AiMT Advances in Military Technology
Vol. 8, No. 2, December 2013

Protection of Soldiers' Feet by Copper Oxide Impregnated Socks

G. Borkow*

Cupron Inc. Hasadnaot 10, Herzelia 46733, Israel

The manuscript was received on 14 June 2013 and was accepted after revision for publication on 9 October 2013

Abstract:

Soldiers' fungal and bacterial infections, especially in their feet, cause significant reduction in their performance. Copper has potent antifungal and antibacterial properties. Copper is also an essential trace element vital for the normal function of skin and wound healing. Socks containing copper oxide particles, such as socks designed to protect the feet of diabetic individuals, are commercially available in many countries. This article describes the results of a trial conducted with 53 soldiers undergoing intensive basic training. The soldiers used the socks with copper oxide daily for a period of three weeks. At the end of the trial the vast majority of soldiers reported a notorious reduction in their feet skin irritation, itching, and dryness and reduction in foot and sock odour. Reduced foot infection and discomfort improves the soldiers' physical and mental health, increases productiveness and decreases medical treatment costs and days lost for treatment. For these reasons, and in view of the results of this trial, socks containing copper oxide particles may be an important part of every soldier's arsenal of personal equipment.

Keywords:

Athlete's foot, biocide, copper, skin infections, socks

1. Introduction

1.1. Athlete's foot

Athlete's foot is a contagious fungal infection that can be spread through direct contact with people, objects, and places such as showers, shoes, socks, locker rooms, or wet surfaces. Those infected may be asymptomatic, while others may experience burning, stinging, or itching. In addition, the skin may become scaled, fissured, inflamed and/or

* *Corresponding author: Cupron Inc. Hasadnaot 10, Herzelia 46733, Israel, phone: +972 546 611 287, E-mail: gadi@cupron.com*

painful. Bacterial superinfection, including cellulitis of the lower extremity, is a complication of athlete's foot [1]. A recently proposed complication that can result from repeated recurrences of fungal foot infections is knee joint osteoarthritis [2]. Unfortunately, in 87% of patients treated with oral anti-fungal agents, used to treat athlete's foot infections of the skin or nails, the infections reoccur [3].

The reported prevalence of foot fungal infections in soldiers varies between 12 % [4] to 70% [5, 6]. The prevalence of these infections depends on many factors, such as the environment (dry versus humid environment), frequency of sock changes, and the length of military service (e.g. [7, 8]). The presence of these fungal infections can not only result in the infected soldiers' discomfort , but can actually result in significant reduction of the soldiers' performance, increased sick call visits, loss of activity and increased costs due to treatment. For example, fungal infections very badly affected the performance of approximately 50 % of the American soldiers in Vietnam in the Mekong Delta during 1966 to 1969 and in Panama during the 1980s [9].

1.2. Wounds

Soldiers' feet endure high pressure and friction, which in many cases results in small cuts and wounds. In addition, the foot is an area that is exposed to significant dirt and, within the shoe, to high humidity and temperature. These factors, taken together, increase the risk of minor wounds and cuts in the soldiers' feet of becoming infected. Indeed, it is well known that soldiers suffer badly from infected wounds, which can eventually result in chronic wounds [10-13]. Further aggravating a soldier's risk of complications is the one of the routes of entry for the fungi that causes athlete's foot, is through injured skin and scars [14].

1.3. Copper Biocidal and Wound Healing Properties

Humans have used copper ions for centuries, either alone or in copper complexes, to disinfect liquids, solids and human tissue and to enhance healing [15]. For example: in ancient Egypt (2000 BC), copper was used to sterilize water and wounds; the ancient Greeks in the time of Hippocrates (400 BC) prescribed copper for pulmonary diseases and for purifying drinking water; during the Roman Empire, copper cooking utensils were used to prevent the spread of disease; the Aztecs used copper oxide for treating skin conditions; by the 18th century, copper had come into wide clinical use in the Western world in the treatment of lung and mental disorders; and in the Second World War, Japanese soldiers put pieces of copper in their water bottles to help prevent dysentery [15].

