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The heat is on: Killing blacklegged ticks in residential washers and dryers to prevent tickborne diseases

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ABSTRACT

Reducing exposure to ticks can help prevent Lyme disease and other tickborne diseases. Although it is currently recommended to dry clothes on high heat for one hour to kill ticks on clothing after spending time outdoors, this recommendation is based on a single published study of tick survival under various washing conditions and a predetermined one-hour drying time. We conducted a series of tests to investigate the effects of temperature, humidity, and drying time on killing nymphal and adult blacklegged ticks (*Ixodes scapularis*). Muslin bags containing 5 ticks each were washed then dried or dried only with six cotton towels during each drying cycle. All nymphal and adult ticks were killed when exposed to wash cycles when the water temperature reached ≥54 °C (≥130 °F); however, 50% of ticks survived hot water washes when the water temperature was <54 °C. The majority (94%) of ticks survived warm washes [temperature range, 27–46 °C (80–115 °F)] and all ticks survived cold washes [15–27 °C (59–80 °F)]. When subsequently dried on high heat setting [54–85 °C (129–185 °F)], it took 50 min to kill all ticks (95% confidence limit, 55 min). Most significantly, we found that all adult and nymphal ticks died when placed directly in the dryer with dry towels and dried for 4 min on high heat (95% confidence limit, 6 min). We have identified effective, easily implemented methods to rid clothing of ticks after spending time outdoors. Placing clothing directly in a dryer and drying for a minimum of 6 min on high heat will effectively kill ticks on clothing. If clothing is soiled and requires washing first, our results indicate clothing should be washed with water temperature ≥54 °C (≥130 °F) to kill ticks. When practiced with other tick-bite prevention methods, these techniques could further reduce the risk of acquiring tickborne diseases.

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1. Introduction

Blacklegged ticks (*Ixodes scapularis*) are known to transmit the pathogens that cause Lyme disease, anaplasmosis, babesiosis, Powassan virus disease, and *Borrelia miyamotoi* disease (Clark and Hu, 2008; Shah and Sood, 2013). In the United States, an estimated 300,000 persons are diagnosed with Lyme disease and nearly 3,000 cases of anaplasmosis are reported each year (Adams et al., 2015; Hinckley et al., 2014; Nelson et al., 2015). Infections transmitted by blacklegged ticks have caused substantial morbidity and even death (Centers for Disease Control and Prevention, 2013; Rothermel et al., 2001; Vannier and Krause, 2012). Therefore, tick bites and the pathogens transmitted by them represent a major public health concern.

A variety of personal protection measures can be used to prevent tick bites when spending time outdoors, including conducting daily tick checks, using repellents on clothing and skin, and showering within two hours after coming indoors (Connally et al., 2009; Hayes and Piesman, 2003; Vazquez et al., 2008). Additional measures such as avoiding tick-infested habitat, wearing long pants and long-sleeved shirts, and tucking pants into socks have also been recommended (Clark and Hu, 2008; Hayes and Piesman, 2003). Unfortunately, these personal tick bite prevention measures are inconsistently practiced by individuals due to safety concerns, time constraints, and other factors (Gould et al., 2008; Herrington, 2004; Mowbray et al., 2014; Valente et al., 2014; Butler et al., 2016). Fur-

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thermore, the steadily increasing incidence of tickborne diseases (TBDs) and lack of vaccines for TBDs in the United States highlight the need for additional effective, easily implemented techniques to prevent tick bites (Mead et al., 2015).

I. scapularis ticks quest openly in leaf litter or from emergent vegetation (Schulze et al., 2011); therefore, any human activity involving close proximity to tick habitat can lead to acquisition of ticks on skin or clothing. In one Maryland study, an investigator simulated outdoor activities such as gardening or clearing brush by crawling through leaf litter for 30-s time periods. *I. scapularis* nymphs were acquired in 58% of crawls, and the majority of ticks were found on pant legs and socks (Carroll and Kramer, 2001). In another study, investigators who walked a series of 100 m transects through a wooded area in New Jersey found an average of nine *I. scapularis* adults on their clothing afterward (Jordan et al., 2012). Ticks that remain on clothing can be carried indoors and potentially bite, underscoring the need to rid clothing of ticks after coming indoors.

