Taylor & Francis
Taylor & Francis Group

Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: https://www.tandfonline.com/loi/uaoh20

Hand-Arm Vibration Syndrome in a Group of U.S. Uranium Miners Exposed to Hand-Arm Vibration

Donald E. Wasserman , Virginia J. Behrens , Peter L. Pelmear , Richard Ilka , Douglas D. Reynolds , Thomas E. Doyle , Shlomo Samueloff & Richard J. Goff

Feature Article

Hand–Arm Vibration Syndrome in a Group of U.S. Uranium Miners Exposed to Hand–Arm Vibration

Donald E. Wasserman,[A] Virginia J. Behrens,[B] Peter L. Pelmear,[C] Richard Ilka,[D] Douglas D. Reynolds,[E] Thomas E. Doyle,[F] Shlomo Samueloff,[G] and Richard J. Goff[H]

Medical evaluations were conducted in New Mexico on 134 uranium mine workers. Ninety-one of these workers were miners who used jack–leg-type drills on their job at the time of the survey. Engineering evaluations of two jack–leg-type drills and a jack hammer were carried out while four of the miners operated the tools. The medical evaluations were designed to diagnose Hand–Arm Vibration Syndrome from use of these vibrating pneumatic hand tools. Among 49 miners, selected for the absence of confounding exposures or medical conditions, 17 percent were in the vascular stages of Hand–Arm Vibration Syndrome and 24 percent in the neurologic stages according to the Taylor–Pelmear Classification System. The median latency of tingling, numbness, and blanching was the same, 4.5 years. Unweighted vibration acceleration levels measured on three pneumatic tools (a small and large jack–leg-type drill and a small jack hammer) ranged from 5.16 to 19.04 g(rms) (corresponding to 50.62–186.78 m/sec/sec) in the axial tool axis (over frequency range of 6.3–1000 Hz). **Wasserman, D.E.; Behrens, V.J.; Pelmear, P.L.; Ilka, R.; Reynolds, D.D.; Doyle, T.E.; Samueloff, S.; Goff, R.J.: Hand–Arm Vibration Syndrome in a Group of U.S. Uranium Miners Exposed to Hand–Arm Vibration. Appl. Occup. Environ. Hyg. 6:183–187; 1991.**

Introduction

Background

In response to increasing concern about the effects of occupational vibration on worker health and safety, the National Institute for Occupational Safety and Health (NIOSH) in 1971 began a comprehensive planned research effort.(1) As part of this effort it was determined that an estimated 1.2 million workers were exposed to "hand–arm" or "segmental" vibration from vibrating hand tools.(2) In 1975, NIOSH hosted the Second International Conference on Hand–Arm Vibration.(3) This meeting concluded that the adverse medical effects of vibrating hand tools should be studied in the United States. Such studies were considered particularly important because an investigator, representing the U.S. Public Health Service, had denied such effects existed in the U.S.(4) despite worldwide reports(5–8) and the studies of Dr. Alice Hamilton in 1918 concerning U.S. limestone cutters and carvers using pneumatic chipping tools.(9)

After the 1975 conference, NIOSH conducted studies of vibrating pneumatic tools resulting in: 1) a number of studies of pneumatic chipping and grinding workers in foundries and a large shipyard;(10–13) 2) a replication of the earlier Hamilton study;(14) and 3) a subsequent study of jack–leg-type drills in mining, the subject of this article.

One purpose of the chipper and grinder studies was to determine the extent Hand–Arm Vibration Syndrome (HAVS) occurred among workers using these tools in the U.S. Complete medical documentation of HAVS was previously reported by Taylor as part of the first international conference on hand–arm vibration.(8) NIOSH found the prevalence of the vascular stages of HAVS in foundry pieceworkers was 51 percent while hourly workers at the same foundries had a prevalence of 28 percent.(10–12) For blanching symptoms, both pieceworkers and hourly workers had short latency periods of two years. (In general, the latency period is the time from the first exposure to hand–arm vibration until the first appearance of HAVS symptoms.) A NIOSH Health Hazard Evaluation of foundry workers showed a 55 percent prevalence of HAVS for pieceworkers with a blanching latency of 2 years.(13) The shipyard (without piecework) showed a lower prevalence of 19 percent and a longer latency (16.8 years).(10–12) Thus, pieceworkers were at higher risk of developing HAVS compared with hourly workers. Unweighted vibration levels on the chipping and grinding tools at these worksites were some 2400 g(rms) on the tool chisel, 200 g(rms) on the tool handle, and up to 80 g(rms) on the horizontal grinder.