The successful and wide use of copper by so many civilizations throughout history is based on two core properties of copper:

The first one is that copper is highly toxic to microorganisms (including bacteria, fungi and viruses). The toxicity is achieved by parallel non-specific damage to the microbial envelopes, microbial genetic materials and key proteins that copper causes [16]. Importantly, microbes tolerant to copper are extremely rare, even though copper has been a part of the earth for millions of years. This is in contrast to the microbes highly resistant to antibiotics that have evolved in less than 50 years of antibiotic use. This lack of resistance to copper may be explained by the capacity of copper to damage in parallel many key factors in microorganisms. Significantly, copper displays potent biocidal activity also against antibiotic resistant bacteria and antiviral resistant

viruses [17-21]. Today copper is used as a water purifier, algaecide, fungicide, nematocide, molluscicide, and as an anti-bacterial and anti-fouling agent [21].

The second core property is that copper is an essential mineral to humans, needed for the normal function of many tissues, such as skin, nerves, and both immune and blood systems [22]. Outstandingly, copper plays a key role in many of the processes that together comprise wound healing, including generation of new capillaries and expression and stabilization of extracellular skin proteins [23, 24]. The recommended daily intake of copper is 1 mg [25]. Exposure to copper is considered safe for humans, as demonstrated by the widespread and prolonged use by women of copper intrauterine devices [26-28] and over-the-counter cosmetic and wound healing ointments containing copper [29, 30]. Human skin is not sensitive to copper and the risk of adverse reactions due to dermal exposure to copper is extremely low [31, 32]. Today copper is being introduced into wound dressings and cosmetic products [24, 33, 34].

1.4. Socks Impregnated with Copper Oxide Particles

A durable platform technology has been developed [17, 18], which introduces copper oxide into polymeric materials (Fig. 1), endowing them with potent broad-spectrum anti-microbial (anti-bacterial, anti-viral, anti-fungal) and anti-mite properties. This technology enables the production of a wide variety of consumer, industrial and medical textile products, such as anti-dust mite fabrics [35]; anti-viral masks [36]; wound dressings that enhance wound healing [24, 34]; and importantly anti-microbial odour control socks, which prevent and cure athlete's foot infections in patients, including in diabetics and the elderly [37-41]. In January 2012 copper oxide containing socks helped the Chilean trapped miners resolve their foot skin infections while they were still trapped 700 meters underground [39].

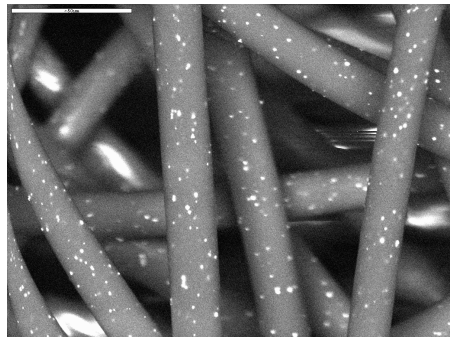

Fig. 1 Scanning electronic microscope picture of copper oxide impregnated polyester yarn used in the tested socks. The white dots are copper oxide particles.

2. Sock Trial

The use of copper oxide containing socks as part of the soldiers' uniform has recently been tested in a trial with 53 soldiers undergoing intensive basic training. The soldiers received socks containing 20 % of polyester yarn impregnated with 1 % copper oxide (weight/weight). All the copper containing yarn was concentrated in the sole of the sock. The soldiers were asked to use the socks daily for 3 weeks. At the end of the

3 weeks the soldiers filled out a questionnaire answering specific questions addressing the effectiveness of the socks in treating their foot skin discomfort and reducing malodour. Before referring to their answers, it is important to point out that the physical design of the sock was flawed. The top edge of the sock was relatively loose. This resulted in the sock slipping into the soldiers' boots, causing discomfort to the soldiers' feet during sustained activity. This, in turn, caused 12 soldiers not to wear the socks continuously. Though the socks defect had nothing to do with the copper oxide impregnated yarn or technology, it probably had a negative impact on some of the soldiers' responses regarding the socks' performance. Despite this issue, as depicted in Figs 2 and 3, after only three weeks, the majority of soldiers reported significant positive results in one or several of the attributes examined.

