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Bone and joint pathology in workers using hand-held vibrating tools

An overview

by Gösta Gemne, MD, PhD,¹ Helena Saraste, MD, PhD²

GEMNE G, SARASTE H. Bone and joint pathology in workers using hand-held vibrating tools: An overview. *Scand J Work Environ Health* 13 (1987) 290–300. A literature evaluation was made with regard to the radiological documentation of bone and joint pathology in the hands and arms of workers using vibrating tools. There is evidence that work with pneumatic percussive tools (such as chipping hammers and scalers) may cause premature elbow and wrist osteoarthritis, although of very low prevalence. This work-related disorder is not specific to vibration exposure. Instead, it is likely to result from the strong dynamic and static joint loading (often in extreme positions of the joint) and the repetitive hand-arm movements (sometimes also repeated minor traumatization) typical for tool manipulation in any heavy labor. Exposure to low-frequency percussion may, however, play a particular etiologic role: damage to the joint cartilage by repeated shocks from the tool, additional articular load (and consequent strain) associated with a vibration-induced increase in the need for joint stabilization and higher gripping forces, the tonic vibration reflex (which increases muscle contraction), and a stronger grip induced when tactile sensibility is diminished by vibration. So far, no investigations have ventured into the great complexity of possible confounders and effect modifiers. — A constitutional susceptibility may be required to produce osteoarthritis. — The allegation that hand-arm vibration exposure causes an excess prevalence of bone cysts, vacuoles, Kienböck's disease, or pseudarthrosis of the scaphoid has not been validly documented. — Exposure to vibration of higher frequencies (such as from rotating drills, grinders, and chain saws) does not seem to be associated with excess bone and joint pathology. — The observed large variation in the prevalence of skeletal disorders may be explained by biodynamic and ergonomic differences between various occupations.

Key terms: bone cysts, elbow, hand, hand-arm vibration, joint load, Kienböck's disease, manual work, osteoarthritis, scaphoid pseudarthrosis, wrist.

The question of whether certain pathological changes in the bones and joints of the hand-arm system can be directly attributed to vibration exposure from hand-held tools is still largely unsettled. There seems to be a common opinion that conclusive evidence is lacking (105), and, as Taylor & Brammer (122) have stated, "it has proved difficult to differentiate between the effects of vibration and those of heavy manual work involving constant repetitive movements of the hands and arms to manipulate the tool or work piece [p 4]".

Already in 1929, German legislation recognized some types of bone and joint pathology as a prescribed disease, liable to workmen's compensation if there were no other probable causes than vibration exposure (41, 111, 120). In France, "hyperostotic arthrosis" and Kienböck's disease have been accepted since 1947 as being vibration-induced (113).

In the present report a literature survey has been made to evaluate the epidemiologic evidence for radiologically demonstrable effects of vibration on the

bones and joints of the hand and arm. The possible relationship between vibration exposure and changes in the shoulder bones and joints requires, for several reasons, a separate survey and has not been included.

Methods

A search was made in data bases such as Medline and CIS, in manual literature systems, eg, *Excerpta Medica*, and in reference lists of papers published during this century. About 250 pertinent works were initially examined. Some 20 rarely cited references could not be retrieved through available library facilities. Many of the references were excluded on the grounds that they proved to be review articles echoing other reviews or were otherwise of peripheral or minor interest. Among the remaining 180 references, about 125 were either original clinical and radiological works pertinent to the subject and allowing a judgment of the validity of results, or orthopedic and radiological surveys of interest.

Reports of original investigations were excluded for the following reasons:

1. Lack of appropriate comparison groups that would have made possible an evaluation of the validity of the radiological diagnosis and the observed prevalences. A few investigations were excluded because there was obvious doubt concerning the data on vibration exposure.
2. Lack of age data for the vibration-exposed subjects and the subjects showing radiological pathology. This lack precludes evaluation of the pathology presented.

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3. Doubt concerning the method of selecting subjects, for example, a study group consisting of only those persons who had consulted a physician because of complaints related to the pathology in question (Berkson's fallacy).
4. Unclear presentation of the results, together with a lack of data which justified the conclusions.
5. Limited number of subjects. This criterion also led to the exclusion of all case reports.

There were a few exceptions to the strict application of these exclusion criteria. Some reports presented original observations in a way that left little doubt as to the validity of the results, especially some German works on coal miners (for instance papers by Betzel, Bürkle de la Camp, Hagen, Laarmann, and Rostock). A few other papers were also considered because they contained data on certain topics of interest. Some works could be used in part to clarify particular types of pathology.

