kinds of cases, but external tying was characterized by a higher incidence of three or more factor knots clustered together for security. Further, Overhand Knots and accidental or residual knots occurred more frequently in self-tying cases.

Sliding or running knots appeared more frequently in suicide ligatures. These included pairs of Half Hitches or multiple Half Hitches, Overhand Slip Knots or Loops, Nooses, and Running Overhand Loops (Figures 2, 14, and Figure 15). Many of the paired Half Hitch combinations could slide in self-tied exhibits, but Half Hitches were taut, to the point of immobility in externally tied exhibits. Half Knot combinations appeared more often in external tying situations.

Finally, other than one Gallows Knot or Hangman's Noose (Figure 16) and one Figure Eight Knot (Figure 17), which may have been accidental, knots from self-tying cases were unsophisticated. In contrast, although occurring in less than 5% of cases, more sophisticated knots like Bowlines, Sheet Bends, and Crossing Hitches appeared in homicides only (not illustrated). The Gallows Knot appeared in both suicide and homicide cases.

### 4.6 | Chirality consistency

Table 6. summarizes the slight difference in chirality consistency in case knots. The data indicate that self-tiers were inconsistent or changed knot chirality more frequently than external tiers did. However, the tying tasks were not standardized and the difference in consistency was moderately significant.

## 5 | RESULTS: SURVEY DATA

Two notable findings emerged from the survey data: wrist gaps and chirality consistency. Figure 18 outlines exact measurements made to ligatures that were self-tied and externally tied at the front during the survey. In general, externally tied ligatures had a small gap or no wrist gap at all, except when the wrists were tied with separate loops (Figure 5). All self-tied wrist ligatures had noticeable gaps. Self-tied ligatures were typically loose, and they could be removed without much difficulty and without being untied. The average self-tied ligature wrist gap was 7.35 cm, and the range was 1.5 to 13 cm, whereas externally tied ligatures had an average wrist gap of 1.77 cm and ranged from 0 to 6 cm.

Miscellaneous characteristics		External tying	Self-tying
Linkages	Arms and legs linked	19 (21.1%)	3 <sup>a</sup> (5.4%)
	External limb anchors	5 (5.6%)	0 (0.0%)
	None or Not applicable	66 (73.3%)	53 (94.6%)
Overhead anchors linked to neck ligatures (Hanging)	Yes	2 (2.2%)	26 (46.4%)
	None or Not applicable	88 (97.8%)	30 (53.6%)
Wrapping configurations (Wrists, Arms)	Round turns	54 (60.0%)	12 (21.4%)
	Racking turns	0 (0.0%)	0 (0.0%)
	Frapping turns	0 (0.0%)	1 (1.8%)
	Mixed	2 (2.2%)	1 (1.8%)
	Unknown	6 (6.7%)	5 (8.9%)
	Not applicable	28 (31.1%)	37 (66.1%)
Wrapping Configurations (Ankles, Legs)	Round turns	38 (42.2%)	8 (14.3%)
	Racking turns	2 (2.2%)	1 (1.8%)
	Round turns with Frapping turns	1 (1.1%)	1 (1.8%)
	Unknown	4 (4.4%)	1 (1.8%)
	Not applicable	45 (50.5%)	45 (80.4%)

Note: Numbers of individuals are indicated where ligature characteristics apply.

<sup>a</sup>Three suicides tied their wrists to their clothing or thighs.

Chirality consistency, or the extent to which a tier produced knots of equal chirality or reversed his or her tying habit, is summarized in Table 7. The survey data indicate that self-tying, the tying of a scarf around one's own neck, presented a chirality reversal situation for some tiers but not all. Chirality reversal occurred relative to the tying of Overhand Knots, Half Hitches, and Half Knots. The data revealed a further complication. The chirality consistency of the three survey tying tasks relative to the neck-tying task revealed that innate S tiers tended to reverse chirality at least twice as often as natural Z tiers when tying neck knots.

## 6 | DISCUSSION

Hanging was rarely observed in the homicides analyzed, whereas most suicide cases involved a neck ligature and hanging. This finding agrees with published studies and case reports [1,2,13–20,22–73]. According to a sample of published data summarized in Table 8, full suspension in hanging suicides appears to be more prevalent than partial suspension in eastern cultures [48–64]. Most suicides in the current study, which occurred in North America, were found partially suspended by their neck ligatures, with their feet or knees touching the ground or nearby furniture. Some decedents were found in a slumped or even a prone position with the neck ligature supporting only the weight of the head. (It takes very little pressure to effect strangulation—4.4 lb. to 10 lb., or 2 kg. to 4.5 kg. [20]). Cultural trends in suicidal hangings and suspension require further study.

