An Analysis of Traditional Un-tensioned Belays and Two-tensioned Rope Systems in Rope Rescue

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The last five years have seen a marked increase in studies and literature highlighting the limitations of un-tensioned belay lines and the potential merits of two-tensioned rope systems **(TTRS)**. The problem is traditional un-tensioned belay lines may not offer safety benefits that surpass those of two-tensioned rope systems **(TTRS)**. As a consequence, rescuers and their patients may be subject to unreasonable fall distances and trauma when the main line system fails, and the load and forces are dynamically shifted to the belay system. This could be especially true during transitions at the edge or failures that take place on long drops where greater than 50’ of rope is in service.

The purpose of this research is to contrast the advantages and disadvantages of traditional un-tensioned belays and two-tensioned rope systems. Like others before, this research will utilize pseudo-experimental backyard testing of both systems. The result will involve some snapshot looks at the potential problems with one technique or the other between **TTRS** and un-tensioned belays.

Background

Kirk Mauthner presented his findings on this topic at ITRS in Golden, CO, in 2014. He demonstrated several drop test configurations of a 200 kg load, with various drop heights, and levels of edge protection, over a 90-degree sharpened edge. The experiment contrasted **TTRS** and 15 cm un-tensioned belays. The conclusion of his drop testing research was that there is no apparent benefit in using un-tensioned belays over

TTRSs. This series of experiments inspired the researcher to conduct another set of similar experiments. The intent was to both validate and expand on Mauthner's research.

Mauthner's Test Footage:

Over the last ten years, many elements of un-tensioned belay techniques, once held dear, have come under scrutiny and revision. These problems include the inconsistency of tandem Prusik belays (TPB), problems with the pulleys in the TPB, elongation of the belay line, and the difficulty of modern multi-use hardware to pay out rope in an un-tensioned belay. **TTRS** were traditionally used with a fixed brake lower using rappel racks. Early testing in the 80s called this practice into question. Many mountain teams pre-tensioned the TPB on long lowers using a brake rack to take stretch out of the rope.

Literature Review

The modern era of rope rescue arguably began after two FDNY firefighters fell to their deaths on June 27, 1980, when a rope supporting them gave way. In the years that followed, white papers, articles, and NFPA standards set about standardizing rescue equipment and practices. The use of belays and two-rope systems would be a hot and contentious topic for the decades that followed.

The use of an un-tensioned rope for a belay can be traced to rock climbers and alpinists. They are primarily supported by the rock, and the belay rope acts as a safety in the event of a fall. As such, early rescue belays in the 80s included body belays, Sticht plates, tube style devices, and the Munter hitch. Later, ascenders such as the Gibbs Ascender and the Petzl Rescucender would be added to the mix.

The Sedona drop tests in 1989 and the Denver, CO drop tests of 1987 would challenge many long-held beliefs. The tests were performed by Arnor Larson, John Dill, Hal Murray, and Reed Thorne. The conclusion of their tests would culminate in the NATRS presentation by John Dill, “Are You Really on Belay?” This work was also published in many trade magazines. The tests denounced nearly all other belays for two person loads, while championing the TBP. As a result, the TPB and the much misunderstood and misapplied BCCTR BCT would be widely proliferated in many rescue circles for years.

The 90s would add fuel to the great belay debate. Schools such as ROCO and instructors Tom Vines, Richie Wright, Norma King, and more would offer alternatives to the TPB such as the Munter hitch. This would lead to many arguments and heated discussions in venues such as NATRS and ITRS. Certain buzzwords and dogma would also come to the forefront. Concepts such as the *belay competency test,* the *whistle test*, and the *critical point test*, all emerged as measures of safety and belay effectiveness.

The late 90s and early 2000s yielded several mechanical belay devices that sought to close capability gaps in earlier belay techniques. The Traverse 540, the Petzl I’D, and later the CMC MPD all overcame many limitations of other belays. This included consistency, the whistle test, and belay competency testing. Two of these devices would reopen the conversation on **TTRS.** The I’D and MPD both work well lowering in tension. Both devices have their limitations in paying out rope in an un-tensioned belay.