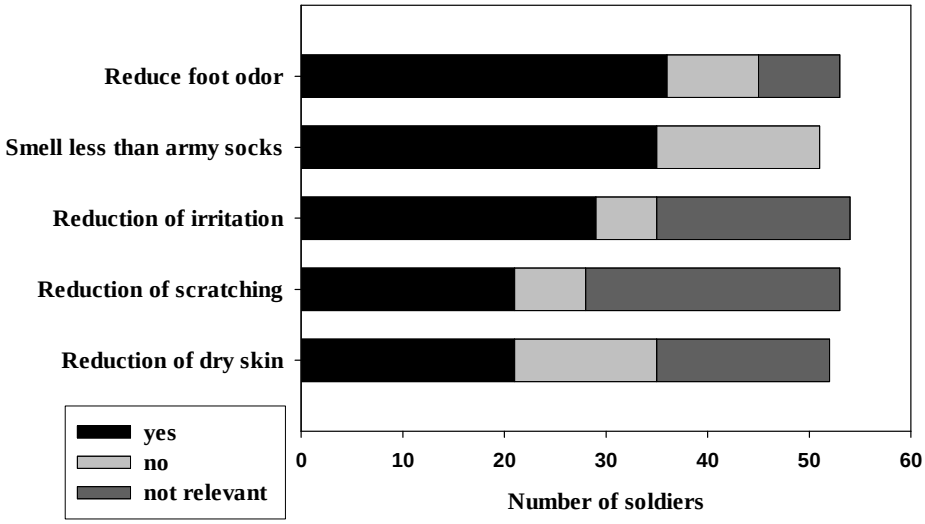

Fig. 2 Overall response by 53 soldiers in basic training after using the socks containing copper oxide in the sole of sock for 3 weeks.

Recently a leading army conducted an extensive rigorous test with socks manufactured according to the regular army sock specs, but containing copper oxide impregnated yarn. The socks were given (distributed) to a large fighting unit and the test showed excellent results in protecting the feet of the soldiers and reducing significantly the number of soldiers reporting to the infirmary due to foot skin problems. Based on this test this army has started to equip all their soldiers with socks containing copper oxide impregnated yarn. These socks are also currently being purchased by other armies.

3. Conclusions

Humidity and elevated temperatures common in a soldier's boot are a perfect environment for proliferation of fungi and bacteria, malodour, wound infection, and athlete's foot. These conditions may significantly reduce the performance of soldiers. Conversely, the conditions that nurture microbial growth are precisely those optimal for ionic copper release. These copper ions, contained in socks made with yarn impregnated with copper oxide particles, act as a biocide that protects the feet from

fungal and bacterial infections and cures athlete's foot infections. In addition, these socks, via the copper ions, may protect the skin by increasing its stability and integrity, reducing irritation and secondary infection, and enhancing wound healing.