Two suicide cases involved pairs of neck ligatures, and similar cases have been reported in the literature [87]. Gags and blindfolds

TABLE 5 A comparison of external and self-tying characteristics pertaining to limb linkages, external and overhead anchors, and the wrapping configurations of ligatures

were present in a small minority of homicide and suicide cases but figured more prominently in external tying. According to the literature, both suicides and homicides can present gags and blindfolds [2,13–20,91]. Anecdotal case reports and retrospective studies indicate that homicide ligatures can be knotted or unknotted, while suicide neck ligatures are usually knotted [2,13–20]. This agrees with the case data analyzed herein.

Polson and other authors have described several neck ligature tying methods used in homicides and suicides [1–4,13–20,74–93]. With homicides, multiple neck wraps may be secured with a Half Hitch or no knots at all may be employed [16,18]. A tourniquet method can be used both in homicides and in suicides [19]. Homicide and suicide tourniquets have been observed firsthand or reported in published cases [17,18,20,91].

The literature data summarized in Table 9 indicate that neck ligatures are knotted more frequently at the back (typical) in external tying situations and more frequently at the front or on the sides of the neck (atypical) with self-tying [49–54,57,61,65–69]. External and self-tying knots can occur in various locations around the neck. It is worth considering that a loose ligature could shift around the decedent's neck when loaded, depending on the physical setup of the overhead anchors and the circumstances of suspension in suicides. In homicides, a neck ligature could shift during a struggle.

Ligature circumference relative to the decedent's neck size, the diameter of the material, and the number of wraps or turns might determine whether or not a neck ligature will ride up or rotate around the neck when loaded. Additionally, certain intrinsic qualities of the ligature material should be considered [95]. The surface friction of the ligature and its working capacity (how flexible the material is) may affect the potential mobility of the neck ligature. Any type of available

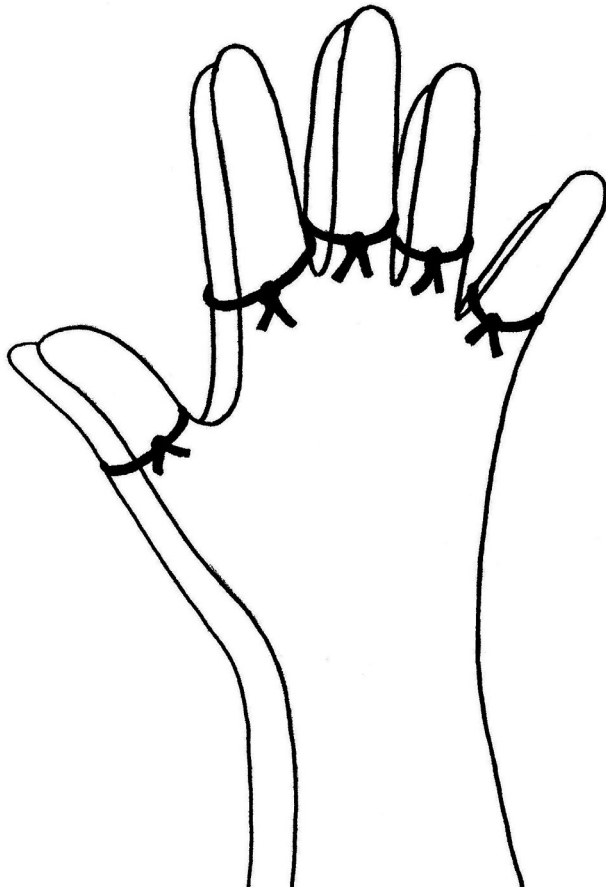


FIGURE 12 Pairs of fingers tied separately; an example of external tying

tying material can be utilized: all manner of clothing, bedding, rope, and electrical cable, to mention the most common examples [45-47]. The use of coat hangers has been reported as well. Several studies indicated that soft neck ligature materials and padding are frequently employed in suicides and autoerotic practices [2,3,92].