In the late 2000s, both Tom Pendley and Reed Thorne continued testing on belay techniques employing the TPB and belays in artificial high directionals (AHDs). Thorne concluded the pulley should be eliminated from the TPB and the belay line should be high in the AHD during the edge transition, but near the edge thereafter. Exhaustive human interactive studies by Pendley demonstrated a 10% rate of failure or unacceptable arrest distance in the TPB. Additionally, studies showed rope stretch to be untenable. He advocated using the CMC MPD in tension as the belay. At the close of the 2000s, even the venerable and tenacious TPB could not withstand the test of time.

Many authors and instructors are advocating the use of **TTRS.** These include Tom Pendley, Pat Rhodes, the CMC team, and others. The simple advantage includes incorporating mechanical belays that satisfy many dogmatic belay requirements. Stretch in the belay line is reduced. The operation of each line is the same. Knot-passes, changes from raises to lowers, pike and pivots, and other techniques are greatly simplified.

Procedures

The first research question will be answered using evaluative research by performing empirical tests. a) What evidence is there to support the use of an un-tensioned belay line when a worst-case failure occurs during the edge transition of a rope rescue? To perform this test, a 200 kg test mass will be dropped over a sharpened 90-degree edge with an un-tensioned belay. The mainline will consist of 250 cm of rope. Variables will include rope type, rope diameter, drop height, number of canvas plies, and the amount of slack in the belay. This can be measured in length difference of the belay over the length of the mainline.

Mauthner (2014) used a difference of 15 cm slack in the belay and states this to be typical of slack in an un-tensioned tandem Prusik belay. This is one of the more conservative slack values one might use. A review of literature demonstrates a larger degree of slack and range in the slack of taught tandem Prusik belays. Pendley (2006) stated loops of 24” or 60.96 cm. Hudson and Vines (2014) advise a 18”-24” or 45.72-60.96 cm bight of rope. Mirza (2014) suggests loops of 14”-18” or 35.56-45.72 cm. Thorne’s (2008) drop tests used a TPB with a loop of 32 cm. Mathews (2009) fire service text states loops of 12”-14” or 30.48-35.56 cm. Padgette and Smith (1996) advise there should be no more slack on a TPB than 10 cm or 4”. This is the only value less than Mauthner’s tests using the un-tensioned belay. It is not clear if this condition is meant only for raising the belay or paying out as well.

The un-tensioned belays in this study will have tests with both 15 cm and 30 cm belay slack. This will address values on the more conservative end, and it will also address instances where more slack may be present or allowed. Most authors that teach TPB in texts or periodicals average 30-45 cm loops when paying out belay line. This is either in the form of a bight or a z-turn.

The data collected from this test will include: fall factor, fall distance, maximum force at mainline anchor, maximum force at the belay anchor, integrity and condition of mainline, integrity and condition of belay line, condition of the canvas plies, and any other noteworthy observations. Each drop will be video recorded near the edge with a Go Pro Hero 4 HD Camera at a rate of 120 frames per second. Forces will be measured using two CMC Enforcer Load Cells with a sampling rate of 500 samples per second. These instruments will allow the researchers to collect data not seen by the eye alone.

The second research question will be answered using the same test parameters but utilizing a two-tensioned rope system. b) What evidence is there to support the use of a two-tensioned rope system when a worst case failure occurs during the edge transition of a rope rescue?