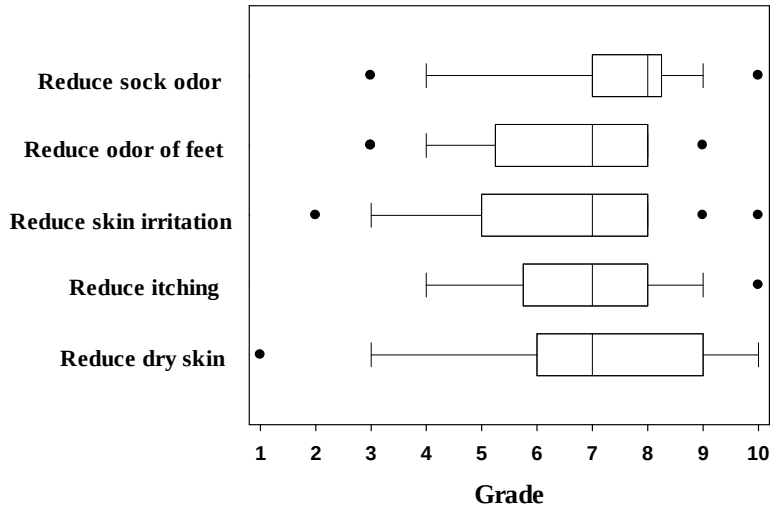

Fig. 3 Among the soldiers claiming that the socks helped, the following is the mean and standard deviation of their scores for each attribute (scale 1 to 10, being 10 the best score). The boxes represent the middle 50 % of the data values. The horizontal black line across the box marks the median value. The error bars show the 10th and 90th percentiles of the population. Individual data-points falling beyond these boundaries are shown as dots.

Freedom from foot discomfort and infection will improve a soldier's health, both physically and mentally. Furthermore, the army will benefit by reducing the costs of medical treatment and productive days lost for that treatment. For these reasons, socks containing copper oxide particles (with their potent anti-microbial and wound healing properties) may be an important part of every soldier's arsenal of personal equipment. Also other personnel, like fire fighters, policemen, and miners, may protect their feet by using copper oxide containing socks.

Acknowledgement

The work presented in this paper has been supported by Cupron Inc, Herzelia, Israel.

References

[1] BRISTOW, I. and MAK, M. Fungal foot infection: the hidden enemy*? Wounds UK*, 2009, vol. 5, no. 4, p. 72-78.

[2] RENC, A. Is fungal foot infection the initiating and maintaining cause of knee osteoarthritis? *Mycoses*, 2013, vol. 56, no. 6, p. 631-637, doi 10.1111/myc.12080.

[3] SIGURGEIRSSON, B., OLAFSSON, JH., STEINSSON, JB., PAUL, C., BILLSTEIN, S. and EVANS, EG. Long-term effectiveness of treatment with

terbinafine vs itraconazole in onychomycosis: a 5-year blinded prospective follow-up study. *Arch. Dermatol.*, 2002, vol. 138, no. 3, p. 353-357.

[4] INGORDO, V., NALDI, L., FRACCHIOLLA, S. and COLECCHIA, B. Prevalence and risk factors for superficial fungal infections among Italian Navy Cadets. *Dermatology*, 2004, vol. 209, no. 3, p. 190-196.

[5] VAKULOVA, IN., MYZNIKOV, IL., KUTELEV, GM. and KOPYLOVA, NS. Epidemiology of mycoses in submariners based on the Kola Peninsula (in Russian). *Aviakosm. Ekolog. Med.*, 2003, vol. 37, no. 4, p. 23-26.

[6] COHEN, AD., WOLAK, A., ALKAN, M., SHALEV, R. and VARDY, DA. Prevalence and risk factors for tinea pedis in Israeli soldiers. *Int J Dermatol.*, 2005, vol. 44, no. 12, p. 1002-1005.

[7] NOGUCHI, H., HIRUMA, M., KAWADA, A., ISHIBASHI, A. and KONO, S. Tinea pedis in members of the Japanese Self-defence Forces: relationships of its prevalence and its severity with length of military service and width of interdigital spaces. *Mycoses*, 1995, vol. 38, no. 11-12, p. 494-499.

[8] NOGUCHI, H., HIRUMA, M., KAWADA, A. and ISHIBASHI, A. Tinea pedis survey in members of the Japanese Self-defence Forces undergoing ranger training. *Mycoses*, 1994, vol. 37, no. 11-12, p. 461-467.

