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ARTICLE

An Effective Nonchemical Treatment for Head Lice: A Lot of Hot Air

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ABSTRACT

OBJECTIVES. Head lice (*Pediculus humanus capitis*) are a major irritant to children and their parents around the world. Each year millions of children are infested with head lice, a condition known as pediculosis, which is responsible for tens of millions of lost school days. Head lice have evolved resistance to many of the currently used pediculicides; therefore, an effective new treatment for head lice is needed. In this study we examined the effectiveness of several methods that use hot air to kill head lice and their eggs.

METHODS. We tested 6 different treatment methods on a total of 169 infested individuals. Each method delivers hot air to the scalp in a different way. We evaluated how well these methods kill lice and their eggs in situ. We also performed follow-up inspections to evaluate whether the sixth, most successful, method can cure head louse infestations.

RESULTS. All 6 methods resulted in high egg mortality (≥88%), but they showed more-variable success in killing hatched lice. The most successful method, which used a custom-built machine called the LouseBuster, resulted in nearly 100% mortality of eggs and 80% mortality of hatched lice. The LouseBuster was effective in killing lice and their eggs when operated at a comfortable temperature, slightly cooler than a standard blow-dryer. Virtually all subjects were cured of head lice when examined 1 week after treatment with the LouseBuster. There were no adverse effects of treatment.

CONCLUSIONS. Our findings demonstrate that one 30-minute application of hot air has the potential to eradicate head lice infestations. In summary, hot air is an effective, safe treatment and one to which lice are unlikely to evolve resistance.

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Key Words
Pediculus humanus capitis, control, heat, desiccation, pediculosis, LouseBuster, nits

Abbreviation
CI— confidence interval

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HEAD LICE (*Pediculus humanus capitis*) have been a ubiquitous problem throughout recorded human history.[1–4] They are a major irritant to children and their parents around the world.[5–7] Millions of cases of head lice (pediculosis) occur annually, including 6 to 12 million cases per year in the United States alone.[8,9] It is estimated that children in the United States missed 12 to 24 million days of school in 1998 because of head lice.[5] The number of cases of head lice is increasing, because lice are evolving resistance to pediculicides.[3,6,10–13] Although head lice do not produce an illness per se, they are physically and psychologically unpleasant for the child and an exasperating problem for parents and school authorities.

The 3 general approaches currently in use for treating head lice infestations are chemical shampoos, specialized louse combs, and "home remedies." Each approach has significant limitations. Chemical shampoos such as those containing pyrethroids or lindane are the most popular methods of treatment in the United States, with sales exceeding $160 million per year.[11] However, in addition to the evolution of a resistance problem, chemical shampoos are not very effective at killing louse eggs.[6,9] An additional treatment with shampoo is necessary 1 week after the first treatment to kill lice from newly hatched eggs. Moreover, many parents prefer not to treat their children with chemicals for fear of the adverse effects that have been reported for some of these insecticides, particularly lindane.[6,14] None of the available pediculicides are considered safe for people who have asthma, a common childhood disease.[15]

Another common method of treatment is the use of a louse comb. There are many varieties, usually involving thin metal or plastic tines that are designed to comb through the hair and pull out lice and their eggs. However, effective combing requires many hours over several days, and most parents do not have the time or patience to comb out all the lice and eggs.[6]

The third group of treatments is home remedies, which parents often feel forced to use because shampoos fail to work and they do not take the time to use a louse comb effectively. Parents use an assortment of "treatments" ranging from bug spray to mayonnaise to kerosene.[16] These remedies can harm the child, and there is little hard evidence to indicate that they are effective. In short, an effective new approach for treating head lice is sorely needed.[17]

An ideal new treatment would be quick, safe, and effective at killing both lice and eggs. It should also be something to which lice cannot easily evolve resistance. Hot air is a promising solution that meets all of these criteria. Nearly 60 years ago, Buxton[1] pointed out that body lice, *Pediculus humanus corporis*, which are closely related to head lice, die when exposed to 51°C air for 5 minutes. More recently, Kobayashi et al[18] reported that body lice can be killed in vitro with air from a blow-dryer at 50°C for 5 minutes, and that body louse eggs fail to hatch in vitro after exposure to hot air at 55°C for 90 seconds. Hot air probably kills the lice and eggs by desiccating them. The high surface/volume ratio of small arthropods, such as lice, makes them vulnerable to control by desiccation, as has also been shown for lice on birds.[19]

Although heat has the potential to kill both head lice and their eggs, we know of no studies that have tested the effectiveness of hot air on individuals infested with head lice. We experimented with this approach as a treatment for lice infestations on local schoolchildren using several forms of heat delivery. In this article we demonstrate that exposure to a large volume of hot air can result in 98% mortality of eggs and 80% mortality of hatched lice. We further show that this method is sufficient to eliminate viable head louse infestations from virtually all subjects, as determined by follow-up examinations 1 week after treatment. We suggest that heat is a preferred method for treating head lice because it is effective, safe, and requires only a single 30-minute treatment. Furthermore, it is unlikely that lice will evolve resistance to heat, because this would require fundamental changes in their water physiology.