A relatively consistent detail observed in this study was the tension of neck ligatures in the cases analyzed, which agrees with the forensic literature [22-70]. Knotted homicide strangulation ligatures were typically tighter than suicide ligatures used for hanging. Tighter suicide neck ligatures could be a consequence of the sliding knots utilized, which can slip and tighten when loaded thus decreasing the ligature circumference.

There is a spectrum of possible postmortem observations across suicidal hangings and homicide strangulations [22-24,97-104]. The qualitative aspects and extent of neck tissue damage depend on the material used, the position of the ligature and knots, whether the knots and ligature tightened or changed position, the number and types of knots employed, and the age and morphology of the decedent among other factors. In homicides, injury variance depends on how a ligature was applied, whether or not there was a struggle, and how much force was used. In determinations of suicide, there may be controversy regarding postmortem findings. This could depend on whether or not there was a drop and the length of that drop. The

## Types of Case Knots

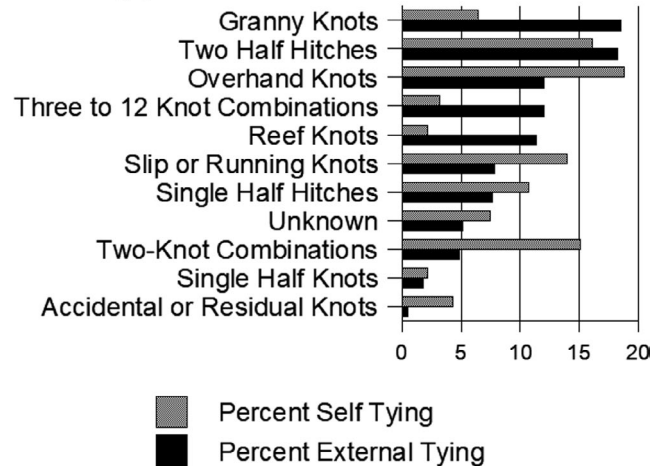


FIGURE 13 Occurrence of case knots compared

duration of suspension, the weight of the decedent, whether or not the decedent was fully suspended, and other details can influence the extent of neck injuries.

Long drops in suicidal hangings occur less frequently than short drops and non-dynamic loading. Patel-Ankur et al. [53] and Naik et al. [54] have reported long and short drops in India. An Australian study of cases documented over a period of 17 years cited three long-drop decapitations in approximately 1,600 suicides [105]. Other decapitation cases have been documented [106]. There have been reports of individuals utilizing neck ligatures in conjunction with motorized vehicles or machinery to strangle or even decapitate themselves [107,108]. The circumstances presented in suicide cases can be unusual, and this also applies to configurations of knots and ligatures found in autoerotic deaths and homicides [2-6].

The forensic literature cites the phenomenon of hair entanglement as being suspicious, indicating possible foul play [2,13-18,22-24]. The data summarized near the bottom of Table 2 suggest that hair entanglement is determined more by hair length rather than the nature of the tying, but more data are needed to learn whether there is a significant difference in the frequencies of hair entanglement during external and self-tying. Other scene evidence and autopsy details must be considered, or if other factors had some influence, to determine whether a struggle occurred, thus pointing to external tying.

The accidental strangulation of children and adults via snagged scarfs, tangled Venetian blind cords, and other common household items has been documented [109-111], but no specific knot details have been reported. As mentioned previously, only disorganized entanglements were noted in accidental strangulations not included in this study.

One of the more critical aspects of differentiating external and self-tying is assessing the binding of arms and hands. If the limb ligatures appeared to be larger than the decedent's limbs, or if the circumferences of those ligatures were greater than known measurements



FIGURE 14 Sliding Knots: Slip Knots (top), Nooses (bottom), S enantiomorphs (left), Z enantiomorphs (right)



FIGURE 15 Running Overhand Loops: S enantiomorph (left), Z enantiomorph (right)

from the decedent, the ligatures were considered to be loose. Further, if escape from ligatures tied around the limbs looked feasible, or if escape could be accomplished using reconstructed ligatures, the bindings were considered to be loose. Conversely, if the ligatures looked to be tighter than the decedent's limbs, or if escape looked difficult or impossible, the ligatures were deemed to be tight. In general, the literature describes suicide wrist bindings as being typically loose, and a reason given for the self-binding of hands is to prevent self-rescue during hanging [13–20,22–24]. Homicide wrist and arm ligatures are typically tight, as confirmed by the case data reported here. No comparative data could be found in the literature regarding wrist gaps, but the general consensus is that externally tied wrist ligatures are tight with minimal space between limbs.