The Centers for Disease Control and Prevention currently recommends drying clothes on high heat for one hour after spending time outdoors in order to kill ticks on clothing. This recommendation is based on a single study which investigated survival of *I. scapularis* nymphs under various washing conditions, followed by a predetermined one-hour drying time (Carroll, 2003). There are no published data, however, on adult ticks or the effects of shorter drying times on tick survival. The objective of this study was to determine optimal wash and dry times and conditions necessary to effectively kill ticks on clothing.

2. Materials & methods

Testing was performed using laboratory-reared, uninfected, unfed *I. scapularis* nymphs, adult males, and adult females obtained from the Oklahoma State University Tick Rearing Facility. The ticks were maintained under optimal conditions prior to testing and were 30–60 days post-molt, during which they are in their prime and also most likely to bite humans. Although they do not pose a risk to humans, adult male ticks were used in this study since adults were only available for purchase as a 1:1 sex ratio. Survival of adult ticks was subsequently analyzed by sex in order to determine whether survival in the dryer differed by sex.

Three different standard-sized, residential washers and dryers in Vermont, Maine, and Massachusetts were used for testing [washers: Kenmore model 110.26832691 (Sears, Hoffman Estates, IL), General Electric model PTWN6050MWT (General Electric, Fairfield, CT), and Fisher & Paykel model IWL16 (Fisher & Paykel, Auckland, NZ); dryers: Admiral model AED4675YQ1 (Whirlpool, Benton Harbor, MI), General Electric model DPSE810EGWT, and Maytag model MDE5500AYW (Whirlpool, Benton Harbor, MI)].

Muslin cloth bags were constructed to contain the ticks during washing and drying. During testing, five ticks were placed into each bag and the opening was secured with a plastic clip and rubber band (Fig. 1). For the majority of trials, five bags of five ticks each were placed in each wash/dry cycle together. In some cases (e.g., when testing detergent and dryer sheets), a smaller number of bags were washed and/or dried together.

Following each wash and dry cycle, tick survival was assessed by observing the ticks for normal behavior and movement. If ticks appeared to be moribund and movement was not readily apparent, ticks were lightly probed with forceps, exposed to carbon dioxide through exhalation, and observed for several additional minutes. To verify that motionless ticks were in fact dead and not simply stunned, ticks were then placed in petri dishes with a piece of wet paper towel and reassessed 20–24 h later.

Water temperature was measured during washing at the beginning of each wash and rinse cycle using the Cooper-Atkins SRH77A Thermo-Hygrometer. Temperature and humidity were also measured inside the dryers before removing the ticks at each predetermined drying time (Fig. 1).

During each round of testing, 10–20 ticks (50 total) were also secured in petri dishes with a piece of moist paper towel to serve as controls. The ticks remained at room temperature in the laundry area and were assessed for survival 20–24 h later. A total of 50 nymphs and adults combined were also dried on fluff cycles (i.e. no heat) for 60 min to ascertain whether agitation alone without heat affected tick survival.

2.1. Washer and dryer trials

A total of 650 ticks (355 nymphs and 295 adults; 55% of adults were female) were washed with cotton towels at hot, warm, or cold temperature settings. All bags were removed to assess tick viability after completion of the wash cycle. Live ticks were then secured in the bags and transferred to the dryer along with six wet towels.

Drying cycles were run on low or high heat for 20–70 min. During initial trials, ticks were removed from the dryer at predetermined time points and assessed for survival immediately after removal from the dryer, then stored as described previously and reassessed 20–24 h later. This allowed us to establish survival proportions over time in the dryer and determine that ticks initially appearing active versus motionless remained alive or dead, respectively, after 20–24 h. During subsequent stages of testing, we focused on determining the amount of time necessary to kill all ticks in the dryer; therefore, if a bag was removed from the dryer and noted to contain live ticks, the bag was dried for additional time until all ticks were dead.

2.2. Dryer only trials

To test survival of ticks on clothing that has not been previously washed, we also conducted trials by placing muslin bags containing ticks directly in the dryer along with six dry towels. A total of 275 ticks (145 nymphs and 130 adults; 54% of adults were female) were dried at either low heat or high heat for 1–7 min (time range was selected based on results of pilot studies). Ticks were assessed for survival immediately after the dry cycles then stored and reassessed 20–24 h later. During later stages of testing, if a bag was removed from the dryer and noted to contain live ticks, the bag was dried for additional time until all ticks were dead.