Thirty-nine papers (of which 26 were reports from original investigations) remained after the exclusion, in addition to some 20 other papers on various relevant subjects and several orthopedic reviews. The excluded works are listed in table 1 together with the reasons for their exclusion.

Results

Nationality of the reviewed works

Fifteen original (or equivalent) works were German (8, 9, 38, 41, 46, 47, 48, 52, 53, 72, 73, 74, 111, 115, 116), of which two were original (9, 38). Eight original works were British (3, 61, 62, 64, 76, 77, 85, 100), three Belgian (11, 16, 87), three Finnish (44, 70, 71), two Norwegian (51, 84), two Polish (34, 108), one American (101), one joint American-British (123), one Dutch (90), one Hungarian (55), one Italian (12), and one Japanese (121).

The evaluated German publications form a special group in the present overview. With two exceptions (9, 38), they are not original works in the sense that they describe the results of a study of a particular cohort of workers established for that particular investigation. Instead they draw upon the clinical experience collected, during the period from about 1925 up through the 1960s, in the examination of workers using pneumatic tools, mostly coal miners in the Ruhr district. Many of these examinations were carried out in the "Bergmannsheil" ("Miners' Cure") hospital in Bochum, now university affiliated. Based on the publications of Holtzmann (52, 53), German legislation in 1929 prescribed "pressurized-air diseases" as a compensable, work-related group of pathological conditions diagnosed on radiological evidence. Further developed by Hagen (46, 48), Rostock (115, 116), Bürkle de la Camp (18, 19), Betzel (8), Laarmann (72, 73, 74), and others, this view, in almost unmodified form, still prevails in today's view on the subject (74, 111, 120). As yet, however, the validity of this nosological entity has not been confirmed in epidemiologic investigations in the Federal Republic of Germany.

Excess pathology in the reviewed works

There were 15 studies reporting on various types of excess pathology that could be assumed to differ reliably from (appropriate) comparison groups. These reports are listed in table 2, which also gives the essential details on the groups examined.

German works. Following the first description of a work-related bone and joint disease by Holtzmann in 1926 (52), which concerned osteoarthritis in the shoulder joints of a tanksmith ("Kesselschmiede"), degenerative changes in the wrist and elbow have been reported in surveys by several German authors (8, 19, 46, 47, 48, 72, 73, 74, 111, 114, 115, 116). An original work on bone and joint pathology in special occupational groups was published by Gelbke (38), who observed a higher than normal prevalence of cysts in the carpal bones of tanksmiths, and another by

Table 1. Chief reasons for excluding specific reports from the overview. (X = reason for exclusion)

Author and year of publication	Reference number	Lack of reference group	No age data on pathological cases	Selection bias
Anda (1960)	2	X	X	
Bario et al (1981)	6	X	X	
Barnes et al (1969)	7	X		
Blau et al (1981)	10		X	
Bovenzi et al (1980) ^a	13			
Brückner et al (1964)	17	X		
Bugnion (1951)	20	X	X	
Bugyi (1957)	22	X		
Burke et al (1977)	23	X		
Caprotti et al (1979)	25	X	X	X
Casciu et al (1968)	26		X	X
Casciu et al (1968)	27		X	X
Cazamian et al (1954)	28		X	X
Cornet et al (1962)	29	X		
Dart (1946)	30	X		
Decoult et al (1957)	31	X		
Deplas et al (1948)	32	X		
DiVito (1970)	33	X		
Fawer (1976)	35	X	X	
Fiorito et al (1977)	36	X		X
Fusco et al (1963)	37	X		X
Germanò et al (1980)	39	X	X	X
Graczyk (1973)	40	X	X	X
Grigorjan (1984)	42		X	X
Grüning (1940)	43	X	X	X
Harada & Fukuhara (1958)	49	X		X
Horváth et al (1979)	54			X
Horváth et al (1969)	56	X	X	
Hunter et al (1945)	57	X		X
Iwata (1968)	59		X	X
Iwata et al (1974)	60	X		
Kouba (1967)	68	X		
Kulicz & Stasiów (1973)	69	X		X
Laitinen et al (1974)	75	X	X	X
Lélek & Magos (1956)	80	X		
Longley (1969)	86	X		
McLaren (1937)	88	X		
Meia et al (1963)	89	X	X	X
Mermet (1960)	91	X	X	
Mintz & Fraga (1973)	93	X		
Müller (1974)	94		X	
Nazarov (1964)	95	X		
Oeser & Selig (1975)	97	X	X	X
Pardi et al (1982)	98	X		X
Peters (1964)	102	X		
Pramatarov & Mitrev (1965)	103	X		
Priolo et al (1979)	104	X	X	X
Ravault et al (1963)	109	X	X	
Roche et al (1961)	112	X	X	
Roche et al (1962)	113	X		
Saito et al (1980)	117	X	X	
Seyring (1930)	118	X		X
Stépanek & Kandus (1970)	119		X	
Viehweg (1966)	124	X		

^a Control group not examined radiologically.