The third test question will be answered using analysis of literary findings and consensus on current best practices. Additionally, observations and validations from the action research will be used to confirm or add to reasoning for one practice or the other. c) What literary and anecdotal justifications are used to argue the application of either un-tensioned belay lines or two-tensioned rope systems? These justifications will extend beyond the scope of this testing concerning edge failure. They include operations, rope stretch, practice, ease of movement, and other arguments offered by authors. In order to frame this idea in manageable and logical list, justifications and reasons will be categorized into three tiers. Tier one justifications will consist of proven differences or benefits of which there is wide consensus and field validation. Tier one differences will also include benefits that have direct implications on the safety and integrity of the users and system. An example of such a problem with the un-tensioned belay line is the potential elongation of the rope on longer rescues. This is widely agreed upon and near-certain risk. Tier two differences or benefits are those which are known to hamper efficiency or limit potential technique. An example of this might be using a **TTRS** while a rappeler descends using a traveling brake. The **TTRS** clearly is more efficient as dual lowering fixed brakes. The last tier, tier three differences, are those which still remain under scrutiny or anecdotal. These may seem logical, but real world instances are few and far between- if any exist at all. This tier could include the possibility of rock fall to sever both ropes on a **TTRS** as opposed to the slack rope in an un-tensioned belay.

The tier system only speaks to the frequency, seriousness, or persistence of the issue. It is not a method of assigning an absolute value or importance of one facet over another. As with so many things, the application of such arguments is situational and varies in the eyes of the audience. Instead the tier system will be used to categorize the seriousness or frequency of arguments for or against the two systems.

Limitations

Well-laid plans are fine until the first shot is fired. This was the case with this testing. The goal was to accomplish approximately 20 tests. A full 26 tests were accomplished in two days, but several series had problems that preclude them from direct comparison. The difference between scientific and “backyard” testing is largely in the ability to fully control the variables. It was apparent early on that this testing would remain “backyard” in spirit.

In attempting to recreate Mauthner’s (2014) study, the engineering of the edge was perhaps the biggest limitation. Conversations with Mike Forbes spoke to the degree of detail some researchers use to engineer their edges. The edge in this test undoubtedly contained subtle inconsistencies and variations that could adversely affect the results of the test. Time permitting; the edge would have been better to be fashioned in a machine shop with more precise equipment. Instead, it was sharpened by feel and eye with an angle grinder.

This testing was but a snapshot, but it builds on the tests of others. Twenty-six tests are nowhere near a statistically significant sample but rather a glimpse into the component behaviors. As such, too much variability lies with the rope samples. Since the testing was of the system and the edge, it would have been adequate to select one type of rope rather than multiple ropes and sizes. This is a variable that could have been eliminated.

Time and raw materials were a limitation of the research. Materials were spent simply exploring combinations to find a medium where differences between the two systems could be observed. In two days time, the researchers were out of time and raw material. They had, however, learned much and identified combinations and processes that expedited the testing and efficiency. More testing by others should be performed.

Results

Video Footage:

Day 1 Testing Sharpened Level Edge

System	Film Identifier & Notes	Rope Size & Type	Edge	Fall Distance / Rope Length (cm)	Fall Factor	Max Anchor A lbf	Max Anchor B lbf	Results & Observations
TTRS	1D Rigid Test Block Pre-tensioned Lines w/ Fork Lift	PMI 11mm Classic Pro	Sharpened Level Edge 2-Ply Canvas	40 / 250	0.16	700 lbf 3.11 kN	816 lbf 3.62 kN	Cut half thru 1 rope Core shot & 1-2 core bundles of other damaged Through all 2 plies
Un-tensioned Belay	2A Rigid Test Block 200kg	PMI 11mm Classic Pro	Sharpened Level Edge 2-Ply Canvas	40 / 250 265 Belay (belay left line)	0.16	**Belay** 728 lbf 3.24 kN	**Main** 1112 lbf 4.95 kN	Main gave way Belay held for @2 seconds Load crashed
TTRS	1E Rigid Test Block Pre-tensioned Lines w/ Fork Lift	PMI 11mm Classic Pro	Sharpened Level Edge 3-Ply Canvas	40 / 250	0.16	790 lbf 3.91 kN	844 lbf 3.75 kN	One Rope shows sheath damage & 1 core bundle damaged No damage to other rope One rope through 3 plies / other 2
Un-tensioned Belay	2B Rigid Test Block 200kg	PMI 11mm Classic Pro	Sharpened Level Edge 3-Ply Canvas	40 / 250 265 Belay (belay left line)	0.16	**Belay** 1014 lbf 4.51 kN	**Main** 804 lbf 3.58 kN	Main gave way Belay held for @1 second Load crashed Both through all 3 plies
TTRS	3A Rigid Test Block Pre-tensioned Lines w/ Fork Lift	12.5mm PMI Classic Pro	Sharpened Level Edge 3-Ply Canvas	40 / 250	0.16	920 lbf 4.09 kN	906 lbf 4.03 kN	Rope held Some fuzzing Through all plies
Un-tensioned Belay	4A Rigid Test Block 200kg	12.5mm PMI Classic Pro	Sharpened Level Edge 3-Ply Canvas	40 / 250 265 Belay Belay Left Line	0.16	**Belay** 698 lbf 3.10 kN	**Main** 1058 lbf 4.71 kN	Cut half way through main Belay fuzzed, belay through 1 ply main through all 3 plies
TTRS	5B Rigid Test Block Pre-tensioned Lines w/ Fork Lift	11mm Extreme Pro	Sharpened Level Edge 3-Ply Canvas	40 / 250	0.16	960 lbf 4.27 kN	1000 lbf 4.45 kN	Damage to 1/4 of 1 sheath Damage to 1 core bundle Both cut through 3 plies
Un-tensioned Belay	6A Rigid Test Block 200kg	11mm Extreme Pro	Sharpened Level Edge 3-Ply Canvas	40 / 250 265 Belay Belay Left Line	0.16	**Belay** 798 lbf 3.55 kN	**Main** 1114 lbf 4.96 kN	Main Line Severed Belay heavy damage Cut 1/3 of sheath, cut several core bundles, both through 3 plies

Table 1. Day 1 Paired Comparisons

The first research question was: a) what evidence is there to support the use of an un-tensioned belay line when a worst-case failure occurs during the edge transition of a rope rescue? In this quasi-experimental set-up, there is no evidence to support the use of an un-tensioned belay. The use of the un-tensioned belay led to total systems failure and the load crashing to the ground in two or 25% of comparative tests. In three more tests the main line was completely severed, and the belay was left to support the load. The remaining three tests showed heavy damage to the sheath of the mainline and the compromise of some core strands.

Day 2 Testing Sharpened Edge Angled 10° Forward & 10° Right

System	Film Identifier & Notes	Rope Size & Type	Edge	Fall Distance / Rope Length (cm)	Fall Factor	Max Anchor A lbf	Max Anchor B lbf	Results & Observations
TTRS In-Tension	11A Stokes w/ Sandbags Pretensioned Skate Block	CMC 11mm Static Pro	3- Ply /10° Forward & 10° Less than Perp	70 /250 70 / 250	0.28	886 lbf 3.94 kN	836 lbf 3.72 kN	Both ropes held Minor fuzzing Cut through 3 plies on both
Un-tensioned Belay In Tension	12A Stokes w/ Sandbags	CMC 11mm Static Pro	3- Ply /10° Forward & 10° Less than Perp	75 / 250 280 Belay 30cm belay slack	0.3	**Belay** 202 lbf 0.90 kN	**Main** 1314 lbf 5.44 kN	Cut main sheath @ 1/4 Main through 3 plies Belay not through canvas
TTRS In Tension	13 A Stokes w/ Sandbags	11mm Extreme Pro	3- Ply /10° Forward & 10° Less than Perp	72 / 250	0.29	932 lbf 4.15 kN	662 lbf 2.94 kN	No cut in canvas Minor fuzzing of sheaths
Un-tensioned Belay In Tension	14 A Stokes w/ Sandbags	11mm Extreme Pro	3- Ply /10° Forward & 10° Less than Perp	78 / 250 280cm Belay (30 cm slack)	0.31	**Belay** 922 lbf 4.10 kN	**Main** 1420 lbf 6.32 kN	Cut main Minor fuzzing on belay Cut through 3 plies on both
TTRS Vortex AHD In Tension	15A Stokes w/ Sandbags (Noticable Warping)	12.5mm PMI CIASSIC Pro	3- Ply /10° Forward & 10° Less than Perp	119 /250	0.476	934 lbf 4.15 kN	910 lbf 4.05 kN	Ropes held w/ glazing Cut through 3 plies on both
Un-tensioned Belay in AZ Vortex AHD In Tension	16A Stokes w/ Sandbags (Noticable Warping)	12.5mm PMI CIASSIC Pro	3- Ply /10° Forward & 10° Less than Perp	119 / 250 280 Belay (30 cm slack)	0.476	**Belay** 1070 lbf 4.76 kN	**Main** 1518 lbf 6.75 kN	Cut main line Cut belay nearly through Big bounce Cut through 3 plies on both
TTRS Vortex AHD In Tension	19A Rigid Test Block	11mm Extreme Pro	4- Ply /10° Forward & 10° Less than Perp	119 / 250	0.476	1336 lbf 5.94 kN	1438 lbf 6.40 kN	Through all 4 plies on both 1 Rope good condition 1 Rope with sheath cut
Un-tensioned Belay in AZ Vortex AHD In Tension	20A Rigid Test Block	11mm Extreme Pro	4- Ply /10° Forward & 10° Less than Perp	119 / 250 280 Belay (30 cm slack)	0.476	**Belay** 1028 lbf 4.57 kN	**Main** 1518 lbf 6.75 kN	Both Ropes Held (same canvas spot) Main Mantle Nearly Gone Cut 2-core bundles Glazing on belay