2.3. Additional variables

Additional trials were conducted to determine the effect of laundry detergent and dryer sheets on tick survival during washing and drying. A total of 30 nymphal and 15 adult ticks were washed with Tide Original liquid laundry detergent (Procter & Gamble, Cincinnati, OH) and dried according to the protocol described above. In addition, 50 nymphal and 40 adult ticks were washed then dried or dried alone with Bounce dryer sheets (Procter & Gamble, Cincinnati, OH).

Ticks were also washed and dried with thin or thick clothing to assess the impact of clothing type on tick survival in the dryer. A total of 40 nymphs and 40 adults were washed then dried or dried alone with thin clothing consisting of polyester, rayon, and nylon fabric. An additional 40 nymphs and 40 adults were washed then dried or dried alone with thick clothing consisting of bulky fleece coats.

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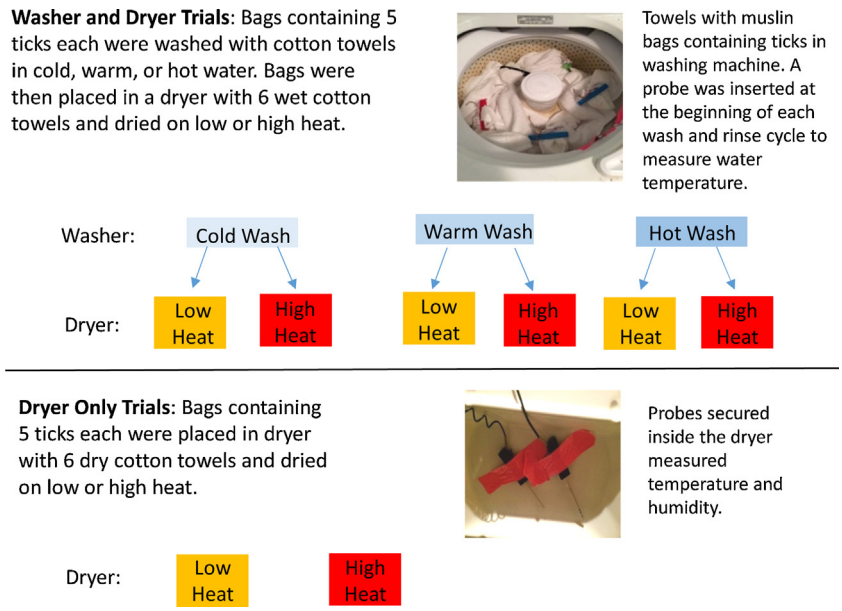

Fig. 1. Description of study methods.

2.4. Statistical analysis

Data were modeled as censored survival times and assumed to follow a Weibull distribution with frailty terms for washer/dryer machine and for ticks within a single bag. For ticks that were washed prior to drying, only ticks that survived the wash stage were included in this analysis. Shape and scale parameters of the Weibull were defined as functions of wash and dry conditions. Standard diagnostics were performed to ensure that model assumptions were met.

Since a survival analysis will only give estimates of survival strictly between 0 and 1, we could not estimate the (finite) time it would take for tick survival to reach 0. Instead, we estimated the amount of time it would take for the probability of survival to reach 0.005 (0.5%); for the presentation of results, we defined the time it would take for the probability of survival to reach 0.005 as the time "all ticks are dead." Variances for the confidence bounds for time were computed by applying the delta method to variance estimates of the model parameters. All statistical analyses were performed using SAS v9.3 and R v3.2.2

Table 1
Estimated time to kill all *I. scapularis* ticks under various washing and drying conditions. The last column shows the 95% upper bound on the time at which the model estimated a tick has only a 0.5% chance of survival.

Wash	Drying temperature	Tick life stage	Time to kill all ticks in trials (minutes)	Estimated 95% upper bound on time to kill all ticks (minutes)
Yes	Low	Nymph	70	85
Yes	Low	Adult	70	96
Yes	High	Nymph	50	45[a]
Yes	High	Adult	41	55
No	Low	Nymph	6	10
No	Low	Adult	7	11
No	High	Nymph	4	6
No	High	Adult	4	6

[a] For nymphs that were washed then dried on high heat, the reported time to kill all nymphs during trials (50 min) was actually higher than the 95% upper bound on time to kill all nymphs (45 min). The reason for this is the vast majority of nymphs did not survive past 30 min drying time. Only one tick was observed to survive at 40 min and subsequently died before the bag was rechecked at 50 min.