The number of turns in a ligature could be a function of the length of the material available for tying. It should be noted that

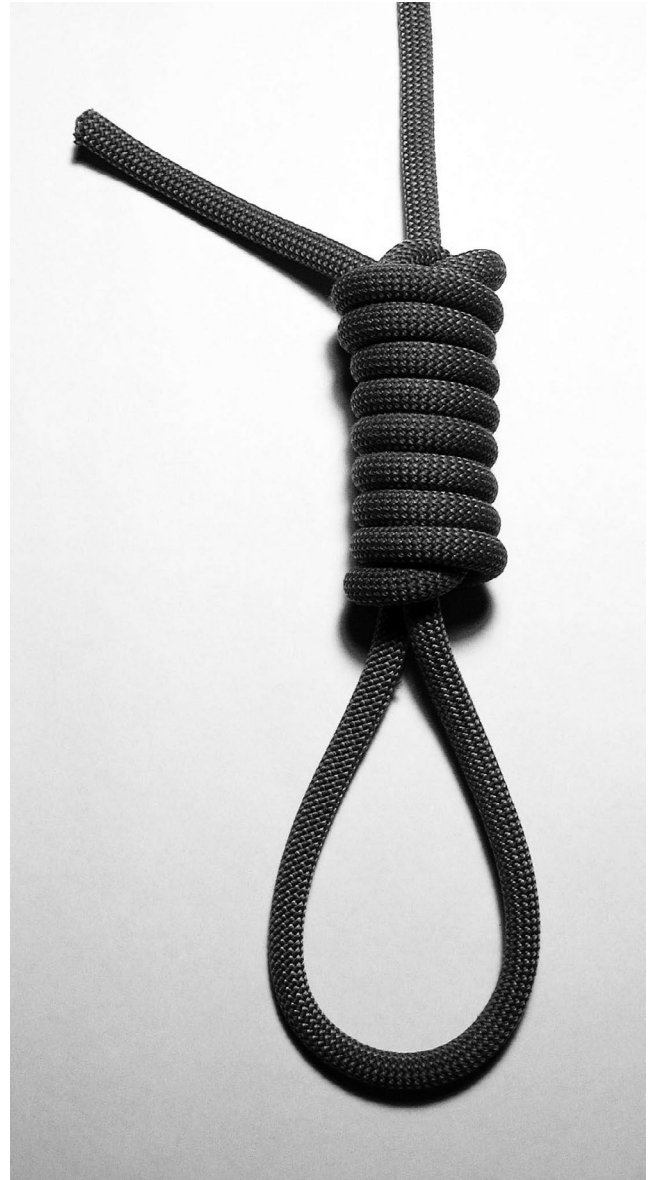


FIGURE 16 Gallows Knot or Hangman's Noose (with nine wraps)

the number of wrist wraps does not necessarily mean the ligature was more secure. Often, one or two wraps can be more secure than multiple wraps. Multiple wraps may introduce extra slack within the ligature, allowing the limbs to be more maneuverable. (The strategic application of multiple unknotted wraps is trick magicians and escape artists use to obfuscate the actual ineffectiveness of their bindings). The difference between secure and insecure wraps is the number of knots and where they are tied. If ligatures are tied after only one or two wraps, and that process is repeated, the ligature will become very secure. In contrast, if the limbs are wrapped many times and ultimately secured with a single set of knots near the ends, security is diminished. This was observed in the case knots and ligatures. Considering the awkwardness of self-tying, it is clear why wrist ligatures were more



FIGURE 17 Figure Eight Knot: S enantiomorph (left), Z enantiomorph (right)

likely to have sliding knots, and why those ligatures were loose with a significant wrist gap.

Another distinctive difference between external and self-tying was residual wend length, and this has not been highlighted in the literature. Long wends should be expected in suicides because the self-tier will perform actions only sufficient to adequately link the wrists and nothing more. Wrapping the entire length of the cord or rope and knotting it many times may be difficult or impossible to accomplish from an ergonomic standpoint in self-tying situations. The self-tier's age, fitness, flexibility, and other physical factors may come into play. Moreover, the ability to apply considerable force to tighten wrist ligatures during self-tying is hindered. Unless there is a struggle, unencumbered external tiers will be more efficient and better able to utilize the entire length of the available ligature material to effectively secure the victim by tying multiple sets of knots.