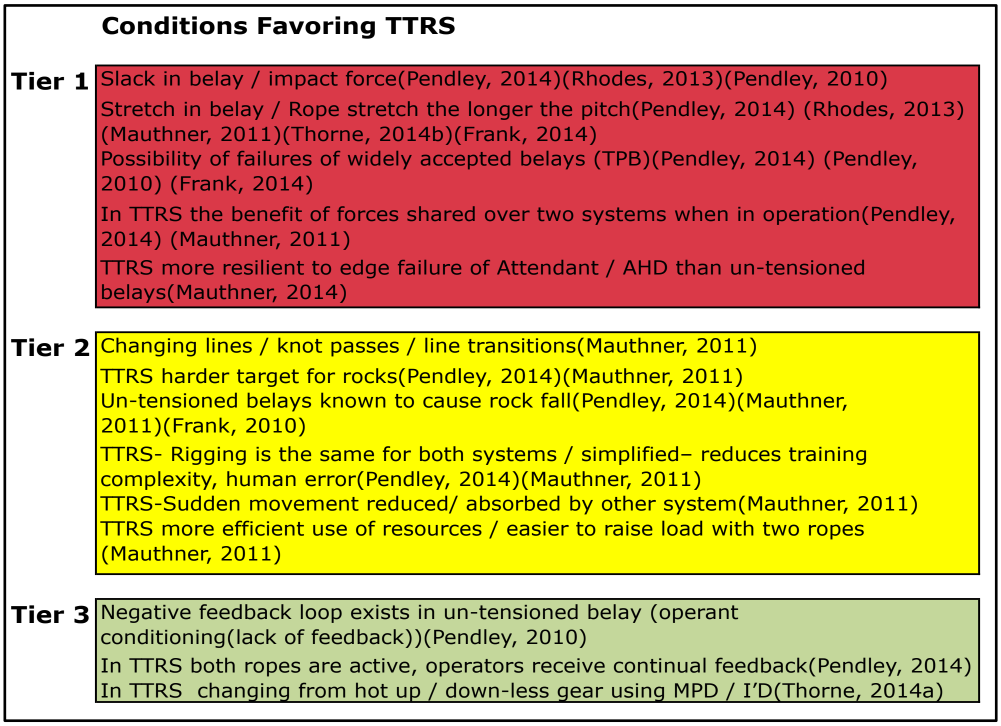
Table 2. Day 2 Paired Comparisons

In ten tests of un-tensioned belays, the main line took an average impact force of 1239.6 lbf or 5.51 kN. This was 25% more force than anchors received when using the same drop parameters on the **TTRS**. Given the increase in impact forces and the extent of damage to system components, the testing does not indicate any significant advantage of using the un-tensioned belay in the conditions administered.