The "high end" of the dose–response relationship had been identified; however, the "low end" of a vibration exposure had yet to be identified. One way was to study workers using tools with characteristics similar to chipping and grinding tools but with lower vibration levels. The

[A]Wasserman & Associates, Inc., Human Vibration Consultants, Cincinnati, Ohio; [B]National Institute for Occupational Safety and Health, Cincinnati, Ohio; [C]Ontario Ministry of Labour, Toronto, Ontario, Canada; [D]Medical Department, Motorola, Inc., Phoenix, Arizona; [E]Mechanical Engineering Department, University of Nevada, Las Vegas, Nevada; [F]Ohio Industrial Commission, State of Ohio, Columbus, Ohio; [G]Hebrew University, Hadassah Medical School, Jerusalem, Israel; [H]U.S. Department of Labor, Mine Safety and Health Administration, Denver, Colorado.

1047-322X/91/0603-183$2.00/5 © 1991 AIH

objective was to find if workers using such tools had a lower prevalence of HAVS and a longer latency than the pieceworkers. It was decided that underground miners using jack–leg-type drills were suitable for this investigation. Both the chipping hammer and the jack–leg-type drill are pneumatic impact tools. The vibration spectrum for the two tools are similar, but the vibration acceleration levels are much lower on the jack–leg-type drill compared with the chipping hammer.

Hand–Arm Vibration and Mining

Since the jack–leg-type drill was introduced to underground mining in the late 1950s, investigators have reported HAVS among miners using these tools. In 1960, Williams and Reigert[15] reported on 11 cases of Raynaud's Phenomenon (the blanching symptoms of HAVS) occurring in a group of Canadian uranium miners. By 1964, Ashe and Williams[16] reported a cumulative total of 42 cases in this group of miners who had such a high turn-over rate that the authors could not determine the group denominator. The research of Ashe and Williams is important for descriptions of pathological changes in finger arteries of advanced cases of HAVS.

Pelnar and Pacina[17] reported in 1963 on examinations of 481 underground ore miners in Czechoslovakia who were using pneumatic drills. These authors medically described a condition of the fingers for 20 percent of these miners that was the same as Raynaud's phenomenon but which they termed "occupational traumatic vasoneurosis" of the extremities. Iwata[18] in Japan reported in 1968 that 52 percent of 529 underground metal miners using jack–leg-type drills had Raynaud's Phenomenon. More than 95 percent of these miners had worked in the mines for more than 4 years. In 1977, Matsumoto and other Japanese investigators[19] reported that of 45 underground zinc miners examined 80 percent had Raynaud's Phenomenon, and 86 percent of these miners had used the jack–leg-type drill for more than 5 years. In the same year, Robert *et al.*[20] reported that 19 percent of French underground uranium miners using jack–leg-type drills had Raynaud's Phenomenon, and 70 of these miners had more than 10 years experience using the drills.

Chatterjee *et al.*[21] surveyed and examined underground fluorspar miners who used jack–leg-type drills in four mines in Weardale (United Kingdom). They reported in 1978 that the prevalence of vibration-induced white finger (again the blanching symptoms of HAVS) ranged from 19 to 50 percent at several mines, and the latent period ranged from 4.5 to 7.0 years. The prevalence increased as the mean exposure time of the miners increased at each mine.