METHODS

Study Design

Effect of Hot Air on Lice and Eggs

We tested 6 methods for delivering hot air to the scalps of infested individuals. With full University of Utah institutional review board approval, we solicited infested subjects from local elementary schools to enroll in our study. Before enrollment, the parents or guardians of these subjects were interviewed by telephone and asked nonleading questions about treatment history. To avoid residual effects from other treatments, we excluded subjects who had used pediculicidal shampoos or home remedies within the previous 2 weeks.[20,21] We also excluded children younger than 6 years of age, because we felt it would be difficult to get them to sit still long enough for us to collect the necessary data. Note, however, that there is no reason why hot air cannot be used to treat head lice in children of any age. Parents and siblings of enrolled subjects were invited to participate in the study if they also had head lice. Treatment trials, which required ~1 hour, were conducted in the homes of infested subjects, providing a more secure and anonymous environment.

Informed consent procedures were followed, and all subjects regardless of age were asked to review and sign consent forms in English or Spanish (as appropriate). Forms tailored to children were easy to understand, and their parents reviewed and signed more-detailed consent forms. Each participant received a small honorarium (usually $10), free educational materials, a free Lice-

Meister comb (National Pediculosis Association, Needham, MA), and a free bottle of Nix shampoo (Insight Pharmaceuticals, Blue Bell, PA). They received detailed instructions on how to use these products effectively to eliminate lice not killed by our experimental treatment. Subjects and their parents were not informed of the honorarium or free materials they would receive until after completion of the treatment trial.

At the start of each trial, we carefully combed the subject's hair with a LiceMeister comb (National Pediculosis Association, Needham, MA) until we confirmed the infestation by detecting 1 or more living, moving lice.[20] Next, we thoroughly combed one side of the scalp (chosen at random) while removing all lice and eggs encountered and placing them in a portable incubator at 33°C. We continued combing, keeping track of time, until no additional lice or eggs were removed from that side of the scalp. Next we treated the subject's entire scalp with 1 of 6 methods (see below). After treatment, we combed the other side of the scalp for the same amount of time as the first side, again placing all lice and eggs in the portable incubator. Hence, each subject served as his or her own control. Although the time spent combing each side of the scalp was equal, we did not necessarily get the same number of lice or eggs from the 2 sides. There was no consistent removal pattern; sometimes we got more lice and/or eggs from the first side of the scalp, other times we got more from the second side (see "Results"). Participants in our study had infestations varying in size from a few lice to hundreds of lice.

Lice and eggs collected from each side of the scalp were brought back to the laboratory within 3 hours of removal. The number of live versus dead lice from each side of the scalp was scored by carefully examining them under a dissecting microscope. Dead lice were reexamined for periods of up to 18 hours to check for the resurrection effect, in which lice "killed" with pediculicides are not really dead.[6] This was never a problem; all of our dead lice remained that way. Eggs were placed in a custom, stainless-steel lined Percival incubator set at 33°C and 75% relative humidity, and their hatching success was monitored daily for 2 weeks.[7] Effectiveness of the different treatment methods was assessed by comparing the percentage of dead lice and nonhatching eggs on the pretreatment and posttreatment sides of the scalp.

Before the start of treatment, each subject was instructed to give a "thumbs-down" sign to indicate any discomfort from the hot air. When this occurred, we immediately reduced the volume of air as described below for each method. Subjects were allowed to ask that we stop the treatment at any time. In summary, we took a conservative approach to comfort (see "Results"). We interviewed study participants and their parents at varying intervals after treatment (up to several months later) and no short- or long-term adverse effects of treatment were ever noted.