The second research question asked: b) what evidence is there to support the use of a two-tensioned rope system when a worst-case failure occurs during the edge transition of a rope rescue? In attempting to determine a failure threshold that would allow for system comparison, every time the **TTRS** experienced a total failure, so too did the un-tensioned belay system. In ten tests where the **TTRS** rendered usable data and was used to contrast un-tensioned belays, all ropes held and maintained their integrity. In six tests of the ten, the ropes showed only glazing or fuzzing. Four of the ten tests had at least one rope with sheath damage. Core bundles had some damage or compromise in only two of the four ropes with sheath damage.

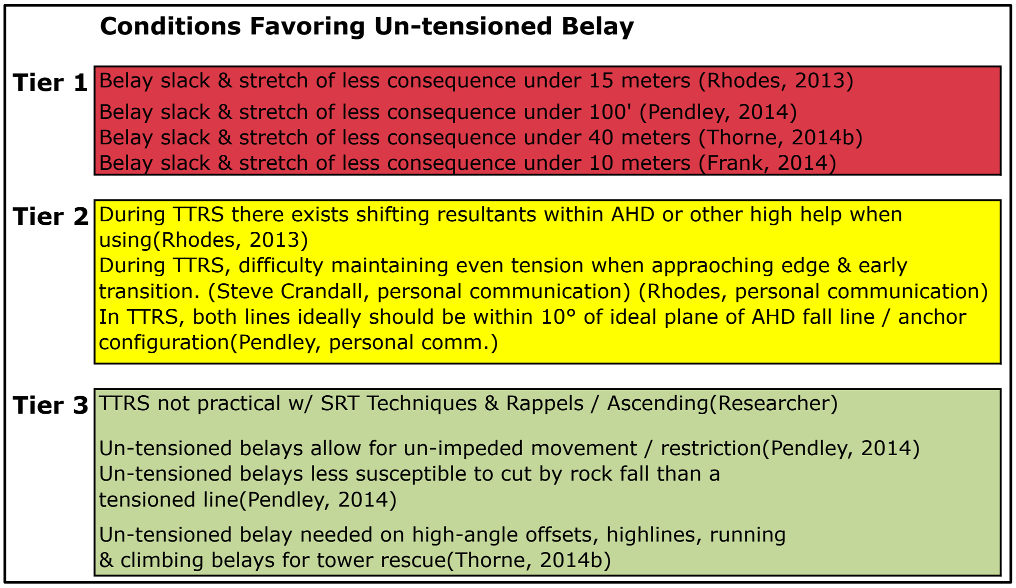
In each like test, shaded in Table 1 and Table 2, the **TTRS** faired better than its un-tensioned belay counterpart. Overall forces on anchors were reduced by 25% when using the **TTRS**. In the tests where the ropes were loose when the drop occurred, forces were down over 19%. In tests where the ropes were in tension, forces were reduced by over 31%. There is compelling evidence favoring the use of **TTRS** over that of an un-tensioned belay in the testing conditions administered.

The third question comes from a review of the literature and input from rope rescue instructors and users: c) what literary and anecdotal justifications are used to argue the application of either un-tensioned belay lines or two-tensioned rope systems? Using the literature review and conversations with subject matter experts, a summary of common justifications for each system is outlined in Table 3 and Table 4. Tier 1 areas shaded in red, illustrate justifications that have serious safety implications. The tier 2 yellow field contains operational concerns, training considerations, or anecdotal reasoning. The tier 3 green fields are ones which do not greatly affect safety and operations.