In 1986, two studies were published in Canada[22,23] reporting HAVS among hard rock miners who used jack–leg-type drills. Pelmear *et al.*[22] found that the prevalence of Raynaud's Phenomenon among 19 hard rock miners was 47 percent with a mean latent period of 16 years. Among 27 control workers at the mine, there was one case of constitutional white fingers (4%). Weighted acceleration measurements of the jack–leg-type drill showed levels ranging from 8 to 28 m/sec/sec with a mean of 17 m/sec/sec. The authors also reported measurements for nine other vibrating hand tools used in the hard rock mine studied.

Brubaker *et al.*[23] studied 95 rock drillers from a hard rock mine in British Columbia where jack–leg-type drills were used. After excluding some of the drillers because of factors other than vibration drilling exposure, which predisposed them to Raynaud's Phenomenon, 58 drillers remained. Among these drillers, the prevalence of Raynaud's Phenomenon was 45 percent with a mean latent period of 7.5 years. The weighted acceleration levels for four kinds of jack–leg-type drills used at the mine ranged from 19 to 20 m/sec/sec.

Methods

Description of Uranium Mining Worksites

NIOSH carried out a study in the Ambrosia Lake region near Grants, New Mexico; an area rich in uranium. Two uranium mine worksites, owned by different companies, were evaluated by performing walk-through surveys. The worksites had vertical shafts, 600–1400 feet below the surface, into ore-bearing shale rock. The haulage drift tunnels off the main shaft had tracks for electric trains that removed ore dropping from development drifts, vertically above the haulage drifts. The miners worked in development drifts in groups of three or four. As a group, the miners contracted with the mining company daily for how much ore they expected to mine.

The work cycle included drilling 15 holes, 6 feet into the mine face. The miners used an 80-pound pneumatic jack–leg-type drill. The 6-foot drilling shaft repeatedly rotates and impacts on and through the rock. As the shaft penetrates, a pneumatic "leg" telescopes in length, keeping a constant force on the drill mechanism. During this process, the drill directs a fine spray of water at the shaft. The miners also used this tool to shore up walls and ceilings with bolts and chain link fencing.

After drilling, the miner kneads the end of a dynamite stick, forces on a percussion cap, and places five or six sticks into the holes. When the holes are filled and wires attached to a blasting timer, the miners go to the main shaft for a meal during which the ore is remotely exploded. After returning, they use a slusher machine with an electrical winch and a large "scoop" to carry ore to a chute. The ore drops down the chute to hopper cars for weighing. Jack hammers are used infrequently to break up pieces of ore that are too large to slide down the chute. This work cycle is repeated twice per shift for an exposure time to vibrating hand tools of 1 to 1.5 hours.

Study Group

Originally, it was planned to study miners at one or more mines in the Ambrosia Lake region with the approval and cooperation of the mining companies. Despite numerous attempts, we were unable to obtain the cooperation from any of the uranium mining companies in the region. Under these circumstances, it was decided to continue the study by asking for volunteer participants from the membership of the local union. The study was advertised at union meetings and on local radio prior to the arrival of the study team. From an address and telephone list, union members were telephoned to ask for their participation or a letter was sent if they were without a telephone. At least three attempts by telephone and two by mail were made for each person listed. Thus, the final study group was comprised of volunteer mine workers, employed by a number of uranium mining companies, who are part of an undefined population of uranium mine workers in the Ambrosia Lake region.

Medical Examinations and Engineering Measurements

The medical and engineering methods used in this study were identical to those used in the aforementioned chipper and grinder study of foundry and shipyard workers.[10-12] Questionnaires were administered by trained interviewers prior to medical examinations. The questionnaires included, among other items, demographic information, work histories, hand–arm vibration exposure histories, and questions about signs and symptoms of HAVS. Medical examinations were sequentially performed by two physicians highly experienced in the diagnosis of HAVS. The examination by the first physician resulted in a differential diagnosis for HAVS, and the examination by the second physician resulted in a specialized diagnosis of HAVS. The diagnosis of HAVS was made without knowledge of the information from the questionnaire. The examinees were staged for HAVS according to the Taylor–Pelmear staging system in use at the time of this study. Detailed descriptions of these examinations are given in our previous publications.[10-12]