Follow-up Examinations

We used the most effective method, the LouseBuster with hand piece (see below), to test whether hot air can completely cure head louse infestations. Subjects with a high probability of reinfestation, such as those with other infested family members or classmates, were excluded from these follow-up trials. We did follow-up examinations on 11 subjects with infestations ranging from several lice to >100 lice. The protocol was to (1) verify the infestation by directly observing living, moving lice in the scalp, (2) treat the entire scalp, and (3) return 1 week after treatment to reexamine the subject for head lice. Subjects and their parents were instructed not to use any head lice treatments for 1 week after our treatment. As an incentive, they were offered double the normal honorarium for participating in the follow-up examination on the condition that they refrained from using any form of treatment for that 1 week.

The follow-up examination was conducted by sampling the scalp with 20 careful swipes of the LiceMeister comb. The 20-swipe criterion was determined by using a repeat-sampling approach[22] on an independent group of 21 subjects reported to have head lice. For 10 subjects with moderate infestations (≥6 lice), a mean of 2 swipes (range: 1–4) was required to detect the first live louse. For 6 subjects with light infestations (<6 lice), a mean of 14 swipes (range: 8–18) was required to detect the first live louse. The remaining 5 subjects did not, in fact, have active head louse infestations; no lice were found even after 250 swipes.

Treatment Methods

We tested the following 6 methods for heating the scalps of infested individuals.

Bonnet-Style Hair Dryer

We combined the airflow from 2 standard bonnet-style hair dryers (Belson, Miami, FL) by attaching the hose from each machine to a single plastic bonnet that enclosed the hair with an elastic band around its perimeter. One hose was attached to the bonnet near the crown of the head, and the other hose was attached near the nape of the neck. The entire scalp was treated simultaneously for a period of 30 minutes.

Handheld Blow-dryer: Diffuse Heating

The subject's hair was divided into 10 sections, each consisting of a large tuft of hair held away from the scalp with a hair clip. Each section was heated with a standard handheld blow-dryer (Conair, Stamford, CT) by removing the clip and then gradually moving the nozzle of the dryer around the base of the section, where lice and eggs tend to congregate. Each section was heated for 3 minutes while moving the dryer to ensure uniform heating of the entire base of the section. Treating all 10 sections required ~35 minutes, including the time necessary to move between sections.

Handheld Blow-dryer: Directed Heating

The diffuse-heating method with the handheld blow-dryer was repeated with the following modifications: we divided the hair into 20 sections and treated each section for 60 seconds, holding the dryer in a stationary position for 30 seconds on one side of the section and then 30 seconds on the opposite side of the section. To heat all 20 sections in this manner required a total of 30 minutes, including the time necessary to move between sections.

Wall-Mounted Dryer

We used a detached wall-mounted blow-dryer (Excel Dryer Inc, East Longmeadow, MA) similar to those found in public restrooms for drying hands and hair. This device delivered far more than twice the volume of air as that delivered by the handheld blow-dryer (Table 1). We attached a 15-cm aluminum hose to the nozzle of the dryer. The dryer was placed on a table, and the hose was used to treat the hair in sections as described for the directed-heating method with a handheld blow-dryer.

LouseBuster With Sections

For this method we developed a custom-built, high-volume, hot-air blower called the LouseBuster (Fig 1; Dexterity Design, Salt Lake City, UT). The LouseBuster delivers hot air at a relatively constant temperature (modulated by an electronic feedback loop) and volume through a long flexible hose that can be aimed at the subject's scalp. During trials we set it to a temperature slightly less than that of the handheld blow-dryer (Table 1). Like the wall-mounted dryer, the LouseBuster delivers more than twice the air volume of a handheld blow-dryer. We divided the hair into 14 to 20 sections depending on the amount of hair. We heated each section for 60 seconds, as described for the directed-heating method with a handheld blow-dryer. To heat all sections in this manner required ~30 minutes.

LouseBuster With Hand Piece

We again used the LouseBuster, together with a custom-designed hand piece, to facilitate exposure of the hair's roots to hot air. The molded-plastic hand piece, which has coarse teeth, is pulled through the hair like a garden rake while hot air blows in the opposite direction (Fig 1). We slowly combed the entire scalp with the hand piece, ensuring that each region of the scalp was exposed to hot air for at least 30 seconds. This approach made sectioning of the hair unnecessary. The entire scalp required ~30 minutes to treat.