3. Results

All control ticks survived when secured in containers in the laundry room for 20–24 h. Forty-nine of the 50 ticks (98%) dried on the fluff cycle survived, demonstrating that agitation in the dryer alone does not typically kill ticks.

3.1. Washer and dryer trials

All nymphal and adult ticks survived washing with cold water [temperature range, 15–27 °C (59–80 °F)]. The majority (212/225, 94%) of nymphal and adult ticks survived washing with warm water [temperature range, 27–46 °C (80–115 °F)]. The 13 nymphal ticks that died were washed in warm wash cycles that reached 43 °C (110 °F). Washing with hot water killed all nymphal and adult ticks when the water temperature was ≥54 °C (130 °F). However, 50% of nymphal and adults ticks (35/70) survived the hot wash cycles when water temperature was <54 °C [temperature range, 41–48 °C (105–118 °F)]. Among ticks that survived the wash cycles, the water temperature used during wash cycles did not significantly affect subsequent rate of death in the dryer ($p = 0.08$).

When subsequently placed in the dryer it took 70 min to kill all nymphs and adults on low heat (Fig. 2). The statistical model estimated that for drying on low heat setting, the 95% upper bounds on time to kill ticks after washing were 85 min for nymphs and 96 min for adults (Table 1). For the high heat setting, it took 50 min drying time to kill all nymphs and adults in our trials. The model estimated that the 95% upper bounds on time to kill ticks after washing were 45 min for nymphs and 55 min for adults on high heat.[1] Temperature inside the dryer ranged from 44 to 76 °C (112–168 °F) during low heat cycles and from 54 to 85 °C (129–185 °F) during high heat cycles.

[1] For nymphs that were washed then dried on high heat, the reported time to kill all nymphs during trials (50 min) was actually higher than the 95% upper bound on time to kill all nymphs (45 min). The reason for this is the vast majority of nymphs did not survive past 30 min drying time. Only one tick was observed to survive at 40 min and subsequently died before the bag was rechecked at 50 min.

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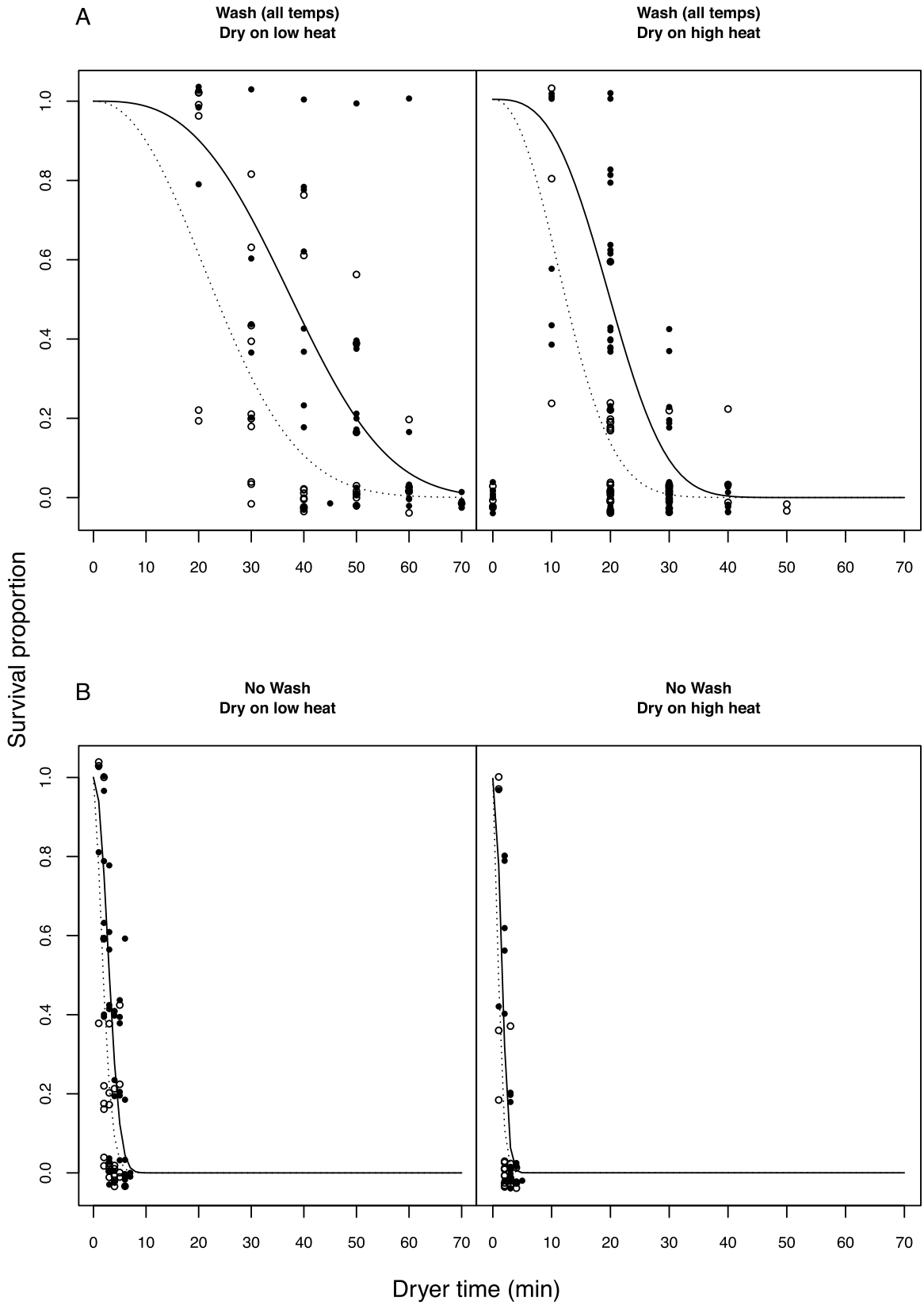