Individuals have been known to tie their legs as well as their wrists when committing suicide, although this occurs infrequently [2,18-19,22-24]. In the current study, the number of wraps in self-tying was generally low compared to external tying. Again, ligature length might have been a determining factor.

The occurrence of Wraps or Turns, Collective Wraps or Turns, Racking Turns, and Frapping Turns (Figures 6-9) has not been documented in the literature. Tying skill or sophistication is not necessarily indicated by these structures.

TABLE 6 Chirality consistency compared according to 130 case knots

Chirality	External Tying	Self-Tying
Mainly Consistent	103 (96%)	20 (87%)
Inconsistent	4 (4%)	3 (13%)
Totals	107	23

Note: The z-score is 1.7937 with a P-value < .07346, when the proportions of inconsistent external and self-tiers are compared. The result is significant at P < .10.

### Survey Wrist Gap Data

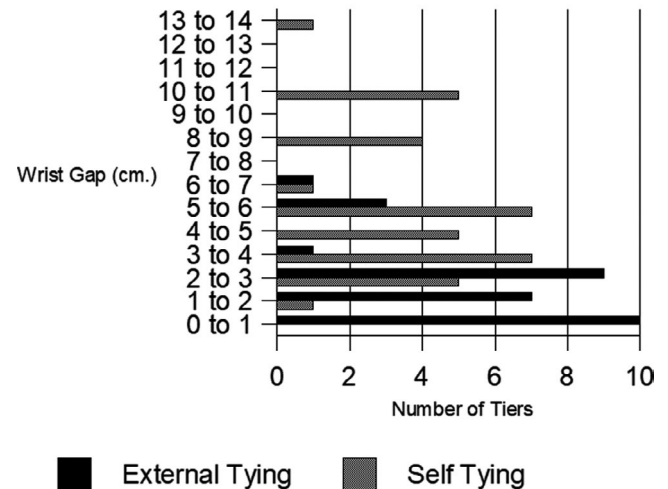


FIGURE 18 Wrist gap survey data

In one documented suicide case, the free end of a noose was attached to the right hand so the cord could be pulled [17]. The weight of the hand could have maintained the minimal pressure required to effect strangulation. There have been other suicide cases where the decedent's hands or fingers were in contact with one or more of the working ends [18,91], as was seen in a few external and self-tying cases in this study.

Several other unusual suicide ligature configurations have been reported in the literature. One documented case involved a couple sharing the opposite ends of the same neck ligature to hang themselves, using each other as a counterbalance weight [82]. Another suicide bound his hands behind his back with the added weight of books, presumably to prevent escape [80].

There was no substantial difference regarding the number of wends employed in self- and external tying. This was a difficult comparison to make because each case involved different circumstances and the tying actions were not standardized. (Also, Half Knots can sometimes capsize into Half Hitches and vice versa [7-9,95]). Nevertheless, it is much easier to tie using two wends when both hands are available.

Patel-Ankur [53] reported 12 out of 12 homicide cases featured fixed knots in neck ligatures. Table 10 summarizes published suicide

Task	Tier totals according to task knot chirality	Number of S neck knot tiers	Number of Z neck knot tiers
Overhand Knots (1 Wend)	S (N = 106)	42 (39.6%) M	64 (60.4%) R
	Z (N = 60)	14 (23.3%) R	46 (76.7%) M
Half Hitches (1 Wend)	S (N = 48)	18 (37.5%) M	30 (63.5%) R
	Z (N = 39)	11 (28.2%) R	28 (71.8%) M
Half Knots (2 Wends)	S (N = 93)	38 (40.9%) M	55 (59.1%) R
	Z (N = 41)	10 (24.4%) R	31 (75.6%) M

Note: R indicates chirality reversal or inconsistency when tying neck knots. M indicates chirality maintenance or consistency when tying neck knots. The small numbers of mixed tiers are not included.

Overhand Knots: The z-score is 4.5942 with a *P*-value < .00001, when the proportions of inconsistent tiers are compared. S tiers switched 2.59 times more than Z tiers. The result is significant at *P* < .01.