Table 2. Reports of reliably or reasonably well documented excess bone and joint pathology in workers using hand-held vibrating tools and other occupational groups (chronological order).

Author and year of publication	Reference number	Findings
Meiss (1933)	90	Humerus exostosis ("myositis ossificans") in 20 of 107 riveters and in 0 of 100 farm workers, painters, etc
Gelbke (1950)	38	Carpal bone cysts in 20 of 50 tanksmiths and in 7 of 67 quarry workers without vibration exposure
Kellgren & Lawrence (1952)	62	Osteoarthritis of carpo-metacarpal joints in 8 of 18 nonvibration-exposed cotton workers (performing repetitive light work with their hands), in 18 of 74 vibration-exposed or unexposed coal miners, and in 12 of 81 other workers with miscellaneous occupations without vibration exposure
Lawrence (1955)	76	Elbow, wrist, and hand osteoarthritis more frequent in miners than in other occupational groups; 16 % elbow osteoarthritis in coal miners who had not drilled, 31 % in those who had drilled for more than one year, no osteoarthritis in light manual and office workers; conclusion: "It is obvious that osteoarthritis often occurs in those who have done no drilling and is, moreover, a feature of all heavy work studied [p 257]"; results attributed to awkward postures of underground workers
Lloyd-Davies et al (1957)	85	Minimal cystic changes in 6 of 31 dockyard workers and in 2 of 36 referents
Bittersohl (1960)	9	More elbow osteoarthritis in tanksmiths and steel construction workers than in nonvibration-exposed workers with or without heavy manual work; more cysts in strongly vibration-exposed quarry workers than in tanksmiths and construction workers
Partridge & Duthie (1968)	100	Joint deformities in the fingers (mostly distal interphalangeal joint) in 36 of 206 dockers without vibration exposure and in 4 of 171 civil servants, after age stratification; trauma considered to be a pathogenic factor in addition to repetitive load on the finger joints
Kumlin et al (1973)	71	Vacuoles in 7 of 35 chain sawyers (39—58 years of age) and 2 cases of small cysts in 2 random, age-matched, nonvibration-exposed persons from a normal population
Horváth et al (1974)	55	6 cases of Kienböck's disease in 450 chain sawyers, 2 of these after acute trauma (0 in 450 age-matched manual workers); 3 cases of navicular pseudarthrosis in vibration-exposed persons, 1 of these posttraumatic (0 in referents)
Rafalski et al (1977) (resumé of results)	108	Longitudinal five-year study of 207 chain sawyers, 97 referents of same age; with statistical significance, more cysts and osteoporosis in the hand, more degeneration and osteoporosis in the elbow of chain sawyers; no detailed statistics given; the pathological changes in the chain sawyers stated to arise mostly in the first 1 to 3 years of sawing
Lie (1980)	84	After age stratification, small excess of hand, wrist and right elbow arthrosis and wrist cysts in 70 road construction workers as compared with 32 nonvibration-exposed referents with manual work; some dose-response relationship
van den Bossche & Lahaye (1984)	11	Excess prevalence of carpal bone vacuoles and cysts in 282 male and 60 female workers using screwdrivers and nutrunners, as compared with 401 referents; this observation also in 78 % of less than 20-year-old workers with less than 5 years of exposure
Härkönen et al (1984)	44	Study on 279 chain sawyers, vibration-exposed at least 1 year (mean exposure 10 years) and 178 regionally and age-matched peat-bog workers without vibration exposure, radiographic evaluation by two independent radiologists without knowledge of patient occupation; 3 of 279 chain sawyers with lunette necrosis, 2 with navicular necrosis, 0 cases among referents; a history of "wrist strain" for 4 of the 5 cases with carpal bone pathology
Malchaire et al (1986)	87	Cross-sectional study on 82 stone quarry workers using pneumatic tools and 75 age-matched manual workers not exposed to vibration; cysts in the hand bones demonstrated in 13 of 82 exposed persons below 30 years of age and in 4 of 70 unexposed subjects
Bovenzi et al (1987)	12	After age adjustment, excess prevalence of wrist osteoarthritis in 67 vibration-exposed foundry workers as compared with 46 referents doing manual work

Bittersohl (9), who reported on elbow arthrosis in tanksmiths and steel construction workers.