We monitored the temperature generated by each of the 6 methods. For the bonnet-style hair-dryer method, we measured temperature by clipping thermistors to the base of clumps of hair in 4 locations: top of the head, base of the scalp, and over each ear. We recorded the temperature from each thermistor every 5 minutes and then obtained the mean temperature for each of the 4 locations over the course of the trial. We used these means to calculate a grand mean temperature for the entire trial. For the handheld blow-dryer and wall-mounted dryer methods, we measured temperature by placing a thermistor near the scalp in the middle of the section of hair being treated. We calculated the temperature of the treatment for each subject by averaging the temperatures across the sections. For the LouseBuster methods, air temperature exiting the hose was recorded continuously, and the temperature data was automatically downloaded to a laptop computer. The LouseBuster produced more even heating than the other methods (Table 1) because of its feedback mechanism.

We also measured the air volume produced by each method (Table 1).

TABLE 1 Demographic Characteristics and Treatment Data

Treatment	*n*	Median Age (Range), y	Gender, Female/Male	% Louse Mortality[a]	% Egg Mortality[b]	Mean (Range) Temperature, °C	Air Volume, cu ft/min
Bonnet-style hair dryer	54	11 (6–33)	51/3	10.1	88.8	54.8 (41–63)	9[c]
Handheld blow-dryer: diffuse heat	26	9 (6–44)	24/2	20.8	96.7	60.8 (50–67)	41
Handheld blow-dryer: directed heat	27	9 (6–32)	25/2	55.3	97.9	58.5 (52–67)	41
Wall-mounted dryer	15	10 (6–13)	15/0	62.1	96.5	58.4 (53–65)	103
LouseBuster with sections	18	10 (9–23)	18/0	76.1	94.0	58.4 (56–60)	88
LouseBuster with hand piece	18	10 (6–33)	16/2	80.1	98.0	58.9 (58–59)	88
LouseBuster with hand piece: follow-up examinations	11	11 (6–61)	10/1	NA[d]	NA[d]	58.9 (58–59)	88
Total	169	10 (6–61)	159/10				

[a] Percentage of lice dead within 3 hours of treatment.
[b] Percentage of incubated eggs still unhatched after 2 weeks.
[c] Decreases rapidly with distance from input hoses under bonnet.
[d] Not calculated (see "Methods").

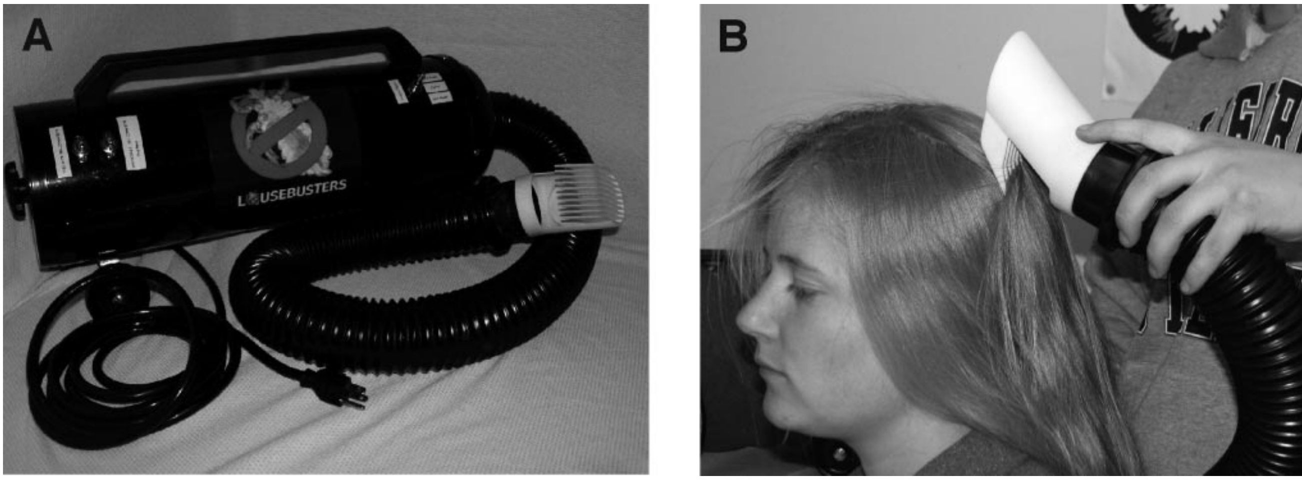

FIGURE 1
A, The LouseBuster, a custom-built, high-volume, hot-air blower with a molded plastic hand piece that supports coarse teeth; B, the hand piece is pulled through the hair slowly while hot air blows opposite the direction of pulling. The combination of high temperature, high air flow, and mechanical lifting of the hair leads to 98% mortality of louse eggs and 80% mortality of hatched lice. These mortality rates are sufficient to cure most subjects of head lice.