Engineering testing consisted of basicentric acceleration measurements (Figure 1) on three tools: a small jack–leg-type drill (Ingersol Model JR38, 2⅝-inch drill bore), a large jack–leg-type drill (Ingersol Model JR300, 3-inch drill bore), and a lightweight jack hammer. Measurements were taken on the handles where a miner normally grasps the tool while drilling into shale rock, the type of rock in the uranium mines studied. The small and large jack–leg-type drills were measured while two experienced miners and two inexperienced operators were drilling. The experience level of operators was compared to find out if this factor affected the measured vibration level. The jack hammer was measured with a mollet bit and a star bit while an experienced miner operated the tool. Measurements were obtained along the axial axis of each tool and FM tape recorded. A total of 16 fifteen-minute vibration simulated work runs were recorded. The data were Fourier spectrum analyzed after computer averaging the work runs.[24]

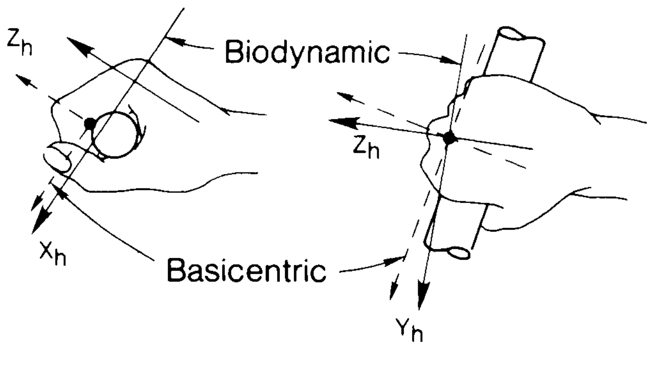

FIGURE 1. Biodynamic and basicentric coordinate systems for hand–arm and tool measurements.

TABLE I. Volunteer Mine Workers

Type of Mine Worker	Number	Percent
Currently employed miners	91	68
Ex-miners, not currently employed as miners	17	12
Other Mine Workers, never employed as miners	26	20
Workers Tested	134	100

Results

Medical

A total of 134 volunteer mine workers were interviewed and examined (Table I); 91 of these workers were currently employed miners at the time of the survey. All of the miners used jack–leg-type drills on their jobs. Some mine workers previously employed as miners (17 workers) and other mine workers who had never been employed as miners (26 workers) also participated. The purpose of this study was to examine miners exposed to hand–arm vibration from jack–leg-type drills at the time of the survey. For this reason, the results for previously exposed miners are not discussed here.

From the examination of occupational and hobby tool histories, 25 of the miners and all 26 of the other mine workers were excluded from further analysis due to confounding vibrating hand tool exposures. The medical histories of the remaining miners were reviewed by the project physicians who determined that 17 miners had confounding medical conditions. Thus, of the 91 miners who participated, 49 were included in the analyses that follow.

The mean age of these 49 miners was 32 years with a range of 20–62 years. Most of these miners were Hispanic (84%) and the remainder were white. Among these miners, 17 percent were in the vascular stages of HAVS (Table II). Almost 60 percent of the exposed miners were asymptomatic, while 24 percent had neurologic symptoms without blanching (Stages OT, ON, TN). Of the eight miners with blanching symptoms (i.e., vascular stages), a single worker was at Stage 2 and no miners were at Stage 3.

In this study, less than 10 percent of the miners included in the analysis had held jobs using vibrating hand tools other than those in underground mining. All of these jobs occurred after the first job in underground mining. The latency for a symptom of HAVS was defined as the time

TABLE II. Hand–Arm Vibration Syndrome Among 49 Miners Included in Final Analysis

Stage	Percent	Number
00	59	29
OT	12	6
ON	8	4
TN	4	2
01	15	7
02	2	1
03	0	0
Total	100	49
Summary: Asymptomatic (00)	59%	
Neurological (OT, ON, TN)	24%	
Blanching (01, 02, 03)	17%	

from the first underground mining job until the onset of a symptom. The median latency for each symptom of tingling, numbness, and blanching was the same, 4.5 years (Table III). In addition, Table IV lists the number of years these 49 miners had used the jack–leg-type drills on their jobs. Miners with symptoms of HAVS had worked longer than asymptomatic miners, while miners with neurologic symptoms only had the longest exposure times.