TABLE 7 Numbers of survey knot tiers who maintained or reversed the chirality of their knots when switching from Overhand Knots, Half Hitches, and Half Knots (external tying) to the scarf-tying task (self-tying)

Reference	N	Country Survey was Conducted	Full or Complete Suspension	Partial or Incomplete Suspension	Unknown or Not Specified
Meer et al. [48]	84	India	88.1%	8.3%	3.6%
Sharija et al. [49]	181	India	48.0%	37.6%	14.4%
Yadav et al. [50]	212	India	91.8%	8.2%	0.0%
Sahoo et al. [51]	77	India	88.3%	11.7%	0.0%
Bullar [52]	232	India	31.9%	68.1%	0.0%
Patel-Ankur et al. [53]	330	India	98.75%	1.25%	0.0%
Naik et al. [54]	257	India	93.5%	6.5%	0.0%
Ambade et al. [55]	127	Egypt	67.7%	32.3%	0.0%
Rao et al. [56]	264	Egypt	88.0%	12.0%	0.0%
Rahman et al. [57]	312	Bangladesh	99.0%	1.0%	0.0%
Karbeyaz et al. [58]	405	Turkey	81.8%	18.2%	0.0%
Aydin et al. [59]	61	Turkey	77.1%	0.0%	22.9%
Uzün et al. [60]	761	Turkey	47.8%	52.2%	0.0%
Tulapunt et al. [61]	244	Thailand	16.4%	83.6%	0.0%
Bennewith et al. [62]	149	England	52.3%	47.7%	0.0%
Tugaleva et al. [63]	364	Canada	33.5%	66.5%	0.0%
Dean et al. [64]	229	USA	16.6%	83.4%	0.0%
Weighted Means			63.2%	35.8%	1.0%

Note: Asia: 9 out of 12 studies show majority fully suspended.

Africa: 2 out of 2 studies show majority fully suspended.

Europe: 1 study shows slight majority fully suspended.

North America: 2 out of 2 studies show majority not fully suspended.

data indicating that hanging ligatures more frequently feature sliding or slip knots. The findings reported herein are in agreement. Other than documenting the prevalence of sliding and fixed knots, the literature has not focused on exact knot identification and their frequencies, which was one aim of this study. As Figure 13 summarizes, Half Knot combinations occurred more often in external tying situations. The tendency for sliding knots to tighten sufficiently to become fixed may be one reason the forensic literature is not consistent regarding the frequency of fixed and running knots in hanging deaths [46–49,53,54,56,65,68]. The relative tension of the knots

themselves may be a potential distinguishing factor, but there were insufficient case data to analyze this detail.

The occurrence of the Gallows Knot, which can be pre-tied in homicides and suicides, does not necessarily point to tying abilities and knowledge beyond that specific knot. The occurrence of more sophisticated knots in 5% of external tying cases may suggest that having both hands available and unfettered makes the tying of more sophisticated knots much easier, and self-tying makes complex knot tying less feasible. (About 5% of external knot tiers in other studies produced sophisticated knots [10,12]).

TABLE 8 Sample statistics reported in the literature regarding suspension in hanging suicides

TABLE 9 Sample statistics reported in the literature regarding the positions of neck ligature knots in hanging suicides

Reference	N	No Knot, Unspecified, or Unknown	Typical	Atypical		
			Back (Occiput)	Front (Mandibular)	Right (Mastoid)	Left (Mastoid)
Sharija et al. [49]	181	25.9%	9.4%	1.7%	29.3%	23.7%
Yadav et al. [50]	212	0.12%	4.7%	0.0%	55.18%	40.0%
Sahoo et al. [51]	77	0.0%	42.86%	0.0%	18.18%	38.96%
Bullar [52]	232	0.0%	21.98%	0.0%	46.99%	31.03%
Patel-Ankur et al. [53]	330	0.0%	2.5%	97.5% Atypical		
Naik et al. [54]	257	0.0%	7.4%	92.6% Atypical		
Rahman et al. [57]	312	14.71%	0.0%	0.0%	35.9%	49.36%
Tulapunt et al. [61]	244	0.0%	67.8%	2.3%	16.1%	13.8%
Badkur et al. [65]	200	0.0%	41.5%	2.0%	32.5%	24.0%
Talukder et al. [66]	66	0.0%	21.21%	21.21%	25.75%	31.81%
Nadar et al. [67]	93	11.92%	62.5%	0.0%	23.08% Lateral	
Ali et al. [68]	334	0.0%	11.4%	0.0%	27.8%	60.8%
Ambade et al. [69]	127	0.0%	37.0%	4.7%	24.4%	33.9%
Weighted Means		3.9% Unknown	20.4% Typical	74.8% Atypical		