Statistics

The effectiveness of each method was determined by comparing the percentage of viable lice and eggs removed from the pretreatment and posttreatment sides of the scalp. Absolute differences were tested for statistical significance by calculating the 95% confidence of the difference and taking nonoverlap with zero as an indication of significance.[23] Data for lice and eggs were analyzed separately. Statistical power was calculated by using G*POWER[24]; we were able to detect a "medium" effect size ($d = 0.50$)[25] with a power of $\geq$0.83 for all 6 of the methods tested. Indeed, in all cases except the first handheld blow-dryer method (Table 1), we had power of $\geq$0.97.

RESULTS

Population Characteristics

Between September 2001 and February 2005 we received >300 calls from parents of children with head lice. Of these, 169 individuals met our inclusion criteria (see "Methods") and were enrolled in the study. Demographic characteristics of the participants are shown in Table 1. The predominant gender was female (94.1%), and the median age was 10 years.

Treatment Groups

All 6 methods had an impact on lice and/or their eggs (Table 1; Fig 2). However, the percent killed varied considerably, particularly for hatched lice, as described below.

Bonnet-Style Hair Dryer

We treated 54 subjects using this method. Although a majority of subjects completed the treatment without incident, 13 (24%) indicated some discomfort during treatment. When this happened, we turned the dryer from "high" to "low" for 2 to 3 minutes, resulting in no further discomfort in 12 of 13 cases. In 1 case (2%), the subject asked to stop the treatment. From the remaining 53 subjects, a total of 108 control lice were combed out before treatment, 3 (2.8%) of which were dead. After treatment, 138 lice were combed out, 14 (10.1%) of which were dead. Despite this low mortality rate, the percent of dead treated lice was significantly higher than the percent of dead control lice, with an absolute difference of 7.3% (95% confidence interval [CI]: 1% to 13%).

In 13 of the 53 trials, no control eggs hatched, indicating that they were from old infestations; these 13 trials were excluded from the egg-hatch analysis. A total of 586 control eggs were combed out from the remaining 40 subjects before treatment, and 546 eggs were combed out after treatment. The control–egg-hatch rate was 30.4%, and the treated–egg-hatch rate was 11.2%, a significant absolute difference of 19.2% (95% CI: 15% to 24%). In 19 (47.5%) of the 40 subjects, none of the treated eggs hatched. In summary, this method killed very few hatched lice but a larger proportion of eggs (Fig 2).

Handheld Blow-dryer: Diffuse Heating

We treated 26 subjects using this method, of which 13 (50%) indicated some discomfort. When this happened, we pulled the blow-dryer away for a few seconds, and in 12 of 13 cases the subject had no further discomfort. One subject (4%) asked to stop the treatment. From the remaining 25 subjects, a total of 101 control lice were combed out before treatment, 12 (11.9%) of which were dead. After heating, a total of 53 lice were combed out, 11 (20.8%) of which were dead. Although the percent of