Fig. 2. Survival proportion of *I. scapularis* ticks over time during drying cycles when (A) clothes were washed first then placed in dryer; and (B) clothes were placed directly in the dryer without washing first. Each point represents the proportion of ticks alive out of five total in each bag assessed at that time period. Adult ticks survived significantly longer than nymphs under all conditions ($P < 0.001$). Grouped graph points were separated vertically for ease of viewing. (—•— – Adult; ·····o····· – Nymph).

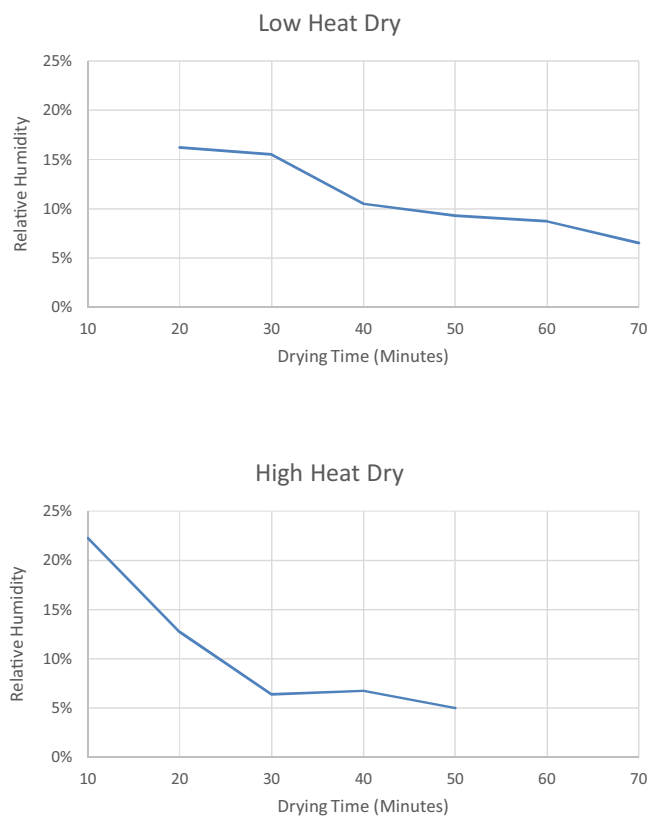

Fig. 3. Average relative humidity in dryer over time when drying wet clothes on low heat (top graph) and high heat (bottom graph). All ticks died by 70 min drying time on low heat (average relative humidity = 6.5%) and 50 min drying time on high heat (average relative humidity = 5.0%).

Average relative humidity was 16.3% and 12.7% after drying for 20 min on low and high heat, respectively, then steadily decreased during the remainder of the drying cycle. After 70 min drying time on low heat the average relative humidity had dropped to 6.5% and all ticks had died. During high heat drying cycles, the average relative humidity dipped to 5.0% after 50 min drying time at which point all ticks had died (Fig. 3).