	Conditions Favoring TTRS
Tier 1	Slack in belay / impact force(Pendley, 2014)(Rhodes, 2013)(Pendley, 2010) Stretch in belay / Rope stretch the longer the pitch(Pendley, 2014) (Rhodes, 2013)(Mauthner, 2011)(Thorne, 2014b)(Frank, 2014) Possibility of failures of widely accepted belays (TPB)(Pendley, 2014) (Pendley, 2010) (Frank, 2014) In TTRS the benefit of forces shared over two systems when in operation(Pendley, 2014) (Mauthner, 2011) TTRS more resilient to edge failure of Attendant / AHD than un-tensioned belays(Mauthner, 2014)
Tier 2	Changing lines / knot passes / line transitions(Mauthner, 2011) TTRS harder target for rocks(Pendley, 2014)(Mauthner, 2011) Un-tensioned belays known to cause rock fall(Pendley, 2014)(Mauthner, 2011)(Frank, 2010) TTRS- Rigging is the same for both systems / simplified– reduces training complexity, human error(Pendley, 2014)(Mauthner, 2011) TTRS-Sudden movement reduced/ absorbed by other system(Mauthner, 2011) TTRS more efficient use of resources / easier to raise load with two ropes (Mauthner, 2011)
Tier 3	Negative feedback loop exists in un-tensioned belay (operant conditioning(lack of feedback))(Pendley, 2010) In TTRS both ropes are active, operators receive continual feedback(Pendley, 2014) In TTRS changing from hot up / down-less gear using MPD / I'D(Thorne, 2014a)

Table 3: Justifications of TTRS



	Conditions Favoring Un-tensioned Belay
Tier 1	Belay slack & stretch of less consequence under 15 meters (Rhodes, 2013) Belay slack & stretch of less consequence under 100' (Pendley, 2014) Belay slack & stretch of less consequence under 40 meters (Thorne, 2014b) Belay slack & stretch of less consequence under 10 meters (Frank, 2014)
Tier 2	During TTRS there exists shifting resultants within AHD or other high help when using(Rhodes, 2013) During TTRS, difficulty maintaining even tension when appraoching edge & early transition. (Steve Crandall, personal communication) (Rhodes, personal communication) In TTRS, both lines ideally should be within 10° of ideal plane of AHD fall line / anchor configuration(Pendley, personal comm.)
Tier 3	TTRS not practical w/ SRT Techniques & Rappels / Ascending(Researcher) Un-tensioned belays allow for un-impeded movement / restriction(Pendley, 2014) Un-tensioned belays less susceptible to cut by rock fall than a tensioned line(Pendley, 2014) Un-tensioned belay needed on high-angle offsets, highlines, running & climbing belays for tower rescue(Thorne, 2014b)

Table 4: Justifications of Un-tensioned Belay Systems

Discussion and Recommendations

A colleague made a clear and succinct point on this topic: the best case for an un-tensioned belay is to be neither slack nor tensioned. The worst case for a **TTRS** is the best case for the un-tensioned belay. The **TTRS** does not solve all problems in rescue, but proves to be an increasingly valuable tool. There are certainly reasons not to use **TTRS** in every situation. There are applications where these systems are not the solution. Single rope technique, tensioned rope systems, highlines, and other instances may preclude their use.

What seemed safe and a good idea in the 80s, may seem crazy today. The TPB of the 90s is an "endangered" technique. Best practices continually evolve. Today's techniques will be archaic to future generations. The myth that greater safety lies in the belay being un-tensioned is nearly busted. This un-tensioned belay that is rooted in rock climbing and was born to rescue four decades ago seems more and more undesirable. It should not be a surprise because recreational rock climbing and professional rescue have vastly different loads, rope, equipment, anchors, and objectives. In rescue settings where two rope systems are required, especially at heights over 15 meters, the **TTRS** should be considered.

The emerging weakness in these systems and techniques rests in the human element. The ability for the rescuers to react to the I'D and the MPD in a line failure is critical. All operators will not catch every load all the time. Techniques must be refined through training. And when AHDs are deployed, they must be bombproof. A failure in the AHD adjunct or guying becomes even more catastrophic.

*McCullar, J. R. (2015). *An analysis of traditional un-tensioned belays and two-tensioned rope systems in rope rescue.* Emmitsburg, MD: National Fire Academy