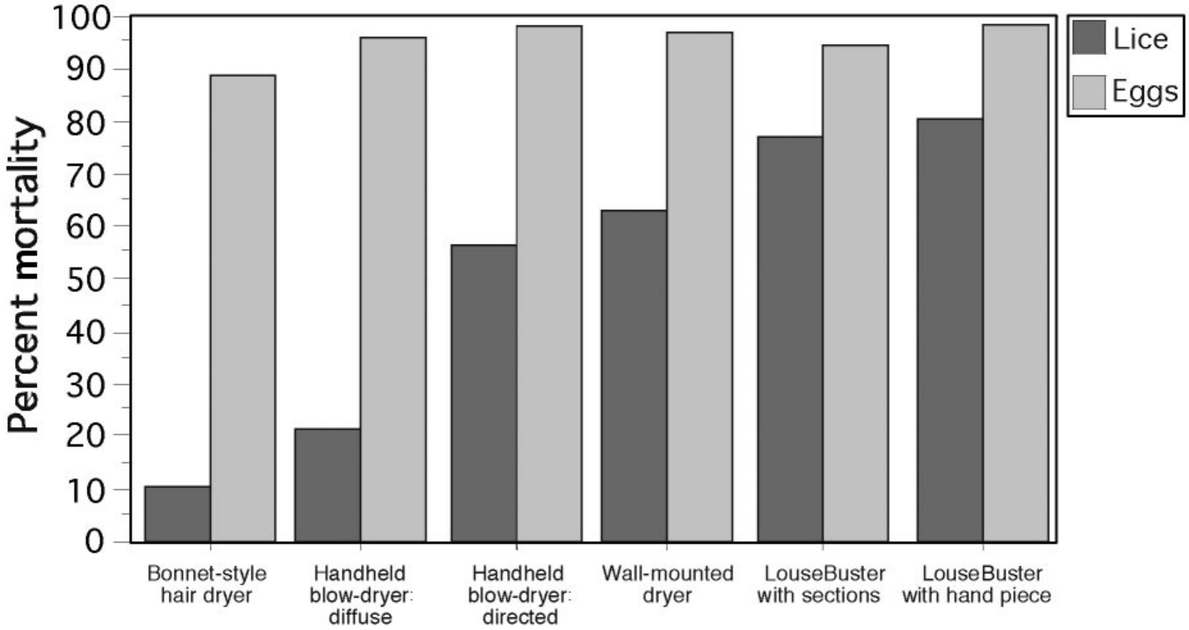

FIGURE 2
Comparative effectiveness of methods for treating head lice and their eggs using hot air (data from Table 1).

dead treated lice was higher than the percent of dead control lice, with an absolute difference of 8.9%, the effect did not differ significantly from zero (95% CI: −4% to 21%).

In 7 of the 25 trials none of the control eggs hatched, and these trials were excluded from egg-hatch analysis. From the remaining 18 subjects, a total of 835 eggs were combed out before treatment, and 582 eggs were combed out after treatment. The control–egg-hatch rate was 48.7% and the treated–egg-hatch rate was 3.3%, a significant absolute difference of 45.4% (95% CI: 42% to 49%). In 8 of the 18 subjects (44.4%), none of the treated eggs hatched. In summary, this method killed few hatched lice but large numbers of eggs (Fig 2).

Handheld Blow-dryer: Directed Heating

We treated 27 subjects using this method, 9 (33%) of which indicated some discomfort. Pulling the blow-dryer away for a few seconds resolved the issue in 8 of 9 cases. One subject (4%) chose to stop the treatment. From the remaining 26 subjects, a total of 263 control lice were combed out before treatment, 28 (10.6%) of which were dead. After treatment, a total of 179 lice were combed out, 99 (55.3%) of which were dead. The percent of dead treated lice was significantly higher than the percent of dead control lice, with an absolute difference of 44.7% (95% CI: 36% to 53%).

Eight of the 26 trials were excluded from egg-hatch analysis because none of the control eggs hatched. From the remaining 18 subjects, a total of 1217 eggs were combed out before treatment, and 863 eggs were combed out after treatment. The control–egg-hatch rate was 44.3% and the treated-egg–hatch rate was 2.1%, a significant absolute difference of 42.2% (95% CI: 39% to 45%). In 8 (44.4%) of the 18 subjects, none of the treated eggs hatched. In summary, this method killed more lice than the previous 2 methods and most of the eggs (Fig 2).

Wall-Mounted Dryer

We treated 15 subjects using this method, 4 (27%) of which indicated some discomfort. Pulling the air hose away for a few seconds resolved the issue in 2 of 4 cases; however, 2 subjects (13%) chose to stop the treatment. From the remaining 13 subjects, a total of 174 control lice were combed out before treatment, 26 (14.9%) of which were dead. After treatment, a total of 235 lice were combed out, 146 (62.1%) of which were dead. The percent of treated lice that were dead was significantly higher than the percent of dead control lice, with an absolute difference of 47.2% (95% CI: 39% to 55%).

One of the 13 trials was excluded from egg-hatch analysis because none of the control eggs hatched. From the remaining 12 subjects, a total of 518 eggs were combed out before treatment, and 647 eggs were combed out after treatment. The control–egg-hatch rate was 51.0% and the treated–egg-hatch rate was 3.5%, a significant absolute difference of 47.5% (95% CI: 43% to 52%). The fraction of subjects on which no treated eggs hatched was 5 (41.7%) of 12. In summary, this method killed a slightly higher proportion of lice than the directed-heating handheld blow-dryer method and a similar proportion of eggs (Fig 2).

LouseBuster With Sections

We treated 18 subjects using this method, 3 (17%) of which indicated some discomfort. Briefly moving the air hose away resolved the issue in all 3 cases, with no requests to stop the treatment. From the 18 subjects, a total of 422 lice were combed out before treatment, 35 (8.3%) of which were dead. After heat treatment, a total of 578 lice were combed out, 440 (76.1%) of which were dead. The percent of dead treated lice was significantly higher than the percent of dead control lice, with an absolute difference of 67.8% (95% CI: 62% to 72%).