TABLE 10 Sample statistics from the literature regarding the general types of ligature knots found in hanging suicides

Reference	N	Sliding or Running Knots	Fixed Knots	Unknown, or No Knot/Ligature
Ambade et al. [46]	127	21.3%	64.5%	14.2%
Yadukul et al. [47]	26	11.5%	84.6%	3.9%
Meera et al. [48]	84	10.7%	89.3%	0.0%
Sharija et al. [49]	181	58.0%	7.75%	34.25%
Patel-Ankur et al. [53]	320	53.75%	46.25%	0.0%
Nail et al. [54]	166	34.33%	6.63%	59.04%
Rao et al. [56]	258	97.7%	2.3%	0.0%
Badkur et al. [65]	200	70.5%	13.0%	12.5%
Ali et al. [68]	334	59.0%	32%	9.0%
Weighted Means		56.8%	28.9%	13.8%

The consistency of knot chirality is challenging to assess because the number and position of the working ends can be chirality reversal factors [9-12]. In theory, external tying should present more consistent knot chirality because the tier is more mobile. The tier can use both hands comfortably and face the knots he or she is tying in the most effective position. In comparison, self-tying should present less consistency, especially when it comes to neck and wrist ligature knots, because those self-tying tasks are awkward and often difficult to perform. Self-tying requires unfamiliar orientations and cord manipulations.

The case data in Table 6 are suggestive regarding chirality consistency differences. The survey data in Table 7 are more supportive of the notion that self-tying is less consistent than external tying, with an added complication. Innate S tiers tended to reverse chirality at least twice as often as natural Z tiers when tying

scarves around their necks. The reasons for this are unknown, but it could be related to the handedness of the tiers and their brain laterality [10,112-114].

## 7 | LIMITATIONS

Homicides, suicides, autoerotic deaths, and other tragic events involving knots and ligatures are relatively rare events. Not all cases are investigated and documented in the same way. Hence, the case data presented here were not standardized, and acquiring sufficient and appropriate data was onerous. There are gaps in the information gleaned, and there were fewer confirmed cases involving self-tying compared to external tying. Also, not all cases were comparable or equal in terms of context and circumstances.

**TABLE 11** Distinguishing between external and self-tying: a checklist of potential details to assess when analyzing case knots and ligatures

External tying	Ligature and knot characteristics	Self-tying
<b>Head and Neck Bindings</b>		
More likely	Strangulation Ligature	Not likely
Less likely, unless staged	Hanging Ligature	More likely
Unusually one, two possible	Number of Ligatures	Usually one
More likely tight	Ligature Tension	More likely loose
More likely fixed	Knots (if present)	More likely sliding
None or multiple likely	Number of Factor Knots	One or two more likely
More Likely	Reef or Granny Knots	Less likely
Back (typical) likely	Knot Position	Front, sides (atypical) likely
More consistent	Chirality Consistency	Less consistent <sup>b</sup>
Not likely	Padding	Can be present
More likely	Blindfold	Not likely
More likely	Gag	Possible
Possible with long hair	Hair Entanglement	Possible with long hair
Not likely, unless staged	Suspension	Full or partial likely
<b>Wrist and arm bindings</b>		
One, more possible	Ligatures Present	One likely
Tight	Tension	Loose
Multiple possible; few wraps separated by multiple secure knots	Number of Wraps <sup>b</sup>	One or two likely; multiple wraps with terminal knots
Likely fixed	Knots (if present)	Likely sliding
One or multiple likely	Number of Factor Knots	Fewer (one to three likely)
More Likely	Reef or Granny Knots	Less likely
Usual back of hands, inaccessible	Knot Location on Wrists, Knot Accessibility	Back, front, sides of hands; accessible (hands can move)
Usually behind the back	Hand Position	Back or front
Smaller (about 0 to 6 cm)	Wrist Gap	Larger (about 2 to 13 cm)
Likely	Wrists Crossed	Unlikely
Usually not possible	Escape From Ligatures	Possible
Short (less than 30 cm)	Wend Lengths	Long (more than 1 m)
Possible	Hand/Finger Contact With Ligature	Possible
More likely	External Anchors	Unlikely+
<b>Ankle and leg bindings</b>		
More likely	Ligatures Present	Less likely
Tight	Tension	Loose
Smaller (less than 3 cm)	Gap	Larger (more than 3 cm)
Three or more	Number of Wraps <sup>a</sup>	Usually one or two
More likely fixed	Knots (if present)	More likely sliding
One to more than four knots	Number of Factor Knots	Fewer knots (one to three)
More Likely	Reef or Granny Knots	Less likely
Behind legs	Knot Location	Anywhere accessible
Multiple Possible	Ligature Number	Usually One
<b>Linkages and related details</b>		
Possible	External Limb Anchors	Unlikely
More likely	Hog-Tying, Limbs Linked	Possible
Round and racking	Types of Wraps or Turns	Round, racking, and frapping
5% of cases	Knot sophistication	Unlikely