The types of pathology recognized by the German school are the following:

I. *Exostoses* at the sites of tendon insertion, mostly at the elbow.

II. Premature *osteoarthrosis* ("arthrosis deformans"), chiefly in the elbow but also occurring in the wrist. *Type I lesions* are considered to arise as a reac-

tive formation of new bone tissue caused by the strain on tendons by the muscles used to manipulate the tools and ward off the shocks they produce. *Type II lesions* are taken to result from eventual damage to the joint cartilage by the constant repeated pressing together of the articular surfaces. This phenomenon is said to occur to a larger extent when the muscles become fatigued and can no longer parry and damp the shocks from the tool. The consequent wear and tear would lead to subchondral necroses and, secondary to this, a deformation of the joint surfaces. This pathogene-

sis is also said to explain the preferred localization of the lesions. In the elbow both types develop, but in the wrist only type II appears since the muscles acting on this joint do not take part in reducing the shock impacts. The overall prevalence in the German material of bone and joint pathology accepted for compensation was (and still is) very low, about 1 % (41, 120, see also the Discussion following this paper). (This rate is in accordance with the early autopsy data of Heine (50), who showed that, at the time of his study, pronounced osteoarthritis in the elbow of the general population was rare before the age of 60 years.) About 70 % of this is osteoarthritis, chiefly of the elbow but also of the wrist and shoulder. Due to the low prevalence and the observed absence of correlation between the severity of the changes and exposure time, the development of the arthrotic lesions is considered to require the presence of a constitutional weakness. The lack of "vibration specificity" has been pointed out repeatedly; the pathology seen in persons working with pneumatic tools can also be observed in nonvibration-exposed occupational groups. *Osteochondritis dissecans* has also been mentioned (41, 47, 74, 115) as a type of pathology often seen in persons working with pneumatic tools.

III. *Special types of pathology* ("Sonderformen"): Kienböck's disease (lunate malacia) and pseudarthrosis of the scaphoid. The general opinion in the German works appears to be that these lesions are to be considered as sequelae of acute trauma or repeated, nonrecognized microtraumatization over a long period, with a disturbance of the blood flow to the afflicted bones. This traumatization may or may not be associated with pneumatic tool work.

IV. *Cysts and vacuoles* in the hand bones.

Works other than German. An excess prevalence of *osteoarthritis* of the wrist and elbow joints in some occupational groups has also been reported from other countries in works that appear to be well-controlled, notably by Lawrence (76) in the wrist of (age-stratified) vibration-exposed and unexposed coal miners, by Lie (84) in the wrists and elbows of Norwegian road workers using pneumatic drilling machines, and by Bovenzi et al (12) in the wrists and elbows of (age-stratified) foundry workers as compared with "manual workers". In the two latter investigations a dose-response relationship was also indicated. Increased osteoarthritis of the elbow was (possibly) also observed by Rafalski et al (108) in chain sawyers ("degeneration in the elbow").

The aforementioned work by Lawrence discussed the role of vibration exposure in explaining the pathology observed. Of those coal miners who had not drilled, 16 % had elbow osteoarthritis, whereas for those who had drilled for more than one year the prevalence was 31 %. The difference was "statistically nonsignifi-

cant". There were no cases of elbow osteoarthritis among the light manual and office workers. The author concluded that "it is obvious that osteoarthritis often occurs in those who have done no drilling and is, moreover, a feature of all heavy work studied".

A similar viewpoint was taken by Anderson (3, 4), who suggested that awkward postures more than other possible etiologic factors (such as heavy lifting) may induce the osteoarthritis seen in, for instance, miners, who often work continuously in stooped positions in narrow coal faces. Anderson also emphasized the observations of Lawrence (77), who described carpometacarpal osteoarthritis in nonvibration-exposed cotton mill workers performing repetitive (although not heavy) movements with their fingers in transferring pieces of cotton from one place to another. These latter findings are in accordance with the results of another well-controlled study, that of Partridge & Duthie (100), who observed excess finger joint arthrosis in dockers without vibration exposure.

An excess prevalence of *Kienböck's disease* and *pseudarthrosis of the scaphoid* was reported by Horváth et al (55) and Härkönen et al (44) in chain sawyers. Higher than normal prevalences of *cyst and/or vacuoles* in various bones of the hand and arm were described in a few reports of investigations without obvious major deficiencies in their design (table 2). Meiss (90) reported on what he considered to be a special form of pathology characteristic for workers using pneumatic tools, namely, "reactive" exostosis on the anterior face of the distal part of the humerus in riveters. Similar observations were reported by Malchaire et al (87) and Bovenzi et al (12).