[9] WHITE, T. and HENN, M. Genomic determinants of infection competence in dermatophyte fungi. [cited 2013-10-06]. Available from: <www.genome.gov/pages/research/.../dermatophyte_wp_seq.pdf>.

[10] DALLO, S. and WEITAO, T. Insights into acinetobacter war-wound infections, biofilms, and control. *Adv Skin Wound Care*, 2010, vol. 23, no. 4, p. 169-174.

[11] MURRAY, CK. Infectious disease complications of combat-related injuries. *Crit Care Med.*, 2008, vol. 36, no. 7 Suppl., p. S358-S364.

[12] SEBENY, PJ., RIDDLE, MS. and PETERSEN, K. Acinetobacter baumannii skin and soft-tissue infection associated with war trauma. *Clin Infect. Dis.*, 2008, vol. 47, no. 4, p. 444-449.

[13] ARONSON, NE., SANDERS, JW. and MORAN, KA. In harm's way: infections in deployed American military forces. *Clin Infect. Dis.*, 2006, vol. 43, no. 8, p. 1045-1051.

[14] LAKSHMIPATHY, DT. and KANNABIRAN, K. Review on dermatomycosis: pathogenesis and treatment. *Natural Science*, 2010, vol. 2, no. 7, p. 726-731.

[15] DOLLWET, HHA. and SORENSON, JRJ. Historic uses of copper compounds in medicine. *Trace Elements in Medicine*, 2001, vol. 2, no. p. 80-87.

[16] BORKOW, G. and GABBAY, J. Copper as a biocidal tool. *Curr. Med. Chem*, 2005, vol. 12, no. 18, p. 2163-2175.

[17] BORKOW, G. and GABBAY, J. Putting copper into action: copper-impregnated products with potent biocidal activities. *FASEB J*, 2004, vol. 18, no. 14, p. 1728-1730.

[18] GABBAY, J., MISHAL, J., MAGEN, E., ZATCOFF, RC., SHEMER-AVNI, Y. and BORKOW, G. Copper oxide impregnated textiles with potent biocidal activities. *Journal of Industrial Textiles*, 2006, vol. 35, no. 4, p. 323-335.

[19] BORKOW, G., LARA, HH., COVINGTON, CY., NYAMATHI, A. and GABBAY, J. Deactivation of human immunodeficiency virus type 1 in medium by copper oxide-containing filters. *Antimicrob. Agents Chemother.*, 2008, vol. 52, no. 2, p. 518-525.

[20] BORKOW, G. and MONK, AB. Fighting nosocomial infections with biocidal non-intrusive hard and soft surfaces . *World J Clin Infect Dis*, 2012, vol. 12, no. 4, p. 77-90.

[21] BORKOW, G. Using copper to fight microorganisms. *Curr Chem Biol*, 2012, vol. 6, no. 2, p. 93-103.

[22] UAUY, R., OLIVARES, M. and GONZALEZ, M. Essentiality of copper in humans. *Am. J Clin. Nutr.*, 1998, vol. 67, no. 5 Suppl., p. 952S-959S.

[23] BORKOW, G., GABBAY, J. and ZATCOFF, RC. Could chronic wounds not heal due to too low local copper levels? *Med. Hypotheses*, 2008, vol. 70, no. 3, p. 610-613.

[24] BORKOW, G., GABBAY, J., DARDIK, R., EIDELMAN, AI., LAVIE, Y., GRUNFELD, Y., IKHER, S., HUSZAR, M., ZATCOFF, RC. and MARIKOVSKY, M. Molecular mechanisms of enhanced wound healing by copper oxide-impregnated dressings. *Wound. Repair Regen.*, 2010, vol. 18, no. 2, p. 266-275.

[25] TRUMBO, P., YATES, AA., SCHLICKER, S. and POOS, M. Dietary reference intakes: vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. *J Am. Diet. Assoc.*, 2001, vol. 101, no. 3, p. 294-301.