TABLE III. Latency of Tingling, Numbness, and Blanching

	Latency (yrs)		
	Median	Mean	Range
Tingling	4.5	9.1	0.3–28.5
Numbness	4.5	5.5	0.3–11.9
Blanching	4.5	6.6	0.3–14.2

Engineering

Table V gives the single axis acceleration measurements for a small jack–leg-type drill, a large jack–leg-type drill, and a jack hammer using a mollet and a star bit. These measurements are unweighted, root-mean-square, overall acceleration levels over a frequency range of 6.3–1000 Hz. The vibration levels for the large jack–leg-type drill and the jack hammer were effectively the same, but the levels for the small jack–leg-type drill were mostly less than half those for the other two tools. Acceleration levels for experienced versus inexperienced operators and mollet bit compared with star bit did not differ appreciably.

Discussion

To the knowledge of the authors, this is the only study that has investigated HAVS among U.S. workers exposed to hand–arm vibration from jack–leg-type drills. Among the miners included in the analysis, the percentage in the vascular stages of HAVS (17%) was low compared with more recent studies in Canada of miners using jack–leg-type drills.[22,23] The results of our study support the hypothesis that vibration levels from the jack–leg-type drill would result in lower rates of HAVS than were found among workers using pneumatic chipping and grinding tools. The results of the Canadian studies of jack–leg-type drillers seem to reject this hypothesis, although those studies are methodologically similar to ours in many respects.

In their separate Canadian studies of hard rock miners using jack–leg-type drills, Pelmear *et al.*[22] and Brubaker *et al.*[23] found a prevalence of Raynaud's Phenomenon (i.e., the blanching symptoms or vascular stages of HAVS) of 47 percent and 45 percent, respectively. Again, in contrast to our study, the mean latency of Raynaud's Phenomenon in their studies was 16 and 7.5 years, respectively, while the mean latency of vascular stages of HAVS in our study was 6.6 years (Table III).

TABLE IV. Years Working on Mining Jobs Using a Jack–Leg-Type Drill

	Median	Mean	Range
Asymptomatic (n = 29)	4.4	6.0	0.9–17.3
Neurologic (n = 12)	7.3	9.4	1.0–22.7
Blanching (n = 8)	5.5	8.2	3.2–19.2

There are a number of possible reasons for the relatively low percentage of miners with blanching symptoms of HAVS in our study. One possibility is that in our study the miners without blanching symptoms had not worked long enough with the jack–leg-type drills to show these symptoms. This is probably not the case because the mean years of exposure to jack–leg-type drills (Table IV) for asymptomatic miners (6.0 years) and miners in the neurologic stages (9.4 years) was nearly equal to or greater than the mean latency of blanching symptoms (6.6 years).

Another possible reason is that drilling into hard rock, as in the Canadian studies, causes greater exposure to hand–arm vibration versus drilling into shale, a softer medium, as in our study. The levels for jack–leg-type drills measured by Pelmear *et al.* ranged from 8 to 28 m/sec/sec and from 19 to 20 m/sec/sec for Brubaker *et al.* Our measurements were considerably greater ranging from 51 to

TABLE V. Overall Unweighted Acceleration Levels[A]

	Number Tests	Acceleration Levels[B] g(rms)	m/sec/sec
Large Jack–leg-type drill			
Experienced operator	2	19.04	186.78
Inexperienced operator	4	16.86	165.40
Small jack–leg-type drill			
Experienced operator	3	5.16	50.62
Inexperienced operator	1	6.90	67.69
Jack hammer			
Experienced operator			
With mollet bit	4	16.52	162.06
With star bit	2	10.20	100.06

[A]Measurement direction: axial; frequency range: 6.3–1000 Hz.
[B]Note: 1 g = 9.81 m/sec/sec; rms = root-mean-square.