Excess pathology in the excluded works

Some of the excluded works reporting on high pathology prevalence may be mentioned particularly. Bovenzi et al (13), who examined shipyard workers radiologically but did not compare them with a reference group, found a 20 % prevalence of wrist and a 10 % prevalence of elbow osteoarthritis, together with a 30 % prevalence of hand bone cysts. Horváth et al (56), using no reference group, reported a 23 % prevalence of hand arthrosis in chain sawyers but did not give age data for the cases with pathology. Among the works excluded because of Berkson's fallacy or other suspected selection bias, Caprotti et al (25) studied 300 road workers who had consulted a clinic because of complaints in the hand and arm, but they had no reference group. These authors claimed prevalences of 79 and 58 % for "osteoarticular lesions" of the elbow and wrist/hand, respectively. Grüning (43) reported on the results of radiological examinations performed on 688 miners in his clinic between 1930 and 1938. In this material he found a 49 % prevalence of elbow changes without mentioning age data for the cases. Horváth et al (54) reported on excess distal radioulnar joint arthrosis in 978 chain

sawyers in comparison with 758 randomly selected adults as referents.

Absence of excess pathology in the reviewed works

There were 17 works which reported that no excess prevalence of certain types of pathology was observed (table 3).

Convincing evidence of the absence of excess cyst prevalence was shown not only by James et al (61) but also by Taylor and his collaborators (123), the latter in a radiographic examination of the hands of 205 foundry workers engaged in chipping and grinding and 63 manual workers without vibration exposure. The radiographs were assessed by two independent radiologists who were unaware of the occupational history of the subjects. There were no statistically significant differences in the prevalence of bone cysts in the two populations.

Absence of excess pathology in the excluded works

Several works among those discarded from the main evaluation because of shortcomings in the exclusion criteria reported on negative findings or markedly low prevalences of various types of bone and joint pathology. Cornet et al (29) found "no elbow arthrosis" in 28 men working with pneumatic hammers, Fusco et al (37) reported "no pathology" in the hands and arms of 60 sheet iron stampers, Harada & Fukuhara (49) observed "no pathology caused by pneumatic tools" in 14 riveters, Peters (102) detected "no pathology" in 13 airplane industry workers, and Pramatarov & Mitrev (103) showed "no pathology related to vibration exposure" in 26 miners (with high-frequency drills). In 50 tanksmiths Lélek & Magos (80) found only two cases of elbow changes of the type that had been described in persons working with pneumatic tools by other authors. Bugnion (20) found an excess occurrence of wrist cysts and vacuoles in nonvibration-exposed manual and nonmanual workers. There were fewer cysts in persons doing manual work than in those who had nonmanual occupations. Brückner et al (17) reported no increased prevalence of cysts and/or vacuoles and denied correlation between cysts and vibration exposure. Bugyi (21, 22) observed an absence of changes in carpal bones. Dart (30) observed "minute cysts" in the carpal bones of only one person out of 20, working with high-speed, rotating, electric polishing tools. Lélek & Magos (80) reported having found no excess of Kienböck's disease or pseudarthrosis of the scaphoid in 50 tanksmiths, and Cornet et al (29) no cases of Kienböck's disease among 28 pneumatic hammer workers.

Discussion

Epidemiologic criteria for the exclusion of publications

To be able to answer the question of whether or not vibration exposure as such may cause bone and joint

changes, the proper design of an investigation into the prevalence of such changes should involve a comparison of radiological pathology between one group working with hand-held vibrating tools and a reference group of manual workers regularly using tools that do not vibrate. Very few papers had taken this requirement into account. Exclusion because of a lack of appropriate reference groups was considered imperative.

The variability in diagnoses made by different radiologists is often considerable. In a survey of joint diseases in the United States, the results of Wright & Acheson (125) corroborated "the fact, already widely acknowledged, that comparisons of prevalence cannot afford to ignore the phenomenon of observer variation [p 390]". This opinion was shared by Kellgren & Lawrence (63). Papers could not be excluded on the basis of radiographs not having been evaluated by two or more independent observers since such a method would have left only a very small number of works. The variability — also emphasized by James et al (61) — was, however, taken as a reason for paying less attention to the results of some investigations that showed only a very small difference between a group working with vibrating tools and a reference group.