[26] Copper IUDs, infection and infertility. *Drug Ther. Bull.*, 2002, vol. 40, no. 9, p. 67-69. [No authors listed].

[27] BILIAN, X. Intrauterine devices. *Best. Pract. Res. Clin. Obstet. Gynaecol.*, 2002, vol. 16, no. 2, p. 155-168.

[28] HUBACHER, D., LARA-RICALDE, R., TAYLOR, DJ., GUERRA-INFANTE, F. and GUZMAN-RODRIGUEZ, R. Use of copper intrauterine devices and the risk of tubal infertility among nulligravid women. *N. Engl. J Med.*, 2001, vol. 345, no. 8, p. 561-567.

[29] PEREIRA, CE. and FELCMAN, J. Correlation between five minerals and the healing effect of Brazilian medicinal plants. *Biol Trace Elem. Res.*, 1998, vol. 65, no. 3, p. 251-259.

[30] SCHLEMM, DJ., CROWE, MJ., MCNEILL, RB., STANLEY, AE. and KELLER, SJ. Medicinal yeast extracts. *Cell Stress. Chaperones.*, 1999, vol. 4, no. 3, p. 171-176.

[31] HOSTYNEK, JJ. and MAIBACH, HI. Copper hypersensitivity: dermatologic aspects – an overview. *Rev. Environ. Health*, 2003, vol. 18, no. 3, p. 153-183.

[32] GORTER, RW., BUTORAC, M. and COBIAN, EP. Examination of the cutaneous absorption of copper after the use of copper-containing ointments. *Am J Ther.*, 2004, vol. 11, no. 6, p. 453-458.

[33] BORKOW, G., GABBAY, J., LYAKHOVITSKY, A. and HUSZAR, M. Improvement of facial skin characteristics using copper oxide containing

pillowcases: a double-blind, placebo-controlled, parallel, randomized study. *Int J Cosmet. Sci.*, 2009, vol. 31, no. 6, p. 437-443.

[34] BORKOW, G., OKON-LEVY, N. and GABBAY, J. Copper oxide impregnated wound dressing: biocidal and safety studies. *Wounds*, 2010, vol. 22, no. 12, p. 301-310.

[35] MUMCUOGLU, KY., GABBAY, J. and BORKOW, G. Copper oxide impregnated fabrics for the control of house dust mites. *International Journal of Pest Management*, 2008, vol. 54, no. 3, p. 235-240.

[36] BORKOW, G., ZHOU, SS., PAGE, T. and GABBAY, J. A novel anti-influenza copper oxide containing respiratory face mask. *PLOS ONE*, 2010, vol. 5, no. 6, doi 10.1371/journal.pone.0011295. ISSN-1932-6203.

[37] ZATCOFF, RC., SMITH, MS. and BORKOW, G. Treatment of tinea pedis with socks containing copper impregnated fibers. *The Foot*, 2008, vol. 18, no. p. 136-141.

[38] BORKOW, G., ZATCOFF, RC. and GABBAY, J. Reducing the risk of skin pathologies in diabetics by using copper impregnated socks. *Med. Hypotheses*, 2009, vol. 73, no. p. 883-886.

[39] BORKOW, G. and MELLIBOVSKY, JC. Resolution of skin maladies of the trapped Chilean miners: the unplanned underground copper-impregnated antifungal socks “trial”. *Arch. Dermatol*, 2012, vol. 148, no. 1, p. 134-136.

[40] GARGIULO, ME., DEL CARMEN-ELIAS, A. and BORKOW, G. Analysis of the effect of wearing copper oxide impregnated socks on *tinea pedis* based on “before and after” pictures – a statistical follow-up tool. *The Open Biology Journal*, 2012, vol. 5, no. p. 17-22.

[41] BRISTOW, I. and TURNER, A. Antifungal socks as part of a regime to prevent recurrence of tinea pedis and onychomycosis. *Podiatry Now*, 2009, vol. 10, 27 p.