<sup>a</sup>May depend on the length of the tying material.

<sup>b</sup>S tiers more likely to switch chirality than Z tiers.



The specific actions required to tie overhead were not explored during the administration of the tying survey. Additionally, there were insufficient survey data to compare left-dominant and right-dominant tiers. Nevertheless, considerable data were accumulated, thus corroborating prior studies and affording a more robust comparison between self-tying and external tying than previously undertaken.

## 8 | A CHECKLIST OF DISTINGUISHING CHARACTERISTICS

Single details alone cannot be regarded as clear indicators of either external tying or self-tying in equivocal cases. Several characteristics must be considered in concert. Nevertheless, too much irrelevant information may hinder the decision-making process and cloud what is important [115–117]. This was a finding during the development of the Goldman algorithm or index of cardiac risk assessment, which combines standardized details and measurements [118]. Likewise, clinical checklists used in forensic psychiatry assist in reducing bias when making critical assessments [119]. A similar strategy can be developed by exploiting the knot data presented to assist experienced knot investigators in determining whether an equivocal case is more likely external tying or self-tying, homicide, or suicide.

Table 11 summarizes and contrasts the characteristics of externally tied and self-tied knots and ligatures discussed herein. In particular, the occurrence of hanging and ligature strangulation, wend access and ease of tying, and characteristics related to ligature tension and security should be noted—especially with regard to wrist ligatures. This comparison provides a useful foundation for evidence analysis. More case data with more complete ligature and knot information will confirm the differences described and hopefully reveal other telltale phenomena in order to fine-tune the proposed checklist.

For example, the direction of ligature wraps may be relevant—whether a ligature was wrapped clockwise or anticlockwise relative to the tier's perspective, and whether the cord or rope ends were wrapped toward or away from the decedent's torso. The pattern of overlaps could reveal the sequence of events during the tying process. Once the evidence is removed and handled, this information may be permanently lost unless the exhibits are preserved exactly as found. Scene and postmortem photographs might be of assistance; however, determining the wrapping directions may be impossible because tangled knot structures, multiple inner wraps, and other ligature features could be hidden beneath outer wraps and knots.

## 9 | CONCLUSIONS

Every relevant detail concerning case knots and ligatures should be precisely recorded for investigative purposes and for possible future study. Care must be taken during evidence collection, knot

identification, ligature measurement, and documentation, no matter how minute or insignificant a variable might seem.

Several differences between external and self-tying were indicated by the data presented, and the proposed checklist can facilitate a structured exhibit analysis. At a general level, analyses of knotted ligatures must include an assessment of numerous characteristics which may indicate the purpose of the tying, how the tying was performed, its relative security and effectiveness, and the degree of violence involved as well as the force applied. The number and tension of ligatures and knots, potential capsizement and slippage, the gaps between limbs, linkages, and suspension, wend lengths and access, and other pertinent factors must be considered.

Ultimately, all scene and collateral evidence can be evaluated holistically to facilitate a well-informed determination. The array of potential differences in knot and ligature characteristics is an important addition to that set of details. There could be exceptions to the general differences described in this study. The more relevant details obtained, the better equipped the analyzer of knot evidence will be to make an informed contribution to the overall investigation.

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