187 m/sec/sec (Table V). Our measurements are probably greater because they are unweighted and the other measurements are weighted. Even with weighting, our measurements are unlikely to fall below these measurements for hard rock mining. Differences in daily exposure time also do not offer an explanation since the two Canadian studies and our study all reported daily exposures of 1 to 1.5 hours.

One other factor was considered in our attempt to explain the relatively low percentage of blanching symptoms in our group of uranium miners. The miners kneaded dynamite with their fingers causing them to be exposed to nitroglycol. Nitroglycol can produce both vasodilation upon exposure and vasoconstriction after withdrawal from exposure.[25] Exposure to nitroglycol might have decreased the appearance of blanching symptoms in the group of miners we studied, although research is needed to investigate this issue in depth.

The results of our study are limited by the examination of volunteer participants from an undefined population of uranium mine workers. We tried to avoid this limitation by gaining company cooperation but were unsuccessful despite numerous attempts. The usual expectation in a volunteer study is that a disproportionate number of workers with the disease outcome under study will show for examination. This does not appear to have happened in our study because we found a lower percentage of miners with HAVS than other North American investigators, as described above.

Our study found a lower rate of HAVS, a longer latency of HAVS, and lower vibration levels among workers using jack–leg-type drills compared with our findings for workers using chipping and grinding tools. These results are limited by studying volunteer participants and the effects of nitroglycol exposure. It was concluded from our results that exposure to hand–arm vibration from the jack–leg-type drill was not "safe" because miners with HAVS were still identified.

Acknowledgments

The authors gratefully acknowledge the interest and the help of The Oil, Chemical, and Atomic Workers Union; NIOSH; the Mine Safety and Health Administration; The Grants, New Mexico, Branch of New Mexico State University; the Ontario Ministry of Labour; and the study participants. We also thank Sherri Wasserman who diligently helped in the typing of this manuscript.