Two of the 18 trials were excluded from egg-hatch analysis because none of the control eggs hatched. From the remaining 16 subjects, a total of 839 eggs were combed out before treatment and 969 after treatment. The control–egg-hatch rate was 52.0% and the treated–egg-hatch rate was 6.0%, a significant absolute difference of 46.0% (95% CI: 42% to 50%). The egg-hatch rate was zero in only 6 (37.5%) of 16 treated subjects. In summary, this method killed more lice than any of the previous methods and an appreciable number of eggs (Fig 2).

LouseBuster With Hand Piece

We treated 18 subjects using this method, 2 (11%) of which indicated some discomfort. Briefly moving the air hose away resolved the problem, with no requests that the treatment be stopped. From the 18 subjects, a total of 217 lice were combed out before treatment, 17 (7.8%) of which were dead. After heat treatment, a total of 287 lice were combed out, 230 (80.1%) of which were dead. The percent of dead treated lice was significantly higher than the percent of dead control lice, with an absolute difference of 72.3% (95% CI: 66% to 78%).

Six of the 18 trials were excluded from egg-hatch analysis because none of the control eggs hatched. From the remaining 12 subjects a total of 309 eggs were combed out before treatment and 439 after treatment. The control–egg-hatch rate was 46.9% and the treated–egg-hatch rate was 2.0%, a significant absolute difference of 44.9% (95% CI: 39% to 51%). The proportion of subjects on which no treated eggs hatched was double that of the previous methods (10 of 12 subjects [83.3%]). In summary, this method killed the largest proportion of lice of any of our other methods and nearly all of the eggs (Fig 2).

Follow-up Examinations

We treated another 11 subjects using the LouseBuster with hand piece. In the case of these subjects we did not comb out lice or eggs on the day of treatment because we wanted to test whether this method could eradicate entire infestations of head lice (see "Methods"). None of the 11 subjects indicated that the treatment was uncomfortably hot, and none asked to stop treatment. At the 1-week follow-up, 10 (91%) of 11 had no lice. The eleventh subject had a single live male louse, which is not a viable breeding population.

DISCUSSION

The initial goal of this study was to test the effect of heated air on head lice and their eggs. We tested 6 methods for delivering hot air to the scalp. The best of these methods, the LouseBuster with hand piece, resulted in 98% mortality of eggs and 80% mortality of hatched lice. The LouseBuster was effective at killing lice and their eggs when operated at a slightly cooler temperature than a standard blow-dryer. Few subjects found it to be uncomfortable, and none asked for the treatment to be stopped.

The second goal of our study was to test whether the best method has the potential to cure children of head lice. This proved to be the case; follow-up examinations 1 week after treatment showed that 10 of 11 subjects were completely cured of lice, and the eleventh subject had just 1 live male louse. The infestations were eliminated by a single 30-minute treatment with the LouseBuster with hand piece. No household cleaning or other preventive measures were taken. Such measures are not essential for curing head lice,[26] which cannot survive for more than a few hours off the host's head (unpublished data).

All 6 treatment methods had a minimum mean temperature of 55°C (Table 1), which is the temperature that Buxton[1] and Kobayashi et al[18] found to be lethal to body lice in vitro. Despite the high temperature, however, none of our methods killed 100% of hatched lice. The reason may be that it is difficult for hot air to penetrate the entire scalp and reach all of the hair bases, where lice tend to hide. This problem underscores the importance of in situ trials when testing antipediculosis agents. Because we did not achieve a 100% kill rate of hatched lice, how do we explain the fact that 10 of 11 of our infested subjects were free of lice 1 week after treatment? In addition to stochastic extinction resulting from small population size, there may be a delayed effect of hot air on lice that are not killed outright. We plan to test this hypothesis in the future.

The first method we tested was the bonnet-style hair dryer. This early in our study we had not perfected procedures for harvesting and incubating intact louse eggs. For this reason, the control–egg-hatching rates in our tests of this method were less than those in subsequent tests of the other 5 methods; these later tests involved control–egg-hatching rates more typical of other studies.[1,27] Low rates aside, the bonnet-style dryer caused a significant reduction in hatch rate, resulting in an overall egg mortality rate that approached 89%. However, this method killed very few hatched lice (Table 1). Therefore, we do not consider it to be a viable means of controlling head lice. The reason for the poor effect of the bonnet-style dryer on lice may be that airflow beneath the bonnet was uneven, as suggested by highly variable air temperatures (Table 1). Lice typically move ~2 mm/second when exposed to heat; however, they are capable of moving 7 mm/second.[18] Lice may well have escaped to cooler microhabitats under the bonnet, which would explain why the bonnet had a stronger effect on immobile eggs.