Relation between tool types and pathology

It is obvious that, in discussions concerning the possible effect of vibration on bones and joints, a clear distinction should be made between the pathology that has been associated with work with hand-held pneumatic tools producing low-frequency spectra and that associated with work with other types of tools producing nonimpulsive vibration with higher frequencies. The low-frequency tools deliver repeated shocks continuously to the hand and arm. Most of these vibrations with frequencies up to about 40 Hz are transmitted to the bones of the elbow joint in work with normal gripping and press forces (67), thus constituting a potential risk for bone and joint injury. In the present review, only one (108) of the papers finally considered (table 2) reported on joint pathology related to the exclusive use of nonstriking tools. An association between this type of tool and pathology was positively denied in several papers (table 3).

Pathogenesis and etiology

Osteoarthritis. Anderson and his co-workers (3, 4, 99), agreeing with, for instance, Kellgren & Lawrence (62) and Lawrence (78), believe local osteoarthritis (65) to be associated with heavy manual work, especially when involving awkward postures and consequent static load which makes the articular surfaces come into prolonged contact. According to this assumption, work with pneumatic tools (which involves a considerable amount of static load and, in several occupations, awkward postures) may conceivably damage articular

Table 3. Reports of valid studies without excess bone and joint pathology in workers using hand-held vibrating tools (chronological order).

Author and year of publication	Reference number	Findings
Meiss (1933)	90	Osteoarthritis and Kienböck's disease (107 riveters, 100 nonvibration-exposed farm workers, painters, etc)
Kellgren & Lawrence (1952)	62	Wrist pathology (84 coal miners, some of them working with pneumatic drills, 45 manual workers without vibration exposure, 42 office workers)
Kellgren & Lawrence (1958)	64	Wrist pathology (74 vibration-exposed or unexposed coal miners, 18 nonvibration-exposed cotton workers, 81 other workers in miscellaneous occupations without vibration exposure)
Lloyd-Davies et al (1957)	85	Wrist arthritis (31 dockyard workers)
Kumlin et al (1971)	70	"Traditional" vibration pathology and osteoporosis (21 densitometrically assessed radiographs of chain sawyers, 21 age-matched forest workers without vibration exposure)
Hellström & Lange Andersen (1972)	51	Hand osteoarthritis and osteoporosis (150 chain sawyers, 57 nonvibration-exposed forest workers)
Kumlin et al (1973)	71	Arthritis and osteoporosis (35 chain sawyers, 35 nonvibration-exposed, random, age-matched persons from a normal population)
Horváth et al (1974)	55	Cysts (450 chain sawyers, 450 age-matched manual workers)
James et al (1975)	61	Hand bone cysts (96 chain sawyers, 48 grinders, 162 nonvibration-exposed referents); radiographs evaluated by three independent radiologists
Dobek et al (1977)	34	Degeneration, deformation, bone cysts and osteoporosis in the arms and hands (1 231 chain sawyers, 272 "workers" without vibration exposure)
Suzuki et al (1978)	121	All wrist pathology (580 chain sawyers, 90 referents)
Brouillard-Wintgens & Malchaire (1980)	16	Osteoarthritis and cysts (83 quarry workers about 45 years of age, exposure time about 29 years, 150 workers from a chemical factory); excess osteoarthritis in the referents over 50 years of age; healthy worker effect not discussed in the report
Pelnar et al (1982)	101	Cysts and arthritis (323 chain sawyers, 243 forest workers without vibration exposure); the radiological changes in this material, "if present at all", stated to be linked more with age and/or heavy, manual work than with exposure to vibration
Härkönen et al (1984)	44	Cysts (279 chain sawyers, 178 regionally and age-matched peat-bog workers without vibration exposure)
Taylor et al (1984)	123	Hand bone cysts (205 foundry workers doing chipping and grinding, 63 unexposed referents with manual work); radiographs evaluated by two independent radiologists
Bovenzi et al (1987)	12	Hand bone cysts, elbow osteoarthritis (67 foundry workers with exposure to hand-arm vibration, 46 unexposed referents with manual work)
Malchaire et al (1987)	87	All radiological changes except semilunar lesions (82 stone quarry workers using pneumatic tools, 75 manual workers without vibration exposure)

cartilage in a way which eventually leads to osteoarthritis.