References

1. Wasserman, D.E.; Badger, D.: The NIOSH Plan for Developing Industrial Vibration Exposure Criteria. J. Safety Res. 4:146–154 (1973).
2. Wasserman, D.E.; Badger, D.; Doyle, T.E.; Margolies, L.: Industrial Vibration—An Overview. J. Am. Soc. Safety Eng. 19:38–43 (1974).
3. Wasserman, D.E.; Taylor, W. (Eds.): Proceedings of the International Occupational Hand–Arm Vibration Conference. DHEW (NIOSH) Pub. No. 77-170. National Institute for Occupational Safety and Health, Cincinnati, OH (1977).
4. Pecora, L.J.; Udel, M.; Christman, R.P.: Survey of The Current Status of Raynaud's Phenomenon. Am. Ind. Hyg. Assoc. J. 21:80–83 (1960).
5. Dart, E.E.: Effects of High Speed Vibrating Tools on Operators Engaged in Work in the Airplane Industry. Occup. Med. 1:515–550 (1946).
6. Peters, F.J.: A Disease Resulting from the Use of Pneumatic Tools. Occup. Med. 2:55–60 (1946).
7. Agate, J.N.; Druett, H.A.; Tobleson, J.B.L.: Raynaud's Phenomenon in Grinders of Small Metal Castings. Br. J. Ind. Med. 3:167–170 (1946).
8. Taylor, W. (Ed.): The Vibration Syndrome. In: Proceedings of a Conference on the Medical, Engineering, and Legal Aspects of Hand–Arm Vibration, University of Dundee (July 12–14, 1972). Academic Press, Inc., London (1974).
9. Hamilton, A.: Effect of the Air Hammer on the Hands of Stonecutters. USBLS/Industrial Accidents and Hygiene Series 236/19 (1918).
10. Wasserman, D.E.; Taylor, W.; Behrens, V.; et al.: Vibration White Finger Disease in U.S. Workers Using Chipping and Grinding Hand Tools, Vol. I. Epidemiology. DHHS (NIOSH) Pub. No. 82–118. National Institute for Occupational Safety and Health, Cincinnati, OH (1982).
11. Wasserman, D.E.; Reynolds, D.; Behrens, V.; et al.: Vibration White Finger Disease in U.S. Workers Using Chipping and Grinding Hand Tools, Vol. II., Engineering. DHHS (NIOSH) Pub. No. 82-101. National Institute for Occupational Safety and Health, Cincinnati, OH (1982).
12. Behrens, V.; Wasserman, D.; Taylor, W.; et al.: Vibration Syndrome in Chipping and Grinding Workers. J. Occup. Med. 26(Spec. Suppl.):765–788 (1984).
13. Taylor, W.; Wilcox, T.; Wasserman, D.: Health Hazard Evaluation Report No. HHE-80-189-870, Neenah Foundry Co., Neenah, Wisconsin. National Institute for Occupational Safety and Health, Cincinnati, OH (1981).
14. Taylor, W.; Wasserman, D.E.; Behrens, V.; et al.: Effects of the Air Hammer on the Hands of Stonecutters, The Limestone Quarries of Bedford, Indiana Revisited. Br. J. Ind. Med. 41:289–295 (1984).
15. Williams, N.; Riegert, A.L.: Raynaud's Phenomenon of Occupational Origin in Uranium Miners. In: Proceedings of the 13th International Congress On Occupational Health, pp. 819–825 (1960).
16. Ashe, W.F.; Williams, N.: Occupational Raynaud's II. Arch. Environ. Health 9:425 (1964).
17. Pelnar, P.; Pacina, V.: The Development of Occupational Traumatic Vasoneurosis in Ore-Mine Drillers. In: Proceedings of the 8th Nation-Wide Congress On Occupational Medicine (Czech.) (1963).
18. Iwata, H.: Effects of Rock Drills on Operators. Part 2: Survey and Examination on Raynaud's Phenomenon. Ind. Health 6:37 (1968).
19. Matsumoto, T.; Yamada, S.; Hisanaga, N.; et al.: On Vibration Hazards in Rock-Drill Operators of a Metal Mine. Jap. J. Ind. Health 19:256–265 (1977).
20. Robert, J.; Mereau, P.; Cavelier, J.; Chemeaud, R.: Occupational Angio-Neurotic Disorders Induced by the Vibration from Manual Tools. A Survey of 100 Miners Using Pneumatic Drills. Arch. Mal. Prof. Med. Trav. Sec. Soc. 38:437 (1977).
21. Chatterjee, D.S.; Petrie, A.; Taylor, W.: Prevalence of Vibration-Induced White Finger in Fluorspar Mines in Weardale. Br. J. Ind. Med. 35:208 (1978).
22. Pelmear, P.L.; Leong, D.; Taraschuk, I.; Wong, L.: Hand–Arm Vibration Syndrome in Foundrymen and Hard Rock Miners. J. Low Freq. Noise Vib. 5:26–43 (1986).
23. Brubaker, R.L.; Mackenzie, C.J.G.; Hutton, S.G.: Vibration-Induced White Finger Among Selected Underground Rock Drillers in British Columbia. Scand. J. Work Environ. Health 12:296–300 (1986).
24. Wasserman, D.E.: Human Aspects of Occupational Vibration. Elsevier Publishers, The Netherlands (1987).
25. National Institute for Occupational Safety and Health: Criteria for a Recommended Standard—Occupational Exposure to Nitroglycerin and Ethylene Glycol Dinitrate. DHEW (NIOSH) Pub. No. 78-167. NIOSH, Cincinnati, OH (1978).

Editor's Note: For additional information on hand–arm (segmental) vibration and the recommended threshold limit values applicable to this area of physical stress, the reader is referred to the July 1990 issue of this journal, pp. 464–470.