The next 2 methods we tested used a handheld blow-dryer to apply hot air to sections of hair diffusely or more directly. Diffuse heating for 3 minutes per section resulted in an egg mortality rate that approached 97%, but the mortality rate of hatched lice was only 21%. Directed heating killed nearly all eggs while increasing the mortality rate of hatched lice to 55%. Hot air probably kills head lice by desiccating them, and effective desiccation may require the sudden onset of hot air, as in the directed heating methods. More diffuse heating may provide the lice with an opportunity to acclimate.

The fourth method involved a wall-mounted dryer of the type found in public restrooms. The air volume of this machine was more than twice that of the handheld blow-dryer (Table 1). A 60-second application per hair section, as in the third method, killed most eggs while increasing the mortality rate of hatched lice to 62%. Although the machine was detached from the wall, it was cumbersome to use and, like the previous methods, was incapable of maintaining a very constant air temperature (Table 1).

The final 2 methods included use of a custom-built machine, the LouseBuster (Fig 1), which was less cumbersome and had the ability to maintain a reasonably constant air temperature (Table 1). In the first method, we used the LouseBuster for 60 seconds per hair section. This method killed most eggs while increasing the mortality rate of hatched lice to ~76%. In the other method we added a molded-plastic hand piece with coarse teeth that were designed to lift the hair slightly, exposing the roots, where lice and eggs congregate. In this case we did not section the hair but simply pulled the hand piece slowly through the hair like a garden rake while the air blew in the opposite direction. Each region of hair was exposed to the airflow for a minimum of 60 seconds. This method proved to be the most successful, resulting in 98% mortality of eggs and 80% mortality of hatched lice. Ten of 11 subjects were also cured of head lice when examined 1 week after treatment.

User comfort was an important consideration in our study. Although most of our subjects completed the various treatments without complaint, a few indicated discomfort at some point during the treatment, especially in the case of the non-LouseBuster methods. A small number of subjects even asked to stop the treatment. In comparison, the 2 LouseBuster methods caused very little discomfort and no requests to halt the treatment. Fortuitously, the most effective methods we tested were the ones that caused the least discomfort.

The effectiveness of hot air was independent of subject age, hair length, or hair thickness.[28] It worked equally well on people of diverse ethnic backgrounds, including those of African, European, Hispanic, and South Pacific Island descent. Effectiveness of this approach was also not dependent on ambient humidity. Although most of our trials were conducted in the arid environment of Salt Lake City, Utah, preliminary trials with the LouseBuster in humid South Florida ($n = 12$) show nearly identical results to those in Utah (unpublished data).

The proximal mechanism by which hot air kills lice is uncertain, although we think desiccation is the most likely candidate. Lice are highly susceptible to desiccation because their small size and flattened shape give them a high surface area/volume ratio.[19] High temperature could conceivably also cause conformational changes in cuticular molecules, promoting rapid desiccation and death.[29] Buxton[1] reported that hot, dry air reduces the amount of amniotic fluid in louse eggs, which makes it more difficult for them to hatch; this could explain why hot air has such a devastating effect on egg-hatch rates. Although we hope to determine the exact proximal effect of hot air on lice in the future, this was not the purpose of the current study.

Our study is one of the few to measure the impact of a treatment regime on actual infested subjects. In a previous such study, Burgess et al[27] reported that 1% permethrin creme rinse (Nix) leads to nearly 60% mortality of eggs in situ. In comparison, we report 98% mortality of eggs and 80% mortality of hatched lice treated in situ with the LouseBuster and hand piece. Our method requires just one 30-minute treatment, unlike permethrin/pyrethroid-based chemical shampoos or suffocation-based pediculicides, which require at least 2, and often 3, treatments 1 week apart.[26] Our method is safe, and it is unlikely that lice will evolve resistance, because that would require fundamental changes in their water physiology. In summary, hot air is a significant improvement over other therapies used to treat head lice.

We envision the LouseBuster to be an institutionally based machine operated by health care providers, school administrators, or trained parents and other volunteers. Although effective use of the LouseBuster is not difficult, it does require a little practice to perfect. The advantage of an institutionally based device, particularly for schools, is that it could be used to simultaneously treat all children with head lice, minimizing the problem of reinfestation. In our experience, this would be particularly useful in the case of children with parents who cannot afford the time, expense, or discipline required to treat head lice effectively in their home.

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