3.2. Dryer only trials

All ticks were killed when dried with dry towels on low heat for 6 min (nymphs) and 7 min (adults) (Fig. 2). The statistical model estimated that the 95% upper bounds on these estimates are 10 min for nymphs and 11 min for adults. For the high heat setting, all nymphal and adult ticks were killed when dried with dry towels for 4 min in our trials. The statistical model estimated that the 95% upper bound on these estimates is 6 min for both nymphs and adults (Table 1). Temperature inside the dryer ranged from 43 to 76 °C (110–168 °F) during low heat cycles and from 53 to 86 °C (127–187 °F) during high heat cycles.

3.3. Additional variables

Adult ticks survived on average longer than nymphs under testing conditions ($p < 0.001$). Use of detergent or dryer sheets did not significantly alter tick survival in the dryer ($p = 0.43$ and $p = 0.54$, respectively). Moreover, clothing thickness also did not significantly alter tick survival in the dryer ($p = 0.80$). There was no significant difference in survival between male and female adult ticks ($p = 0.21$).

4. Discussion

Through this study we have identified an effective, easy method to kill blacklegged ticks that may remain on clothing following outdoor activity, potentially reducing the risk of tickborne diseases. Placing clothing directly in a dryer and running for 6 min on high heat will kill all ticks. This is substantially less time than the current recommendation of 60 min drying time and therefore will be much easier to implement. Although this finding challenges the status quo, it is not unexpected given that *I. scapularis* ticks have been shown to be extremely sensitive to desiccation (Eisen et al., 2016; Needham and Teel, 1991).

It is worth noting that the recommendation to dry clothing on high heat for 6 min after coming indoors should be practiced only when the clothing is completely dry. If clothing is damp with precipitation or perspiration, longer drying times may be necessary.

If clothing is heavily soiled and requires washing first, if possible it should be washed with water temperature ≥54 °C (130 °F) to kill blacklegged ticks. This is consistent with findings from two previous studies of wash temperatures necessary to kill *Ixodes* spp. ticks (Carroll 2003; Jennett and Wall, 2012), although Carroll found that only 76% of *I. scapularis* nymphs were dead or moribund after a hot wash cycle with average inflow water temperature of 51 °C (124 °F). If washing with water temperature ≥54 °C is not feasible, substantially longer drying times will be necessary to kill ticks if clothing is wet from being washed. In this case clothing should then be dried for 55 min on high heat to ensure residual blacklegged ticks are killed.

We found that water temperature during washing varied considerably by location of testing. This could be due to washer model or variations in the set point of the water heater at residences where testing took place. The American Academy of Pediatrics recommends that water heaters be set no higher than 49–54 °C (120–130 °F) to prevent burns in children (Lukefahr and Ezekiel, 1994). Persons living in households that include small children should continue to follow this recommendation.

This study was subject to several limitations. The muslin bags which contained the test ticks may have protected the ticks somewhat from heat and dryness, particularly for ticks that crawled into folded material adjacent to the plastic clips. In addition, stopping and restarting the dryer at pre-determined time points likely released heat and decreased the temperature inside the dryer. Therefore, the drying times we found necessary to kill ticks are likely conservative and could be even shorter. Also, only top-loading washing machines were used in this study; survival of ticks in front-loading washing machines may differ since clothing is not typically immersed in water during washing with these types of machines. However, one study that used a front-loading washing machine found that all adult *Ixodes ricinus* ticks perished during a 60 °C (140 °F) hot wash cycle (Jennett and Wall, 2012).

We used only laboratory-reared *I. scapularis* ticks for this study; however, survival of ticks from the field and for other species of ticks may vary. For example, *Amblyomma americanum* ticks (also known as lone star ticks) are more resistant to low humidity and would potentially survive longer in dryers (Schulze and Jordan, 2003). Notably, Carroll found that lone star ticks had greater survival rates during hot wash cycles than blacklegged ticks (Carroll, 2003). Additional research using field-collected *I. scapularis* and *A. americanum* ticks will further our understanding of tick survival under various washing and drying conditions.

In conclusion, we have identified an effective, easily implemented means to rid clothing of ticks after spending time outdoors. When practiced with other tick bite prevention methods such as daily tick checks and repellent use, drying clothes on high heat for

6 min after coming indoors will likely further reduce the risk of acquiring tickborne diseases.

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