The phases of this pathogenetic theory, as well as that expressed by the German school, closely resemble views expressed in recent surveys, for instance by Lee et al (79) and Radin and co-workers (106, 107). Supported by their findings in animal experiments, the latter authors believe that "impulsive loading" of the joint (such as by shocks from pneumatic tools) eventually damages the cartilage. The sequelae of this phenomenon can be of the following two types: either disorganization of the subchondral bone and a nonprogressive chondromalacia or trabecular bone remodeling and stiffening, which results in progressive cartilage damage and osteoarthritis. Lee et al (79) agree and point out that there seems to be an optimum cartilage load above and below which the prevalence of joint disease increases. If this threshold is surpassed (which may well happen in occupations with heavy loads on the joints) extrinsic forces — especially those caused by isometric muscle contraction — may result in osteoarthritis by the mechanism just described.

With this interpretation, there are additional joint-loading factors specifically related to work with hand-held vibrating tools that may contribute to the development of osteoarthritis. In comparison with work with nonvibrating tools, guiding a vibrating tool properly (especially a low-frequency tool producing shocks) necessitates a firmer grip around the handle and a greater amount of joint stabilization. Efficient work also requires pressing the tool against the workpiece. Furthermore, vibration stimulates muscle contraction by way of the so-called tonic vibration reflex (45) and impairs tactility (82, 96). The increase in vibration perception threshold during vibration is even greater in persons occupationally exposed to vibration from hand-held tools (83). Both of these mechanisms lead to a tendency towards the use of extra muscle force (5), which may increase the risk not only of chronic tendon and nerve disorders but also, quite conceivably, of arthritis by increasing joint load. Awkward postures of the hand and arm (frequent in many occupations employing vibrating tools) may increase this risk still further (3, 4) by increasing joint load on less wear-

resistant susceptible parts of the articular surfaces. Other factors may contribute as well. In a study without a comparison group, Mintz & Fraga (93) described cases of severe, premature osteoarthritis in workers who used thongs as levers for lifting metal rods in a foundry. The changes were interpreted to have resulted from a greater load on the joint and stronger tangential friction on the articular cartilage caused by this method of work.

The "wear and tear" of everyday life eventually takes its toll in the form of the degeneration of joints (66). Repeated minor traumatization, for instance, by loads on the joint during heavy labor, has been assumed (100) to result in osteoarthritis at a premature age. Similarly, long-time work involving constant repetition of movements with the fingers and hands, as for instance in cotton mill workers (64, 77) and coal miners (76), has caused premature osteoarthritis.

According to the opinion expressed by Brailsford (14), osteoarthritis is only manifested in those joints which have been subjected to abnormal stress and strain in a person "who also exhibits elsewhere the signs and symptoms referred to as rheumatism, fibrositis, etc [p 659]". This assumption agrees with the aforesaid German view, based on the very low prevalence of osteoarthritis in workers using pneumatic tools, that a constitutional weakness is required to produce the damage. However, the relative importance of such a constitutional factor has not been clarified in epidemiologic studies on occupational groups.

Kienböck's disease and pseudarthrosis of the scaphoid.

The prevalence of Kienböck's disease in occupational groups as a condition caused by the long-time use of hand-held vibrating tools has been estimated (81) at the low figure of 0.4 % in a male worker population, but this figure varies widely. The main etiologic factor in Kienböck's disease is considered to be an "unfavourable anatomical environment" (92) — which means anatomical variations in, for instance, ulnar length — while trauma is considered to be a rare cause. The etiology of Kienböck's disease has been discussed for a long time. In contrast to Laarmann (72) — who advocated a disturbance in the blood flow to the lunate bone as the cause of the malacia — Bürkle de la Camp (19) regarded the condition as the result of a fatigue fracture, eventually produced by a series of repeated small traumata. This reasoning also applied to the pseudarthrosis of the scaphoid seen as a very rare condition among the numerous coal miners consulting his clinic. Both authors agreed, however, that Kienböck's disease was an occupational disease entity that might be caused by work with pneumatic tools. In modern literature, pseudarthrosis of the scaphoid is considered to be the direct result of fracture, and microtraumatization has not been seriously considered as an etiologic factor (110).

Amphoux and his co-workers (1) made a radiographic examination of 30 workers with Kienböck's disease in the building industry and found evidence of previous unrecognized fracture in about half of the cases. In these workers, exposure to low-frequency vibrating tools was said to be very uncommon.

Cysts and vacuoles. Cysts in the hand bones, particularly the scaphoid, were described early (15) as sequelae of trauma. This idea has received support from more recent work. Thus, James et al (61) stated that these lesions are characterized clinically by an injury, a latency period, and, finally, the development of symptoms. The predilection sites were the first and third metacarpal bones, the styloid process of the ulna, and the scaphoid. It was concluded that heavy manual activity would appear to be an important predisposing factor in cyst formation.

Differences in pathology and prevalence in various studies

In view of the possible pathogenic mechanisms that have been described in this overview, it is obvious that biodynamic and ergonomic differences between various types of work (5) may well explain the variation in the observed prevalence of bone and joint pathology in occupational groups using hand-held vibrating tools.

Conclusions

There is evidence of an association between work with hand-held vibrating tools of the percussive, low-frequency type (less than about 40 Hz) — such as chipping hammers and scalers — and a higher than normal, although very low, prevalence of premature elbow and wrist osteoarthritis. This excess work-related risk is, however, not specific to vibration exposure. Instead, the major etiologic factors appear to be the joint load associated with the manipulation of any tool in heavy manual work, repetitive movements of the hand and arm (often together with minor traumatization), loading of the joint surfaces in extreme positions (such as occurs in awkward postures), and static work. All these factors are prominent in work with hand-held vibrating tools of the percussive type.

Against this background it is, however, obvious that the following vibration-specific factors may also be incriminated: damage to the articular cartilage from shocks from pneumatic tools with low-frequency vibration, additional articular load (and consequent strain) associated with a vibration-induced increase in the need for joint stabilization and higher gripping and pressing forces to work with and guide the tools optimally, the tonic vibration reflex (which increases muscle contraction), and a stronger grip on the tool handle induced when tactile sensibility is diminished

by vibration. So far, no investigations have even begun to take into account the great complexity of possible confounders and effect modifiers.

A constitutional susceptibility may be required to produce the osteoarthrotic lesion.

Available data show a lack of a causal relationship between vibration exposure and the formation of bone cysts or vacuoles. Manual work, with or without concomitant trauma, seems to be the primary etiologic factor for this type of pathology.

The allegation that Kienböck's disease or pseudarthrosis of the scaphoid may be typically induced by hand-arm vibration has not been validly documented.

An excess risk for bone and joint pathology has not been conclusively demonstrated to be caused by vibration exposure from tools with medium or high frequencies (such as rotating drills, grinders, and chain saws).

The variation in observed prevalences of osteoarthrosis and other bone and joint pathology may be explained by biodynamic and ergonomic differences between various occupations.

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Discussion

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In Germany, vibration-induced diseases of the hand-arm system have been compensated for more than 50 years in cases of earning capacity reduction. Before 1976, bone and joint injuries due to vibration (no 25 in the list of occupational diseases) were only compensated after long-term intensive use of pneumatic tools. The majority of the cases occurred in the mining industry. Since 1977, hand-held vibrating tools with electric or combustion-engine drives have also been accepted as causing this disease (no 2103). Compensation has been paid to about 7 500 persons because of bone and joint injuries due to vibration. In 1984 this disease was in third place (about 10 % of all compensated cases), after noise-induced hearing impairment and silicosis. The average reduction of earning capacity was about 24 % and the average compensation DM 5 440 per year.

The incidence of "new" cases (ie, compensated for the first time) peaked in 1950 (1 210 cases). After a decrease to 200—300 in the 1970s, it was only 137 in 1984. In the 1970s, the mining industry predominated with 85 % of the cases. After the inclusion of other vibrating hand-held tools, however, the proportion of cases in the remaining industrial branches (mainly the building, and the iron and metal industries) has increased to almost 30 %.

In the mining industry, pneumatic pick hammers, without exception, are regarded as tools that may cause vibration-induced diseases. These tools are also extensively used in the building industry (partly with electric or combustion-engine drives). The cases occurring in the building industry are mainly caused by pick hammers, but also by track-packing machines, vibrating compressors, and pile drivers. In the iron and metal industry, pick hammers play an important role in installation and metallurgical operations. In addition, riveting hammers, chisel hammers, other hand-held hammers, and the right angle grinders used in steel construction and casting cleaning have been shown to be health hazards.

The strong coupling between the hand and the tool handle, as well as resonance phenomena in the frequency range 15—20 Hz, are obviously important for the pathogenesis. In addition, however, constitutional factors in the form of a predisposition to degenerative processes in the joints of the hand-arm system seem to be important, since the prevalence of premature chronic degeneration in the group of workers exposed in the Federal Republic of Germany is below 1 %. About 70 % of all compensated cases concern the elbow joint, and 24.5 % the wrist bones and joint. The minimum of exposure required for compensation is two years of work with low-frequency vibrating tools and strong coupling hand forces. The diagnostic procedure includes clinical and radiographic examinations. The radiographs must show clear degenerative changes, which must be considered as obviously premature and must be more pronounced in the most exposed arm.

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